Monsoon extremes, and relevance of ocean drivers

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Broad Division of the talk

- Introduction
- Extremes – types and recent decadal conditions
- *Changing drivers*
- *Changing Links*
- *Some new results – Extreme Chennai event Nov.-Dec. 2015*

Conclusions

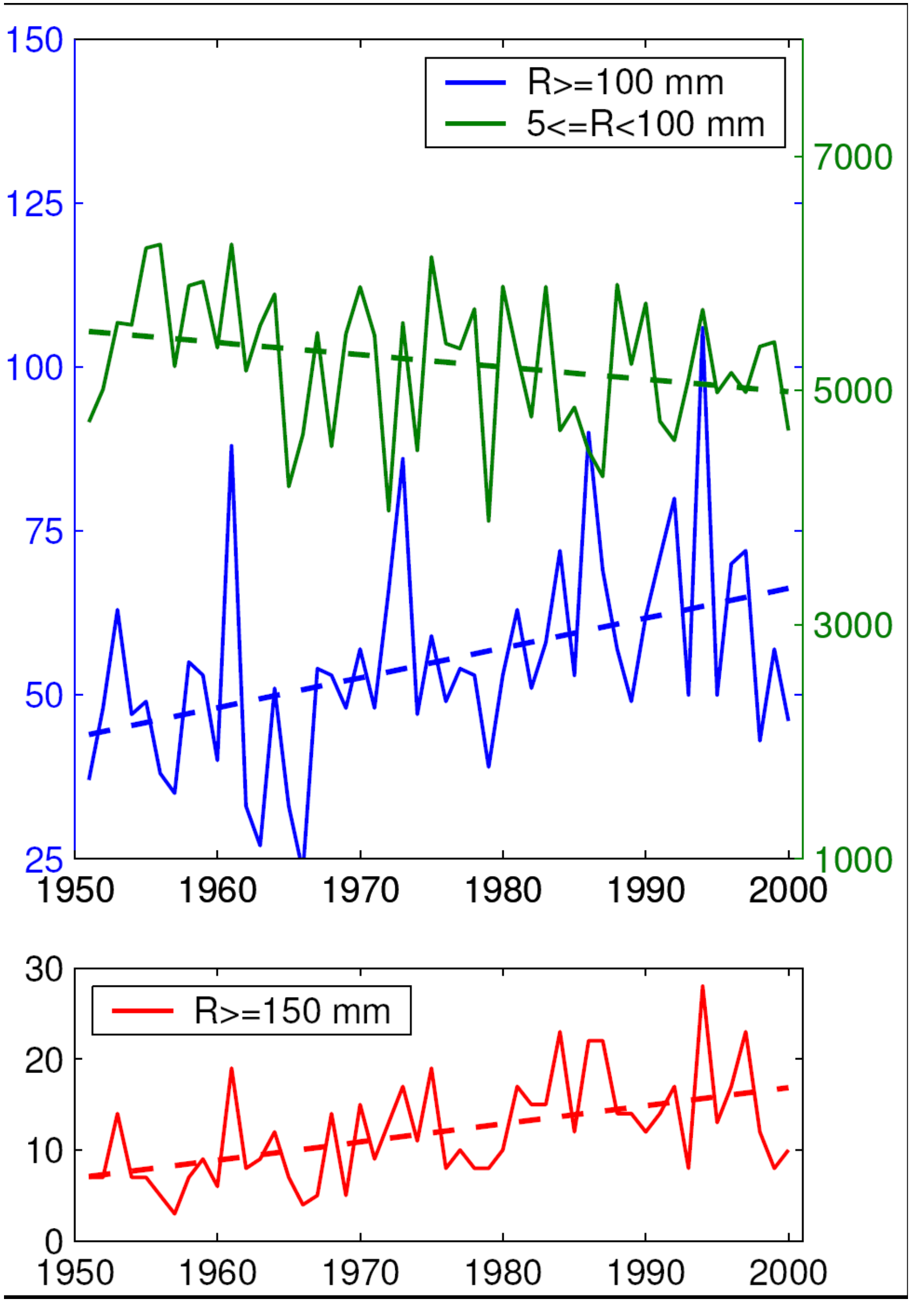
Extremes

- Can be of seasonal scale – or transients.
- Droughts and Floods
- Weakening depressions
- Change in frequency or intensity in tropical cyclones during the OND season.

And tropical Oceans..

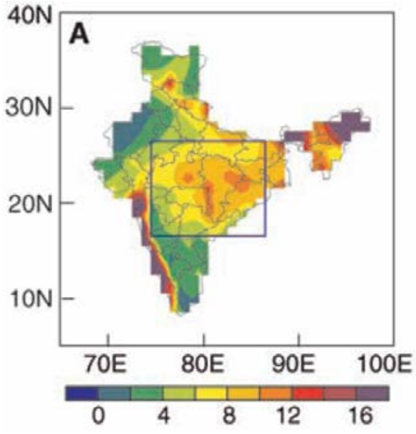
- The changing ENSO Characteristics.
- canonical ENSO & ENSO Modoki
- *Basin-wide warming manifestations in the tropical Pacific during 2009 & 2014*
- *Indian Ocean basinwide warming*
- *Decadal modulation of the Indian Ocean Dipole*
- *Atlantic also receiving lot of attention.*

Time series of count over CI



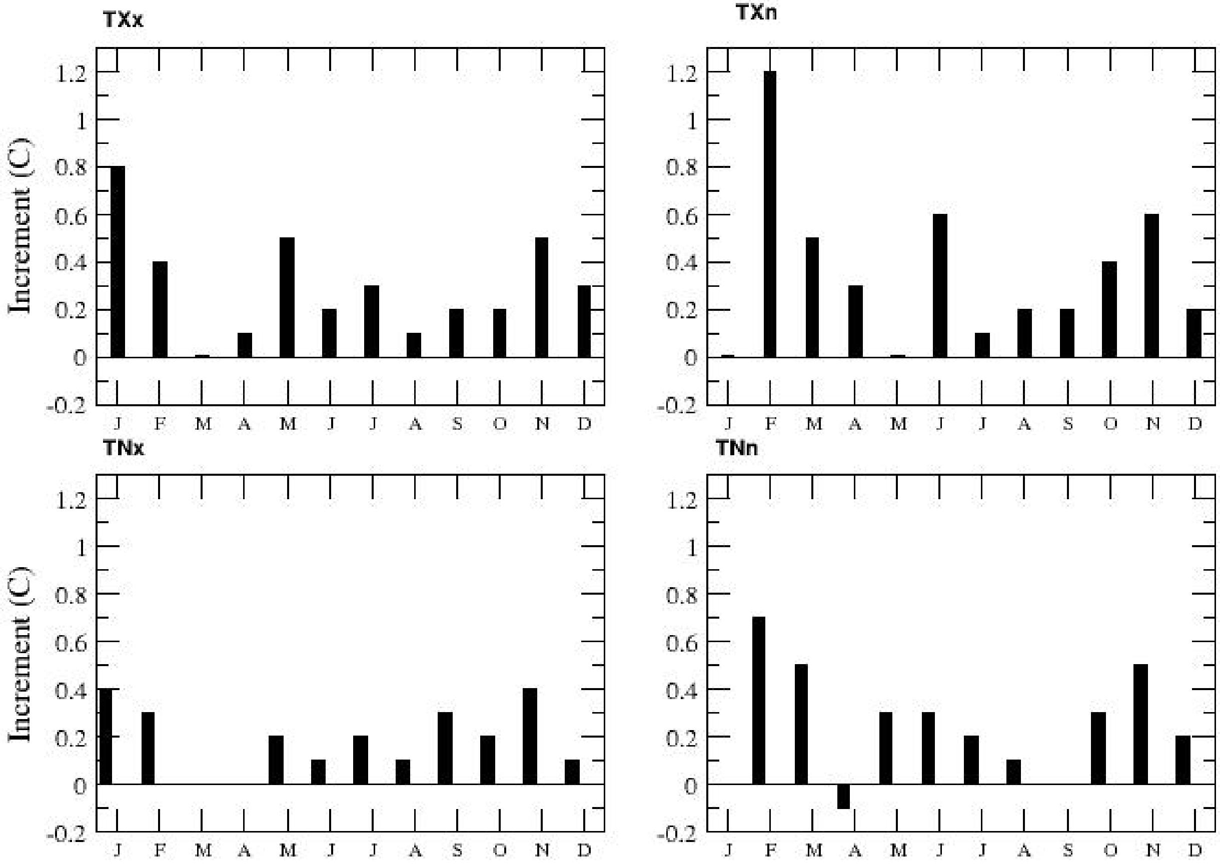
Low & Moderate events

Heavy events (>10cm)



V. Heavy events (>15cm)

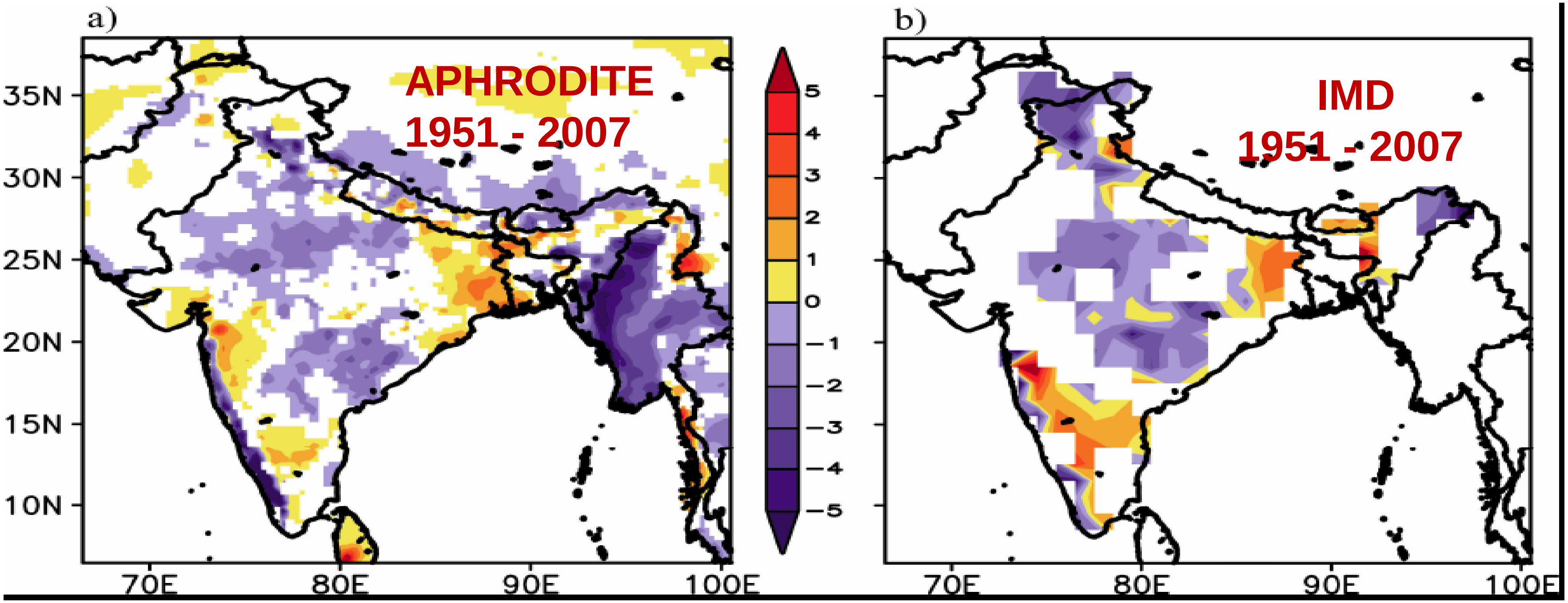
Goswami et al., 2006

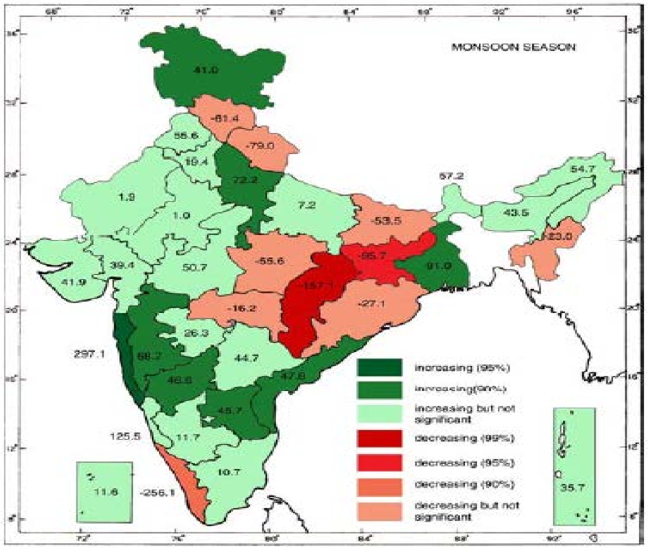


Revadekar et al. (2011)

Epochal increment between 1970-1986 and 1987-2003 for highest maximum temperature in ˚C, (TXx, top-left); lowest maximum temperature in ˚C, (TXn, top-left); highest minimum temperature in ˚C, (TNx, bottom-left) and lowest minimum temperature in ˚C, (TNn, bottom-left)

Spatial map of linear trend: JJAS rainfall





Guhathakurtha and Rajeevan, 2006: Trends in the rainfall pattern over India (1901-2003)

Significant negative trends: Kerala, Jharkhand, Chhattisgarh

Increase/Decrease in rainfall in mm in 100 year for each of 36 subdivisions for the south-west monsoon season. Different levels of significance are shaded with colors

Courtesy: Krishnan

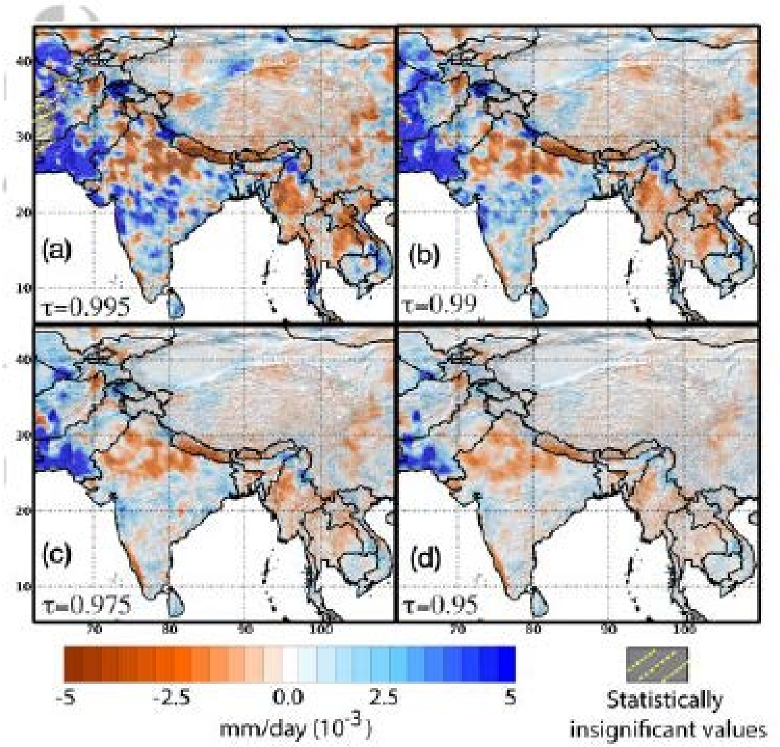
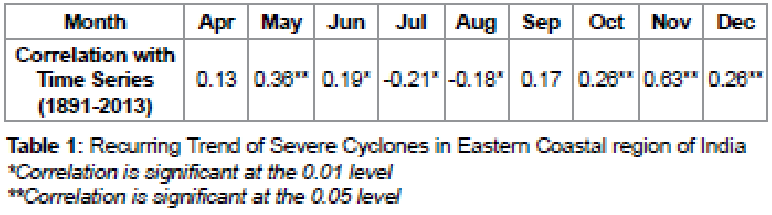


Figure 4. Synthesis showing spatial patterns of strongest rainfall trends in the extremes during the ISM season over the past 57 years. Brown regions indicate increasing trends in lower quantiles, often associated with drought conditions, while blue regions indicate areas with increasing rainfall at the higher percentiles, generally characterized by an increase in flooding. Region numbers and associated geographic regions are shown on the right. The demarcation of drought regions has also been corroborated by our observed trends (Fig. 1). We use light blue (flood) stars and orange (droughts) dots to indicate particular events during the recent past (between the years 2000 to 2013). These events were either extensively studied by the scientific community or have been reported by international media coverage (see SI material Table S1, Fig. S12, S13 and Sec. S5 for additional information).

- Malik et al. (GRL, 2016):
- quantile regression “that avoids making any subjective choices on spatial, temporal, or intensity pattern of extreme rainfall events”

“…….Our analysis divides the Indian monsoon region into climatic compartments that show different and partly opposing trends. These include strong trends towards intensified droughts in Northwest India, parts of Peninsular India, and Myanmar; in contrast, parts of Pakistan, Northwest Himalaya, and Central India show increased extreme daily rain intensity leading to higher flood vulnerability.”



Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Correlation with Time Series (1891-2013)	0.13	0.36**	0.19*	-0.21*	-0.18*	0.17	0.26**	0.63**	0.26**

Table 1: Recurring Trend of Severe Cyclones in Eastern Coastal region of India
**Correlation is significant at the 0.01 level*
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Based on: EM-DAT: The OFDA/CRED International Disaster Database and Cyclone

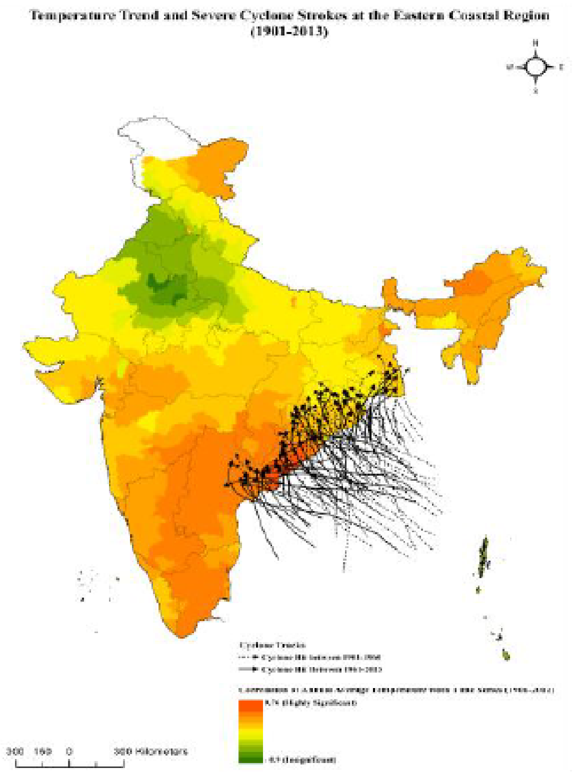
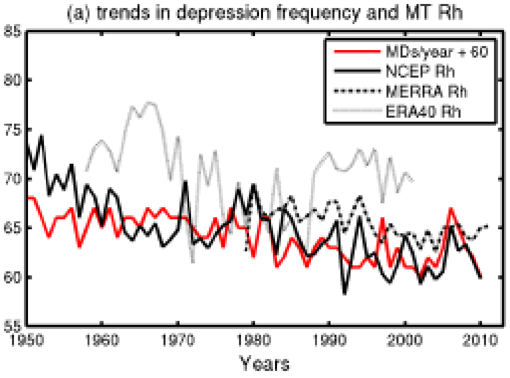


Figure 3: Temperature Trend and Severe Cyclone Strokes at the Eastern Coastal Region (1901-2013)
Based on: District Level Temperature Records, IMD; EM-DAT: The OFDA/CRED International Disaster Database; Cyclone e-Atlas, IMD; and Vulnerability Atlas of India, BMTPC.

Mishra 2013, J. Earth Sci. Clim. Change



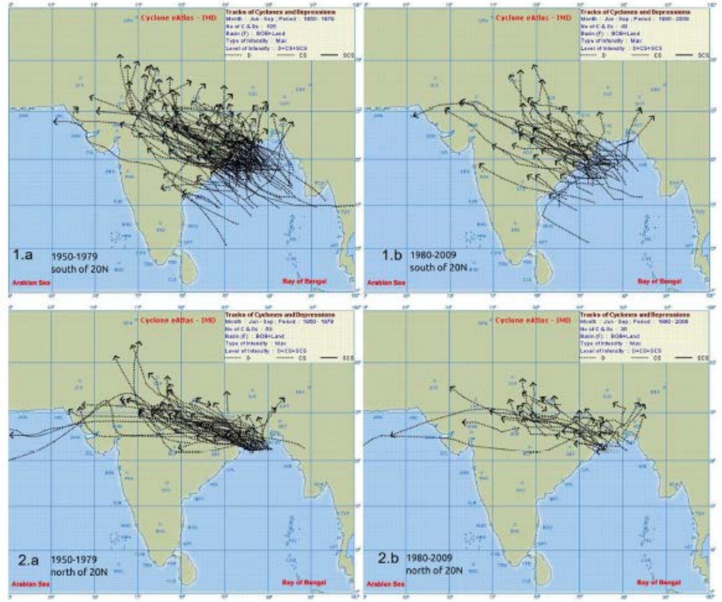


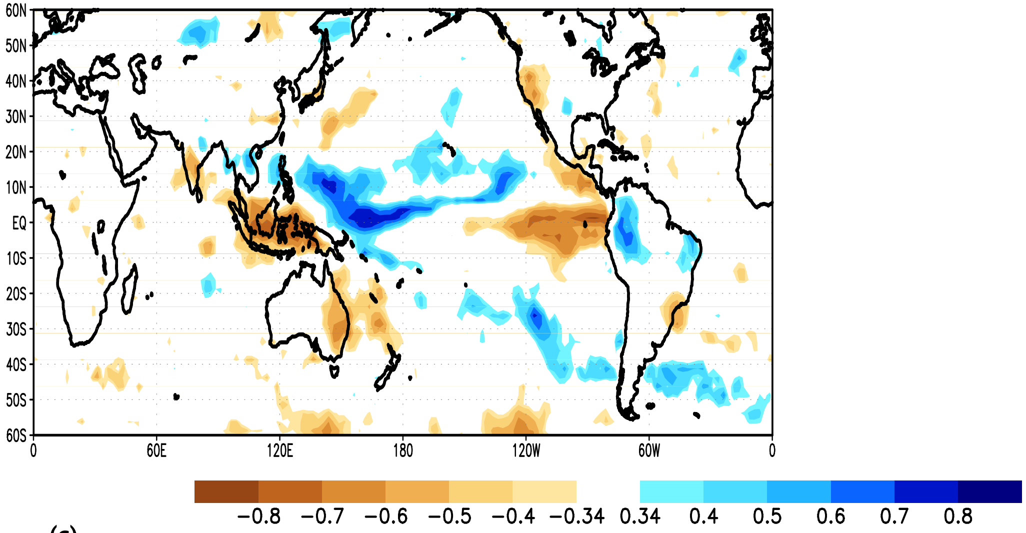
Figure 3 | Tracks of the monsoon depressions from IMD cyclone e-atlas having genesis, 1.a) south of 20°N for the period 1950–1979, 1.b) south of 20°N for the period 1980–2009, 2.a) north of 20°N for the period 1950–1979, and 2.b) north of 20°N for the period 1980–2009. The figures, and the relevant statistics, have been generated using the online Cyclone eAtlas of the India Meteorological Department <http://www.rmcchennaieatlas.tn.nic.in>.

stage. All this will eventually not allow the initial incipient distur-

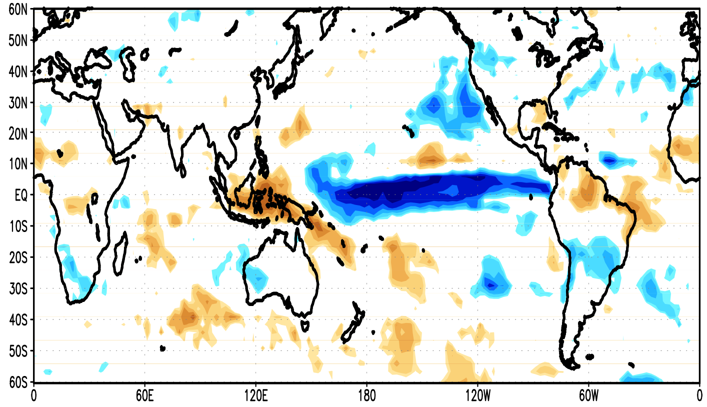
Interestingly, it has been documented that large-scale summer

Prajeesh et al., 2013, Scientific Reports

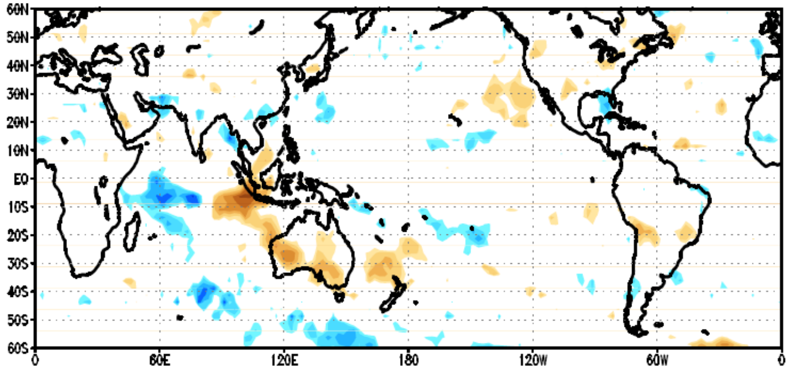
(a)



(b)



(c)



JJAS Partial Corr. of GPCP rainfall With

(a) EMI (b) NINO3 © IODMI

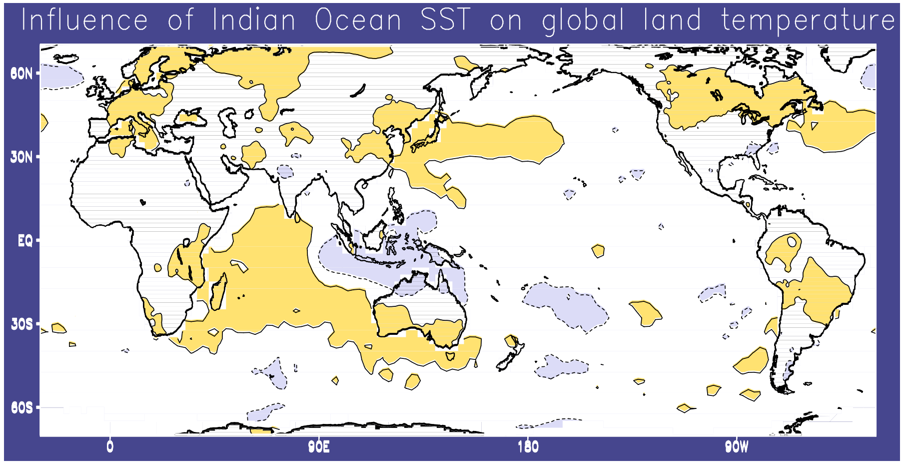
Ashok et al., 2007

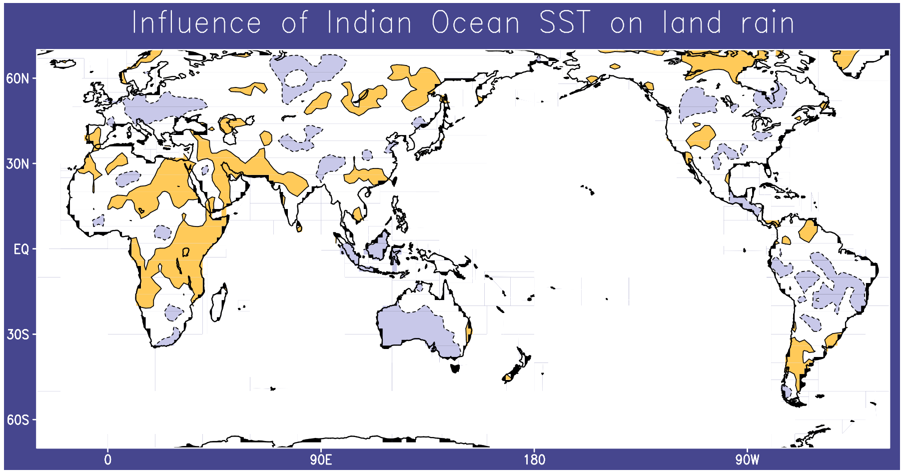
AGCM sensitivity experiments confirm the suggested teleconnections and mechanism in tropics (Ashok et al., GRL 2001; 2009; J. Clim 2004;)

Correlation with land rain, temperature

From Saji & Yamagata, 2003

- Floods to the west, droughts to the east.
- Floods over the monsoon trough
- warmer temperatures and droughts over extratropics


Influence of Indian Ocean SST on global land temperature


Influence of Indian Ocean SST on land rain

Recent strengthening of the IOD impact on the ISMR extremes

Krishnaswamy et al., 2014, Clim. Dyn.

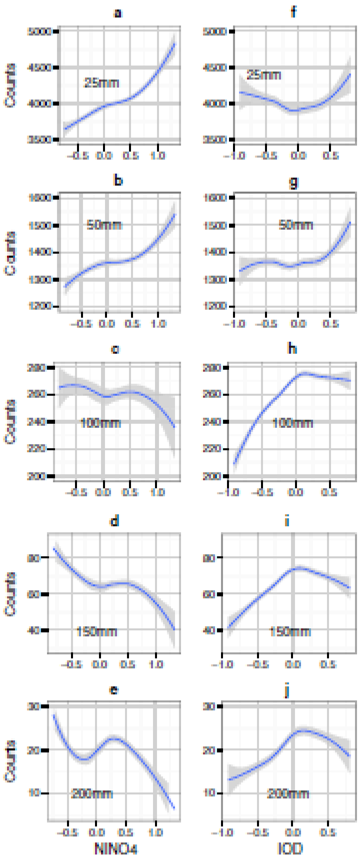
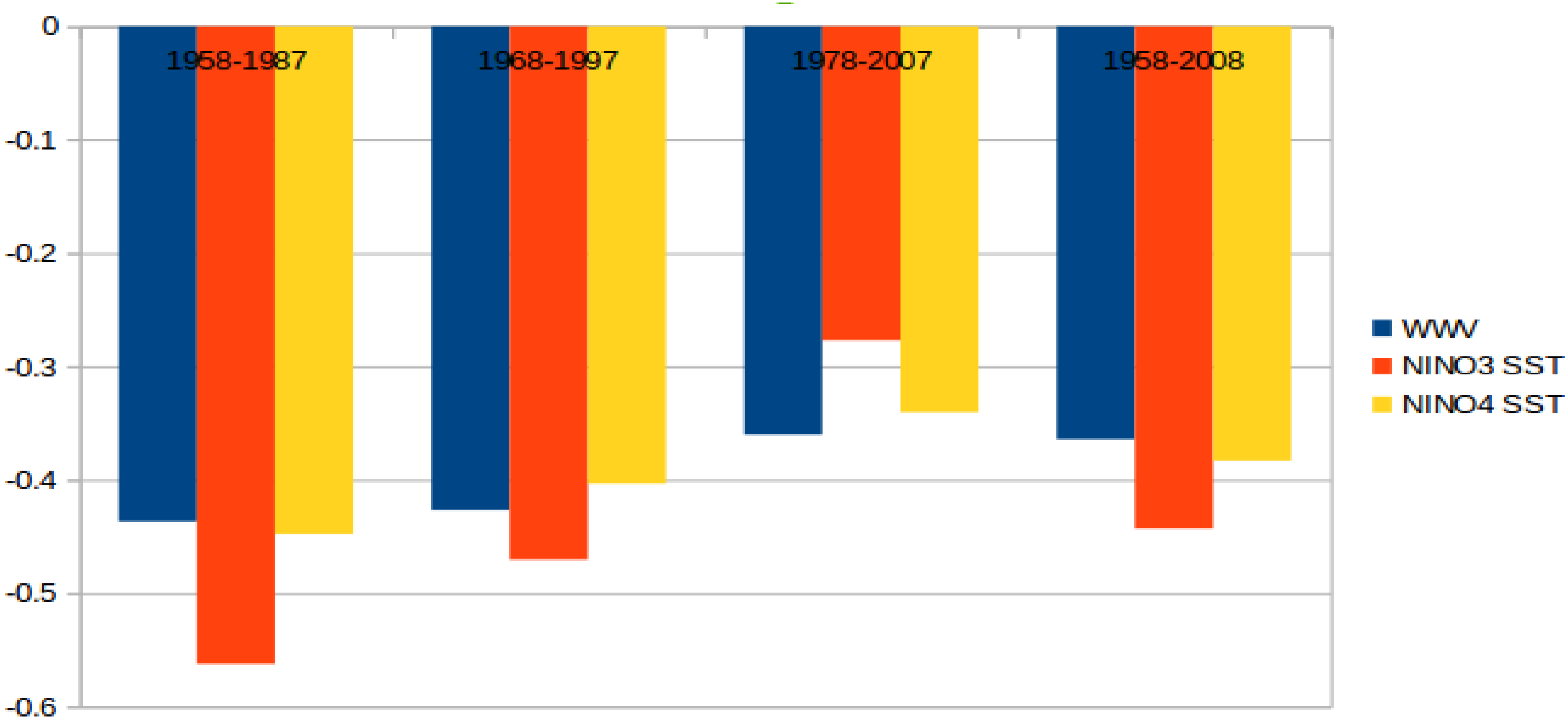


Fig. 5 Non linear response of ERE counts to NINO4 and IOD. Modelled ERE counts as a function of NINO4 (a–e) and IOD (f–j) for time periods 1901–2004 for rainfall exceedance thresholds of 25 mm (row 1), 50 mm (row 2), 100 mm (row 3), 150 mm (row 4) and 200 mm (row 5). The *solid lines* represent the fitted values of ERE counts as a function of either NINO4 or IOD based on generalized additive modelling, while the *shaded areas* represent the standard error bands. IOD emerges as the more monotonic and consistent driver of EREs especially at higher exceedance thresholds. All models are significant at $p < 0.001$

Abstract The El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are widely recognized as major drivers of inter-annual variability of the Indian monsoon (IM) and extreme rainfall events (EREs). We assess the time-varying strength and non-linearity of these linkages using dynamic linear regression and Generalized Additive Models. Our results suggest that IOD has evolved independently of ENSO, with its influence on IM and EREs strengthening in recent decades when compared to ENSO, whose relationship with IM seems to be weakening and more uncertain. A unit change in IOD currently has a proportionately greater impact on IM. ENSO positively influences EREs only below a threshold of 100 mm day^{-1}. Furthermore, there is a non-linear and positive relationship between IOD and IM totals and the frequency of EREs (>100 mm day^{-1}). Improvements in modeling this complex system can enhance the forecasting accuracy of the IM and EREs.

Correlation of SST and WWV indices with ISMR during JJAS. For 30 years, the critical value for two-tailed significance is 0.306 and for 51 years is 0.276 at 95% confidence level



Slide Courtesy: Feba Francis, UoH

Regression of winds during JJAS with ISMR

Figure 5c **1978-2007**

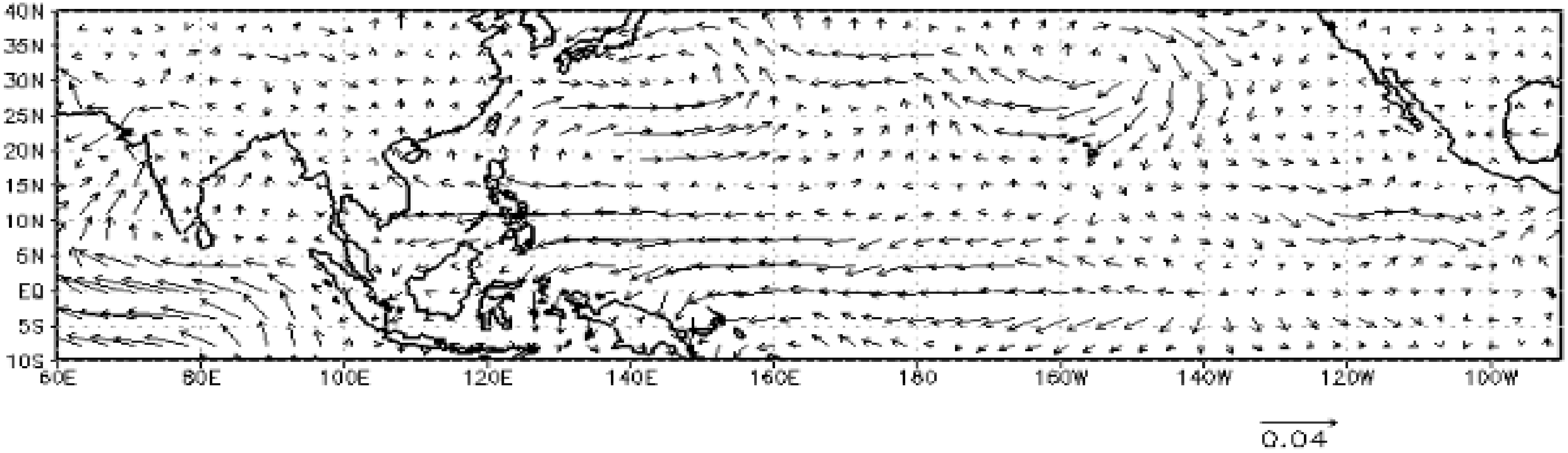
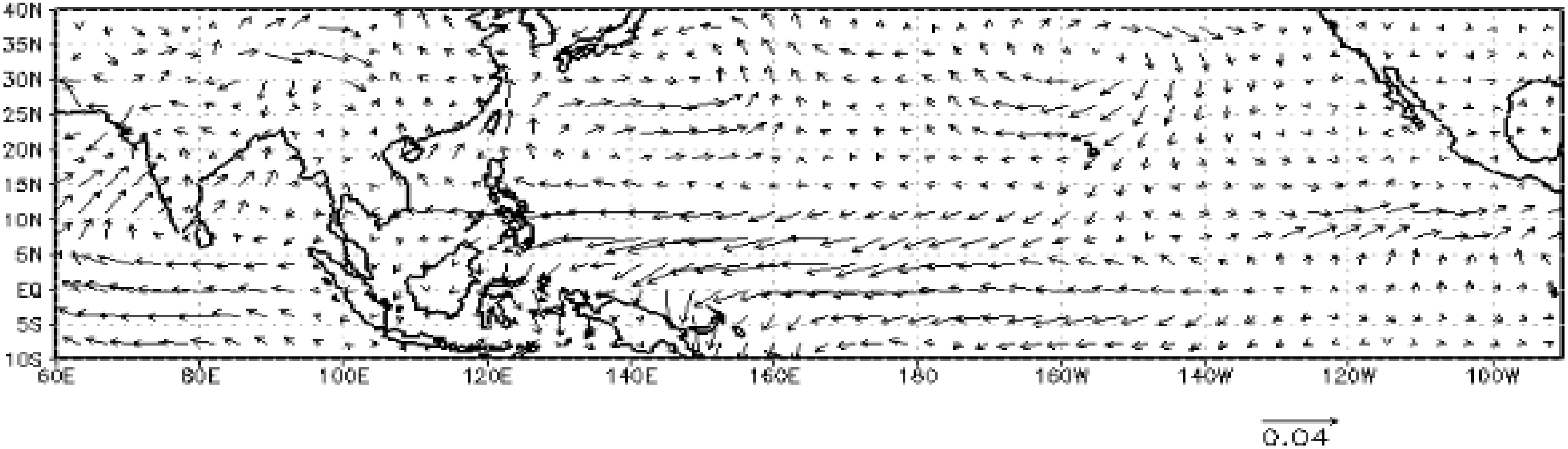


Figure 5d **1958-2008**

Slide Courtesy: Feba Francis, UoH



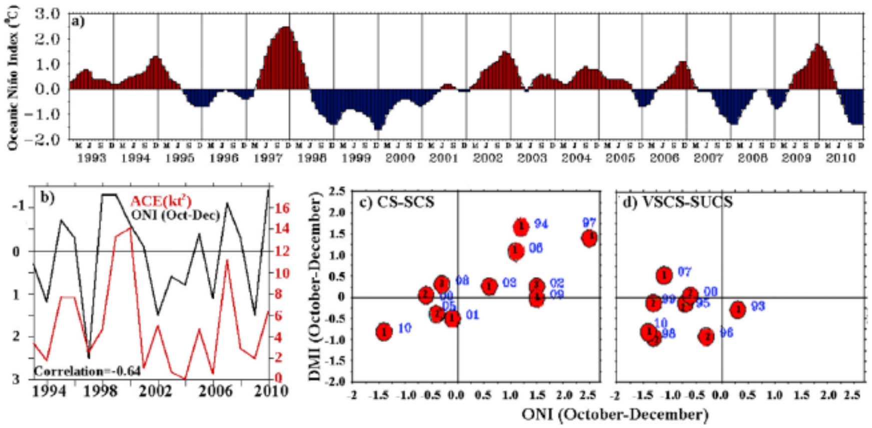


Figure 1. (a) Time series of 3 month running mean of the ONI (°C) during 1993–2010 (red and blue color indicates warm and cold years, respectively). (b) The interannual variability of ACE (1e + 04, kt^2) in the BoB during primary TC peak season (red line) and seasonal average of ONI (°C) (black line) for the period of 1993–2010. (Note in Figure 1b *y* axis is reversed for ACE). The relationship between ONI (°C) and DMI (°C) on TC numbers in the BoB during primary TC peak season in the categories (c) CS-SCS and (d) VSCS-SUCS. Each circle represents a year and the corresponding year is mentioned adjacent to the circle (blue color). The number in each circle indicates the number of cyclones formed during that particular year under that category.

[1] The El Niño–Southern Oscillation (ENSO) influence on tropical cyclone (TC) activity (frequency, genesis location, and intensity) in the Bay of Bengal (BoB) during the primary TC peak season (October–December) are studied for the period of 1993–2010. The study shows that during primary TC peak season, accumulated cyclone energy in the BoB is negatively correlated with Niño3.4 sea surface temperature anomaly. Under La Niña regime number of extreme TC cases (wind speed >64 kt) increases significantly in the BoB during the primary TC peak season. The analysis further shows that negative Indian Ocean dipole year is also favorable for extreme TC activity in the BoB during the primary TC peak season. The existence of low-level cyclonic (anticyclonic) vorticity, enhanced (suppressed) convection, and high (low) tropical cyclonic heat potential (TCHP) in the BoB provides favorable (unfavorable) conditions for the TC activity under La Niña (El Niño) regimes together with weak vertical wind shear and high sea surface temperature (SST). The genesis location of TC shifts to the east (west) of 87°E in the BoB during La Niña (El Niño) regime due to the variability in convective activity. The probable reason for the intense TC during a La Niña regime is likely explained in terms of longer track for TCs over warm SST and high TCHP due to eastward shifting of genesis location together with other favorable conditions. The variability of Madden-Julian Oscillation and its influence on TC activity in the BoB during La Niña and El Niño regime are also examined.

Girishkumar and Ravichandran 2012 JGR

Table 1. TC Cases in the BoB During 1993–2010[a]

Years (October–December ONI, DMI)	CS-SCS	VSCS-SUCS
Cold regime		
Year 1: 1995 (−0.70, −0.14)	*0*	*2*
Year 2: 1998 (−1.30, −0.94)[b]	*0*	*2*
Year 3: 1999 (−1.30, −0.13)	*0*	*2*
Year 4: 2000 (−0.60, 0.05)	*2*	*2*
Year 5: 2007 (−1.10, 0.52)	*0*	*1*
Year 6: 2010 (−1.4, −0.82)[b]	*1*	*1*
Total (La Niña years 1–6)	*3*	*10*
Total cyclone (La Niña years CS-SUCS)	*13*[c]	
Year 7: 1996 (−0.30, −0.93)[b]	0	2
Year 8: 2005 (−0.40, −0.40)	2	0
Year 9: 2008 (−0.30, 0.30)	3	0
Total (years 1–9)	8	12
Total cyclone (CS-SUCS)	20[d]	
Warm regime		
Year 1: 1993 (0.30, −0.30)[b]	*0*	*1*
Year 2: 1994 (1.20, 1.65)[e]	*1*	*0*
Year 3: 1997 (2.50, 1.40)[e]	*1*	*0*
Year 4: 2002 (1.50, 0.25)	*3*	*0*
Year 5: 2004 (0.80, 0.05)	*0*	*0*
Year 6: 2006 (1.10, 1.07)[e]	*1*	*0*
Year 7: 2009 (1.50, −0.02)	*1*	*0*
Total (El Niño years 1–7)	*7*	*1*
Total cyclone (El Niño years CS-SUCS)	*8*[f]	
Year 8: 2003 (0.6, 0.25)	1	0
Total (years 1–8)	8	1
Total cyclone (CS-SUCS)	9[g]	

[a] The October–December ONI and DMI (°C) averaged during primary TC peak season are shown in parentheses (La Niña and El Niño year marked in italics).

[b] Negative IOD years.

[c] Value shown is the sum of the CS-SCS and VSCS-SUCS columns. Average is 2.16 TC per season.

[d] Value shown is the sum of the CS-SCS and VSCS-SUCS columns. Average is 2.25 TC per season.

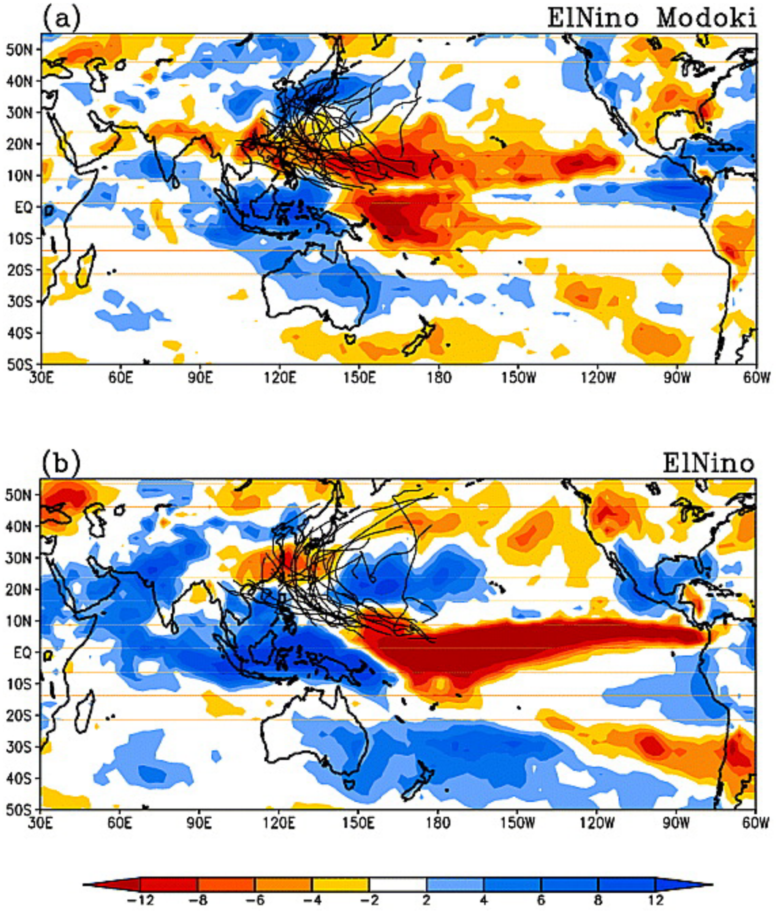
[e] Positive IOD years.

[f] Value shown is the sum of the CS-SCS and VSCS-SUCS columns. Average is 1.14 TC per season.

[g] Value shown is the sum of the CS-SCS and VSCS-SUCS columns.

Modoki, Indian Ocean Dipole, and western North Pacific typhoons: Possible implications for extreme events

Pradhan et al., 2011



Journal of Geophysical Research: Atmospheres
Volume 116, Issue D18, D18108, 23 SEP 2011 DOI: 10.1029/2011JD015666
http://onlinelibrary.wiley.com/doi/10.1029/2011JD015666/full#jgrd17133-fig-0003

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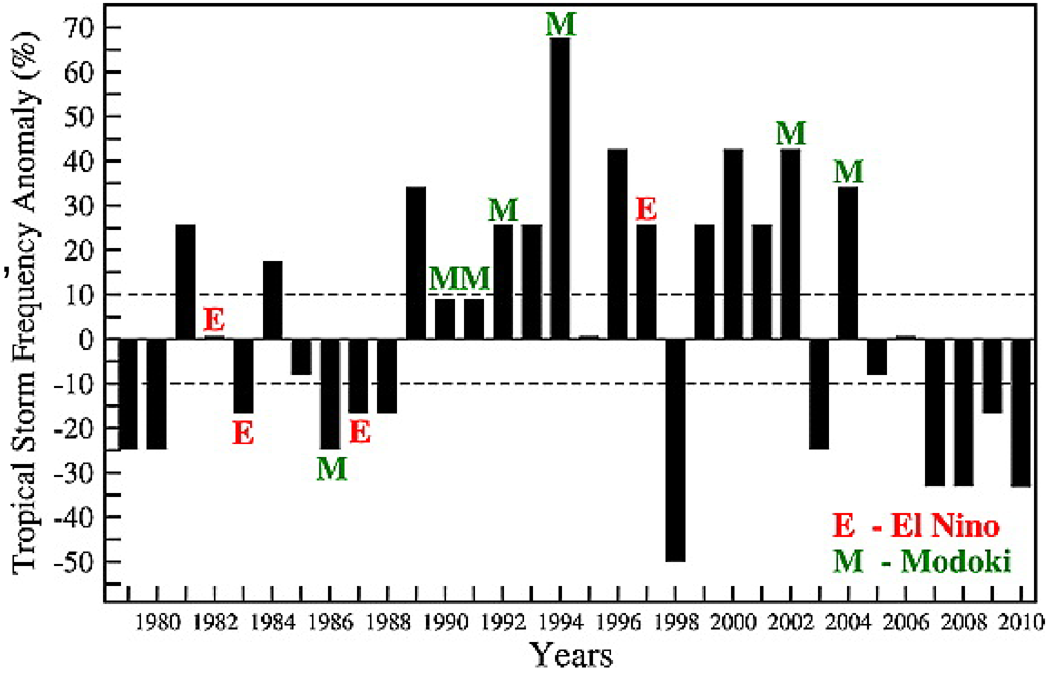

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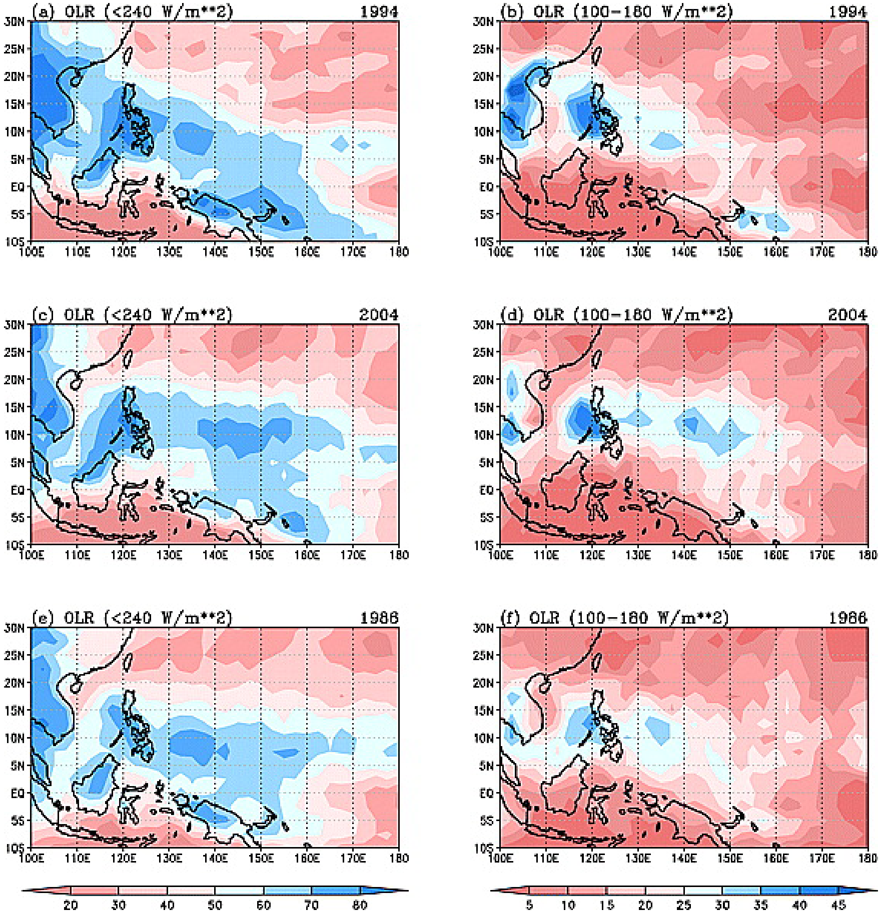

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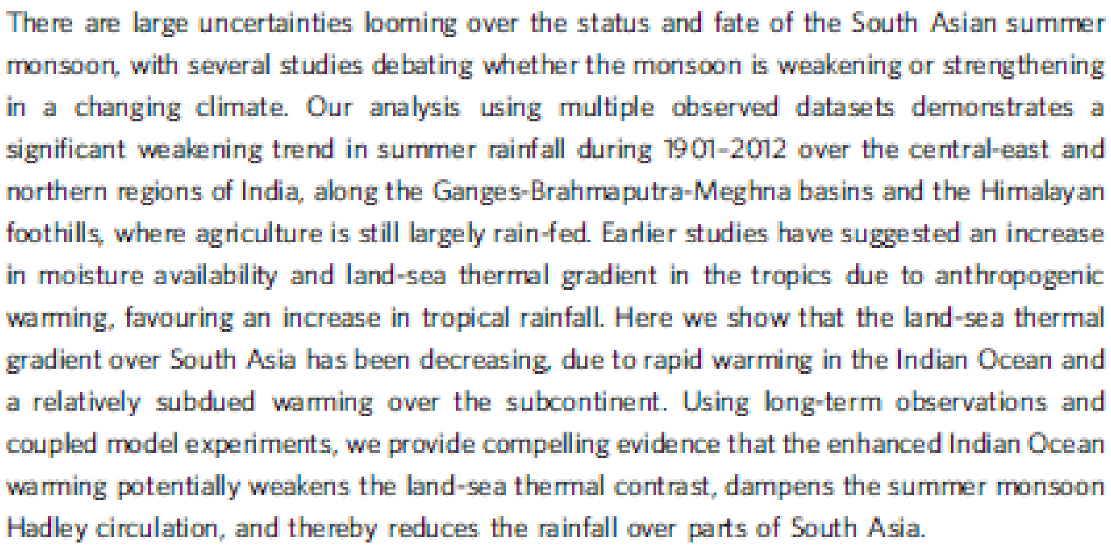
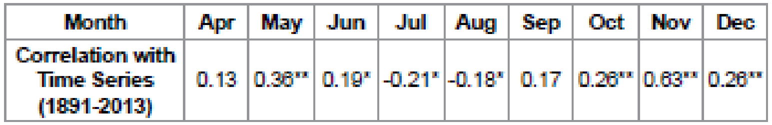
Indian Ocean Warming and decreasing Land Ocean contrast, and monsoon rainfall..



There are large uncertainties looming over the status and fate of the South Asian summer monsoon, with several studies debating whether the monsoon is weakening or strengthening in a changing climate. Our analysis using multiple observed datasets demonstrates a significant weakening trend in summer rainfall during 1901–2012 over the central-east and northern regions of India, along the Ganges-Brahmaputra-Meghna basins and the Himalayan foothills, where agriculture is still largely rain-fed. Earlier studies have suggested an increase in moisture availability and land-sea thermal gradient in the tropics due to anthropogenic warming, favouring an increase in tropical rainfall. Here we show that the land-sea thermal gradient over South Asia has been decreasing, due to rapid warming in the Indian Ocean and a relatively subdued warming over the subcontinent. Using long-term observations and coupled model experiments, we provide compelling evidence that the enhanced Indian Ocean warming potentially weakens the land-sea thermal contrast, dampens the summer monsoon Hadley circulation, and thereby reduces the rainfall over parts of South Asia.

Roxy et al.
2015

Preliminary results on Chennai events



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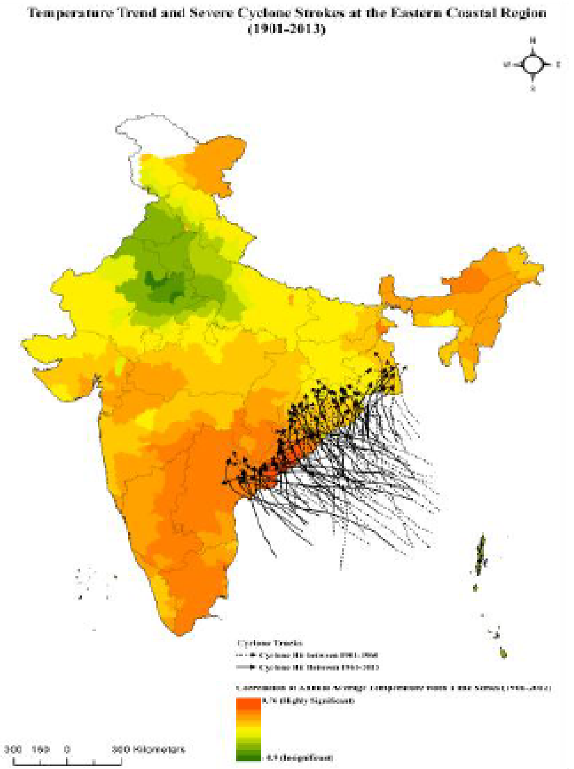

Figure 3: Temperature Trend and Severe Cyclone Strokes at the Eastern Coastal Region (1901-2013)
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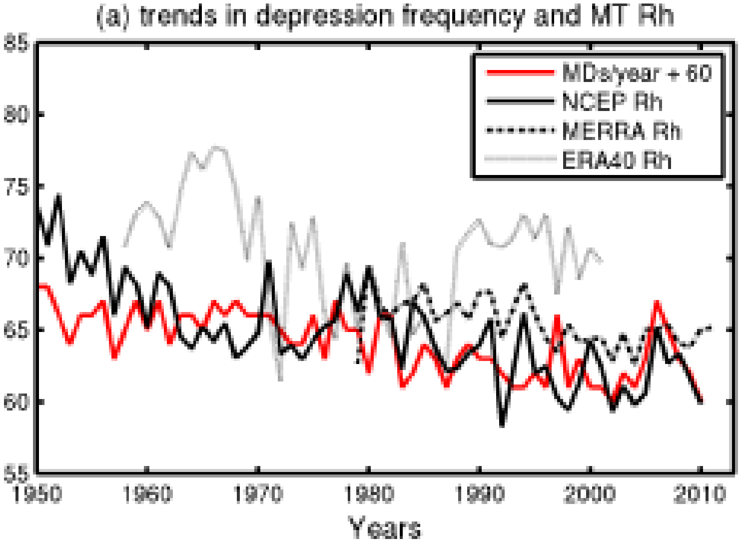
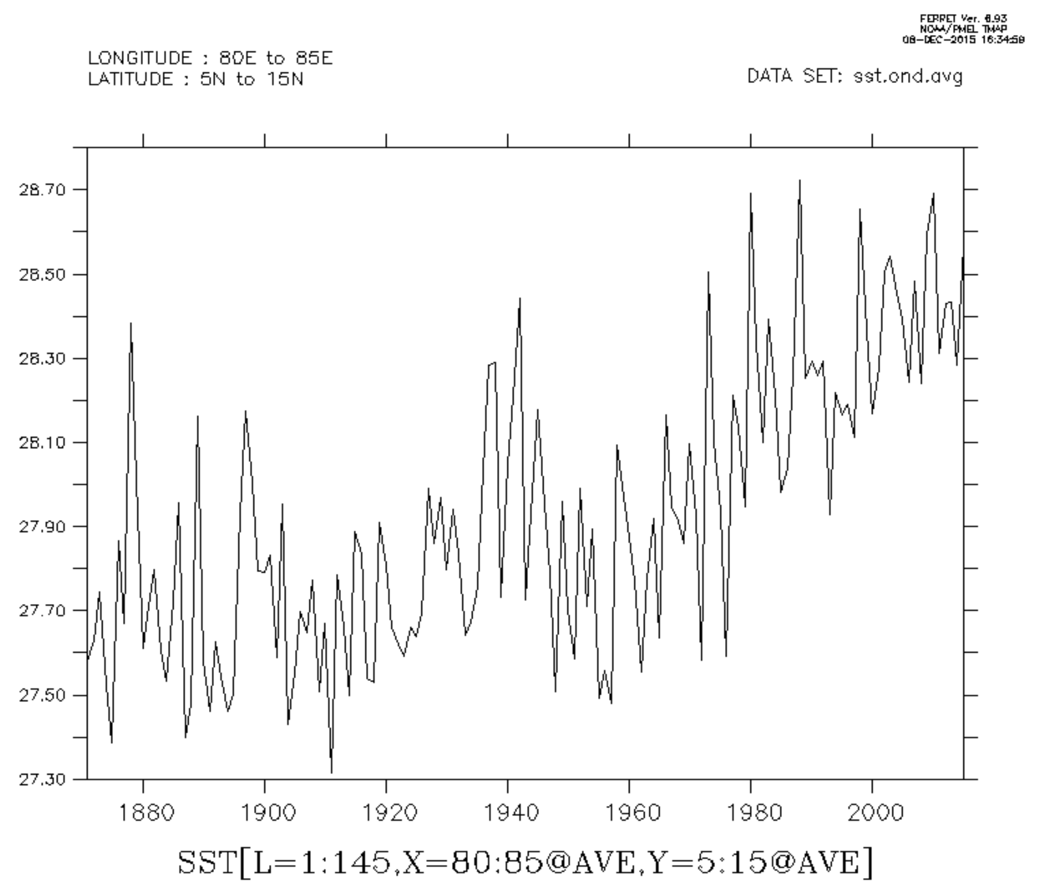
Mishra 2013, J. Earth Sci. Clim. Change



Prajeesh et al., 2013, Scientific Reports

Increasing trend in tropical cyclones (TC) in BoB (Mishra 2013), Balaguru et al. (2014), though there is a weakening frequency in monsoon depressions (Prajeesh et al. , 2013)

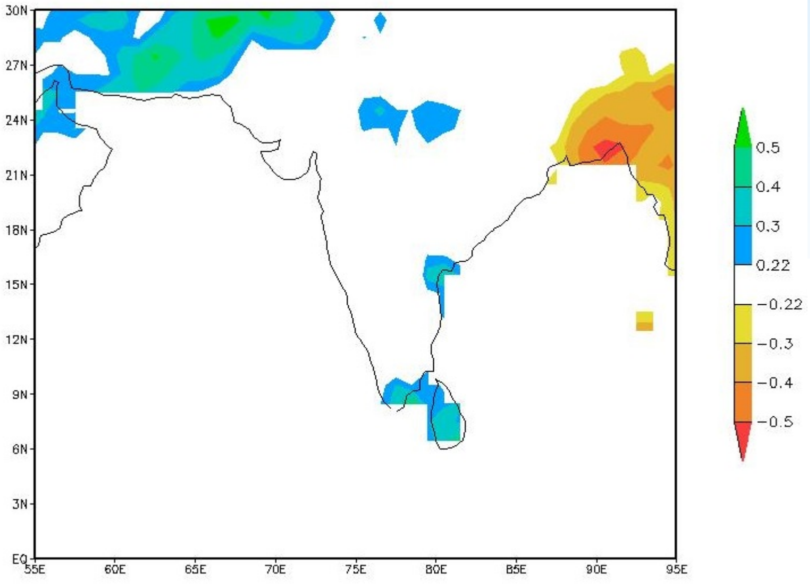
Preliminary results on Chennai events (Courtesy: A. Boyaj)



The BoB SST warming trend

BoB shows an increasing SST trend since the beginning of 20 century, though we need to be careful about the quality of the data. Could this be the reason for increasing trend in the TCs and extreme events? In fact, analysing datasets since 1980s, Balaguru et al. conjecture the role of increasing BoB temperature in increasing the frequency of the TCs.

Slide Courtesy: A. Boyaj



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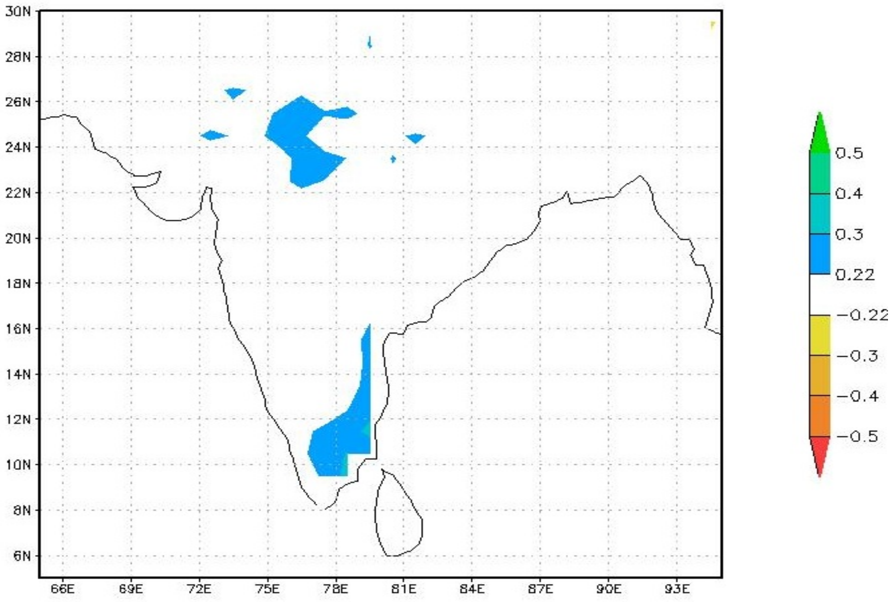
Correlation of detrended NINO3 index and GPCC rainfall data during OND months.

Slide Courtesy: A. Boyaj



Correlation with IMD rainfall and detrended BoB SST during November month.

The seasonal rainfall for the NE monsoon also seems to be more related to the BoB SST rather than El Nino for the period of analysis.

- Did the 2015 El Niño or the BOB warming trend play a role in the extremity of the Chennai event?

- To find an answer, we made two experiments, by changing the domain as follows, with WRF model at 50 km resolution, with GFS lateral boundary conditions, and observed SST as lower boundary conditions.

1. Indian Ocean theatre experiment.

2. Indo-Pacific Ocean theatre experiment.

Data and Methodology

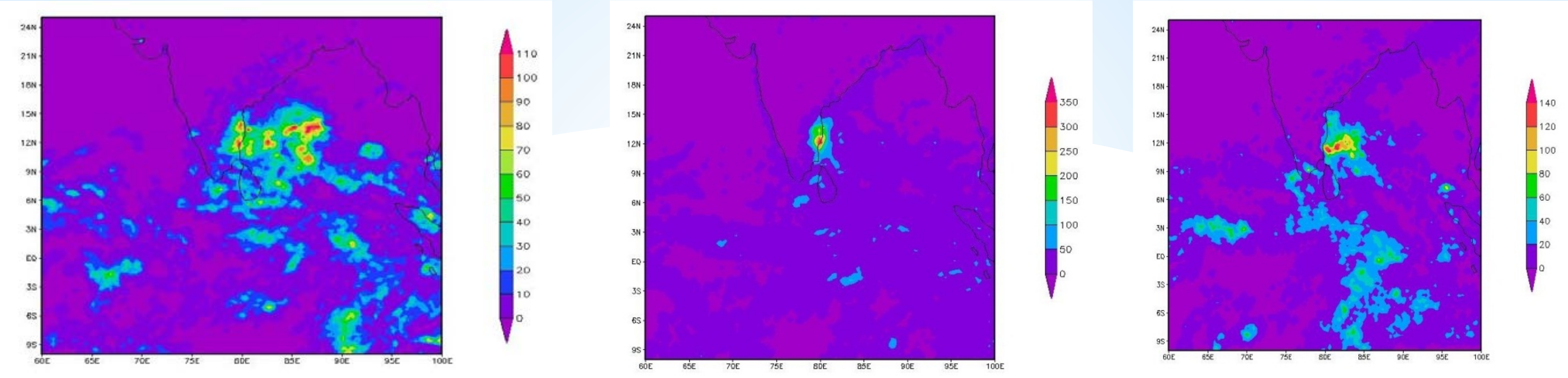
Datasets:

- Observation data from TRMM about 27Nov-06Dec,2015 at 50km resolution.
- HadISST data for the period 1871-2014.
- GPCC rainfall data from 1960-2013.
- Gridded Indian rainfall datasets 25km resolution the period of 1901-2014 (Rajeevan et al).
- GFS data for initial boundary conditions for the WRF simulations.

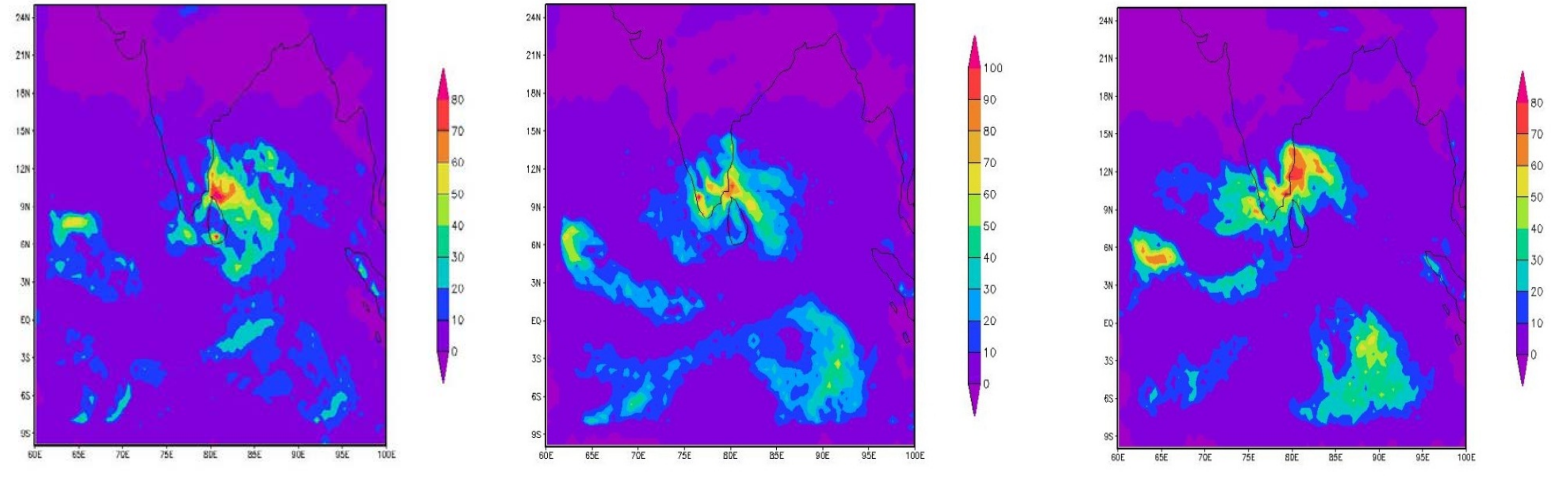
Methodology:

- Run the WRF model for 7 days since 29Nov-06Dec,2015, used GFS data for initial boundary conditions.
- Plotted time series area average and compare observation daily rainfall data and WRF simulation rainfall data.

Observed daily rainfall from TRMM period of 30Nov-02Dec 2015.

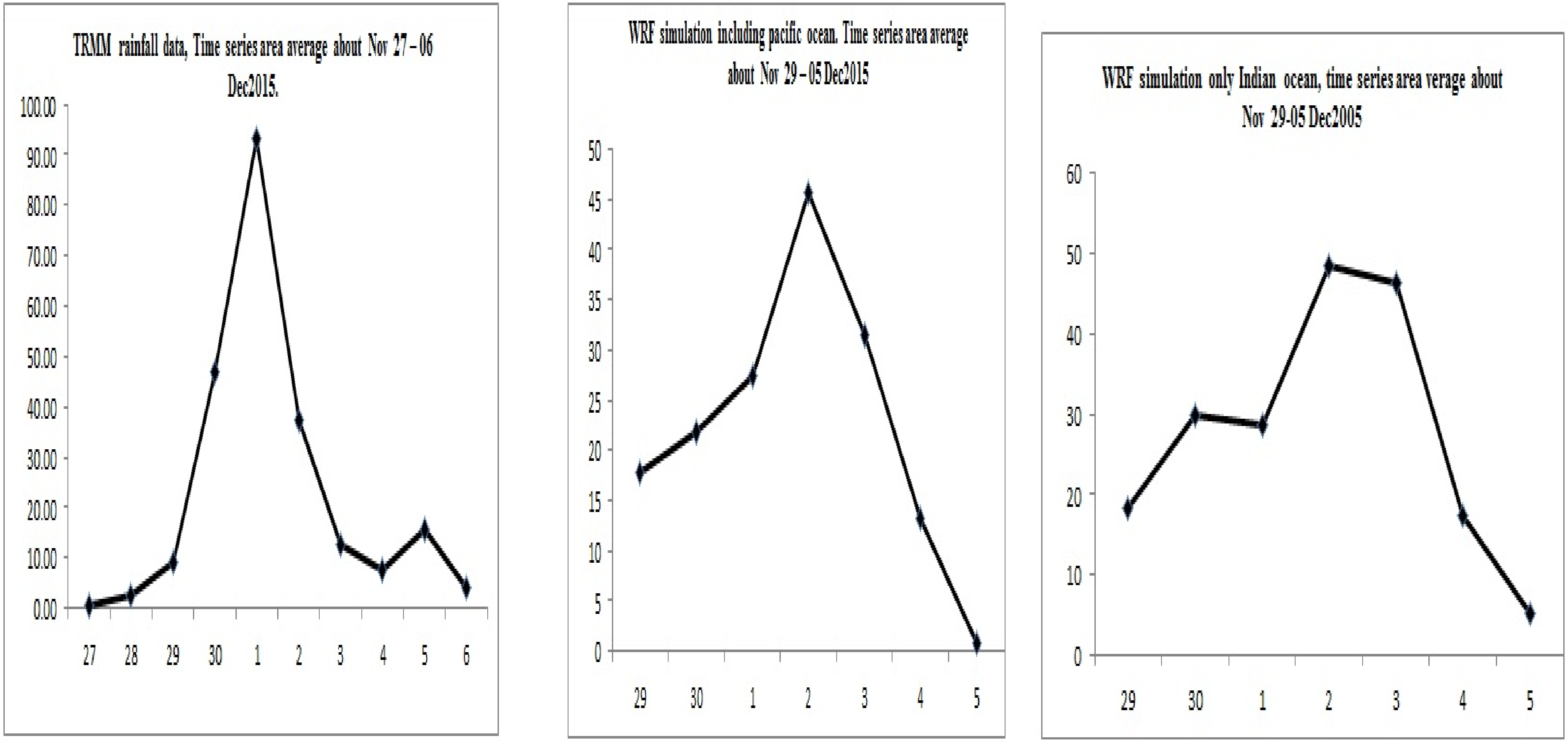


Daily rainfall WRF simulated in the Indian theatre experiment period of 30Nov-02Dec 2015



Results and Discussions:

Rainfall evolution from (left) TRMM (middle) Indo-pacific theatre experiment (iii) Indian theatre experiment, area-averaged over 78^0 E-82^0E and 11^0N-14^0N.



- WRF is able to reproduce broad features of Chennai extreme event. The model also simulates the onset and well though it peaks and weeks a day later than the observation.

- The only Indian Ocean extent simulates an unrealistic 02-03Dec 2015 peak.

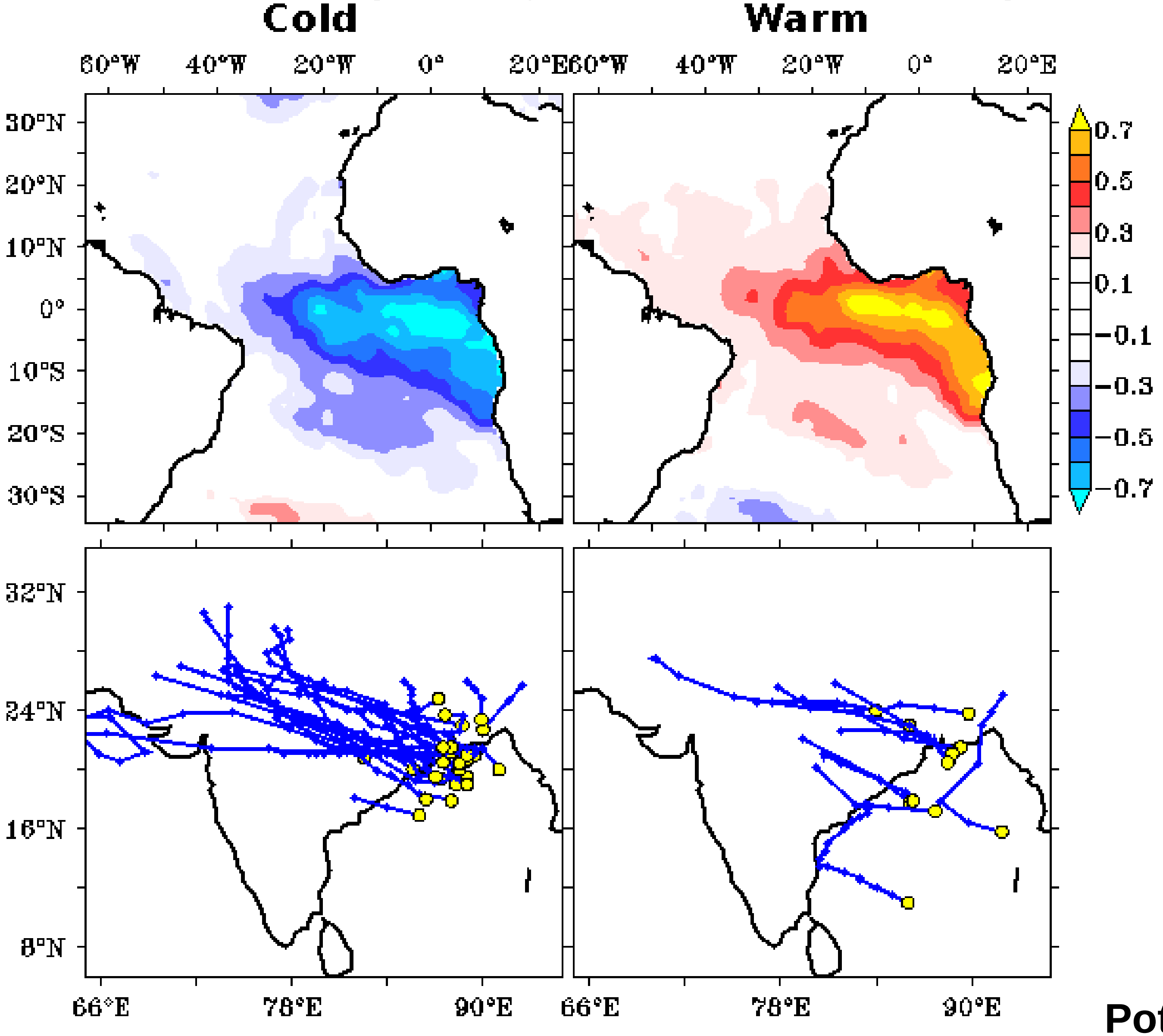
Preliminary Conjuncture:

- These results suggest that the increasing SST trend in the BoB may have been instrumental in the extremity of the event.

- If anything, the signals from the concurrent El Niño have tempered the extremity down.

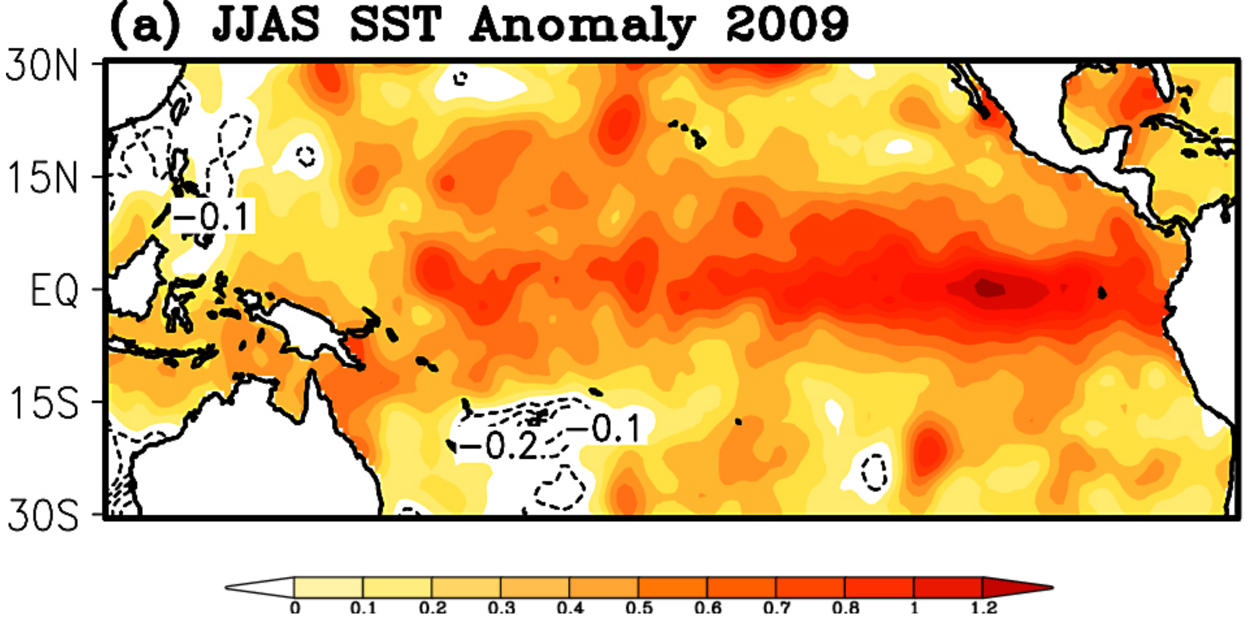
Some other higher simulations have been carried out
by Subimal and Anjana, and a few more at Hyderabad

The warm phase of Atlantic Zonal Mode decreases the frequency of monsoon depressions



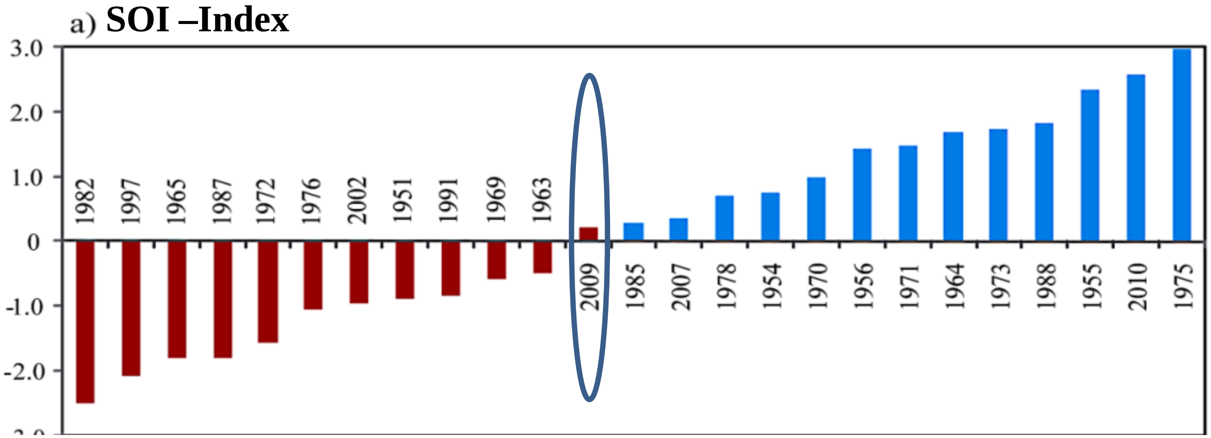
Composite of JJA SST anomalies during the cold and warm phases of AZM (top panel) and the corresponding monsoon depression tracks (bottom panel) during the period 1975-2012.

Pottapinjara et al., 2014



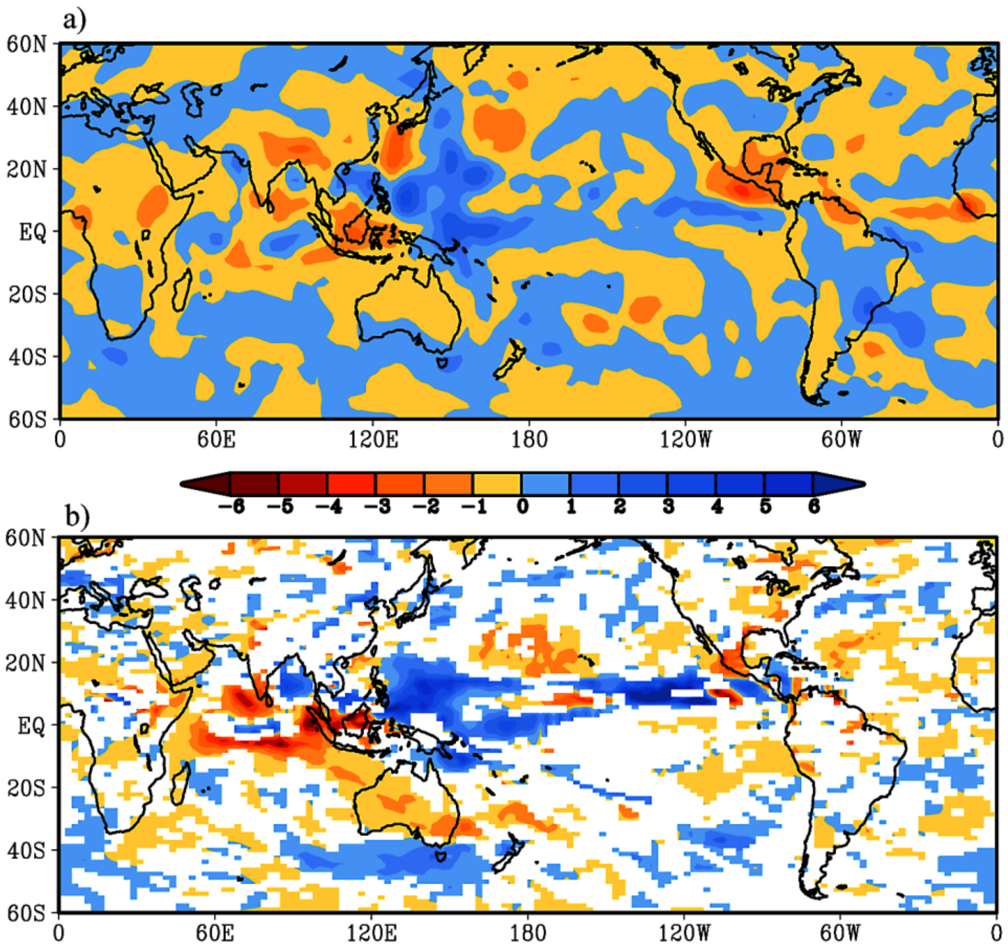
Top: A hitherto unseen anomalous basin-wide warming from May 2009 through April 2010

Ashok et al 2012



Similar SST conditions seen in June-July 2014

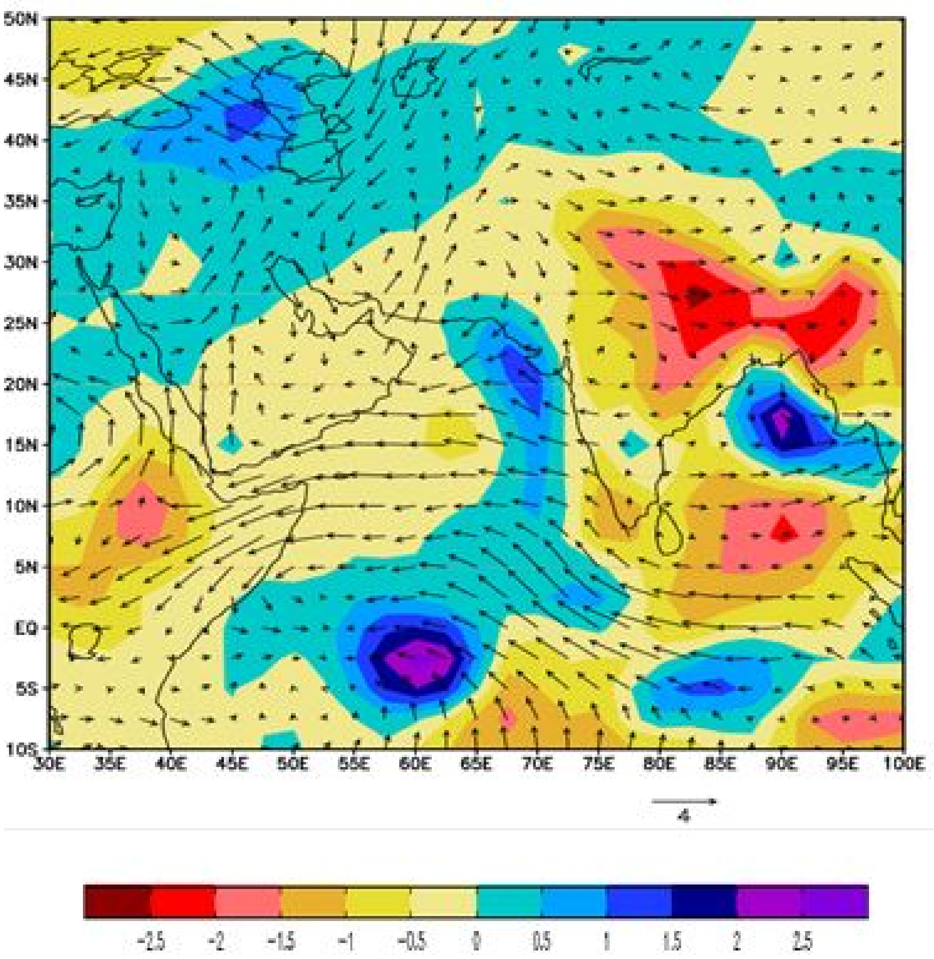
- Bottom: The SOI is one of the weakest as compared to the canonicals ENSOs since 1950s.

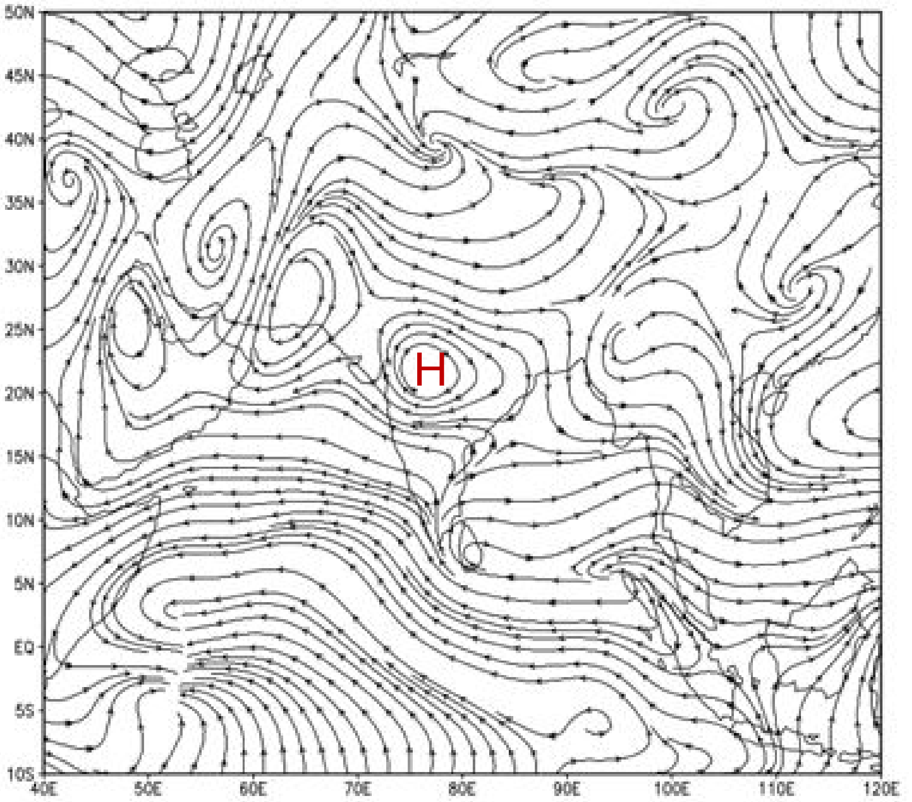


Rainfall anomalies during JJAS 2009 (a) Observed (b) simulated in an AGCM experiment.

Precipitation patterns affected worldwide. India faced a severe drought(77%) in 2009 and received deficient rainfall(88%) in 2014

Precipitation and 850hPa wind anomalies for JJAS 2009





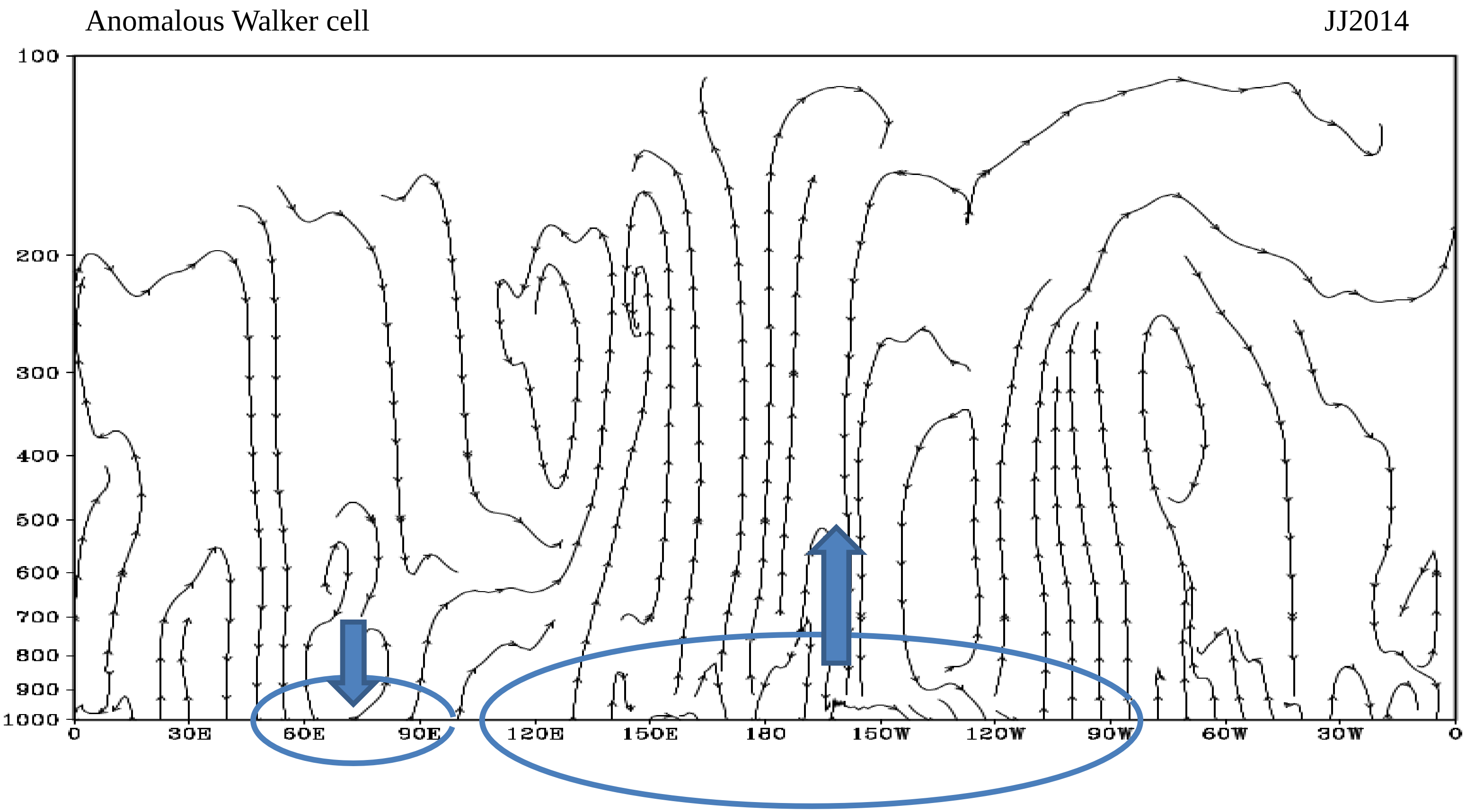
Precipitation(shaded)
winds(streamlines)

Winds(vectors)

Jha, A., K. Ashok, T. P. Sabin, M. Roxy, & R. Krishnan, 2016
-to be submitted to GRL

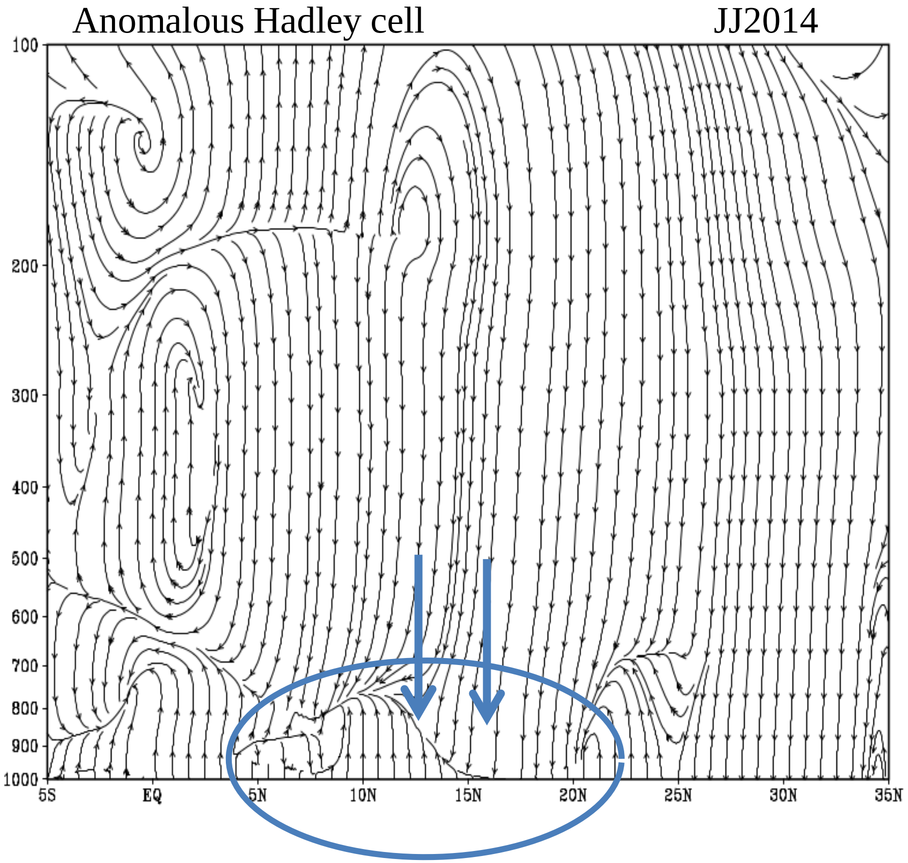
Tropical teleconnection

- Walker cell for June-July 2014



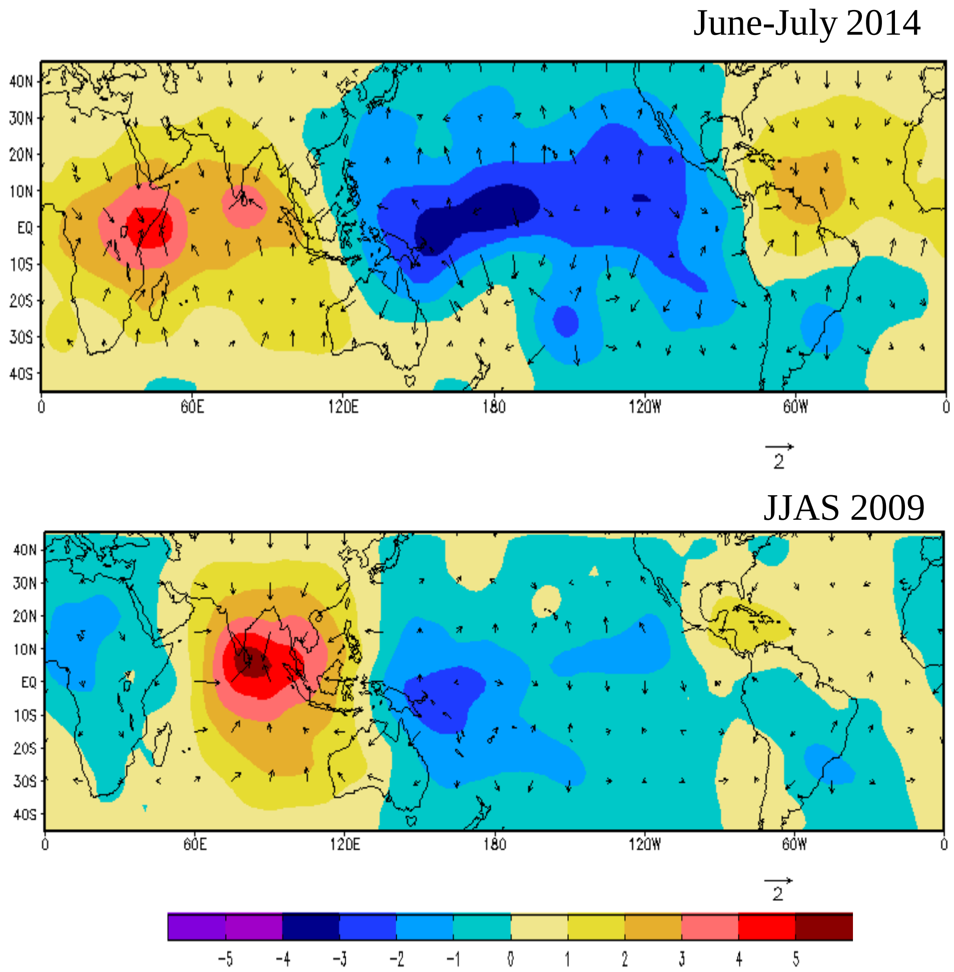
Jha, A. et al. 2016
-to be submitted to GRL

Hadley cell for June-July 2014



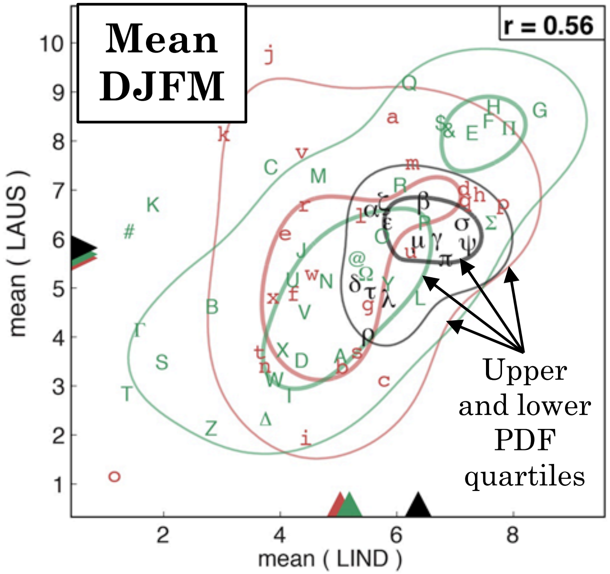
Subsidence over Indian landmass

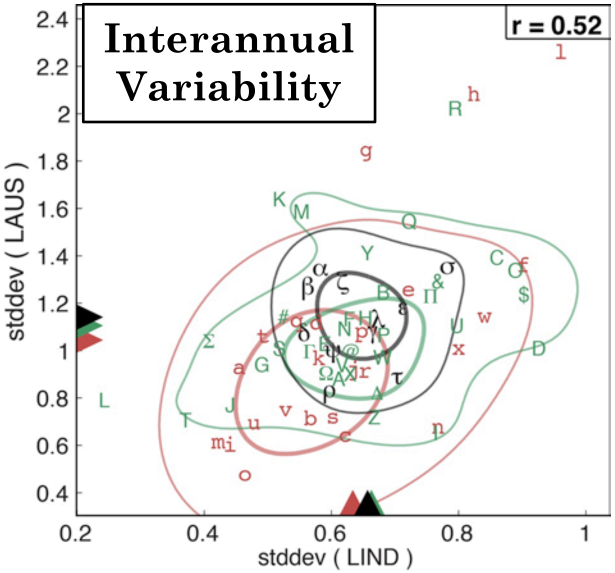
200hPa Velocity Potential & Divergent wind anomalies

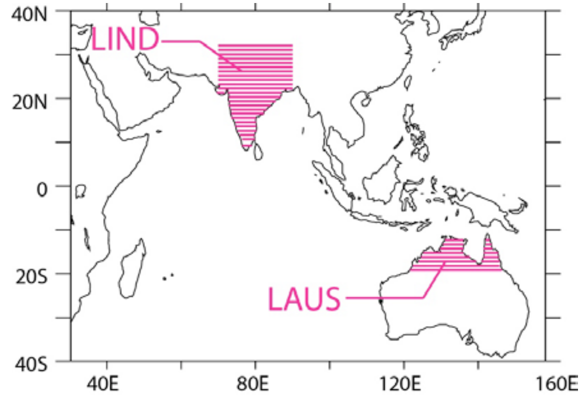


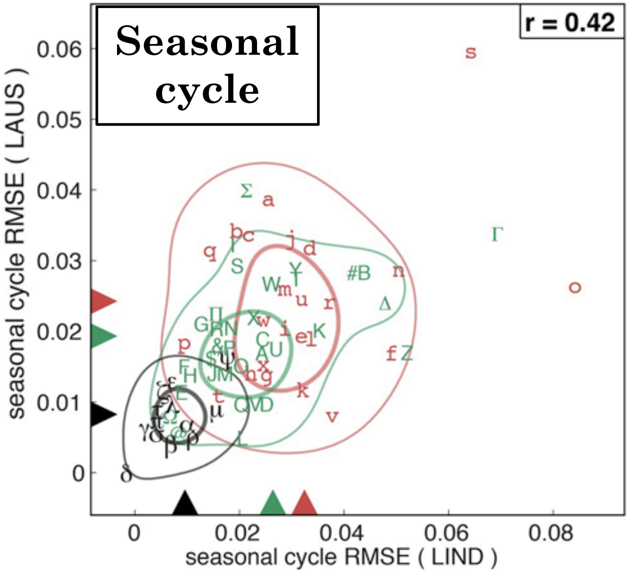
Jha, A., K. Ashok, T. P. Sabin, M. Roxy, & R. Krishnan, 2016
-to be submitted to GRL

Characteristics of simulated Indo-Australian summer monsoon rainfall









α	CMAP
β	GPCP
γ	GPCC
δ	AWAP/APHRODITE
ε	TRMM-3B42
ζ	TRMM-3B43
λ	NCEP-NCAR-I
μ	NCEP-DOE-II
π	NCEP-CFSR
ρ	ERA-40
τ	ERAinterim
ψ	JRA-25
σ	MERRA

OBS./ REA.

CMIP3

CMIP5

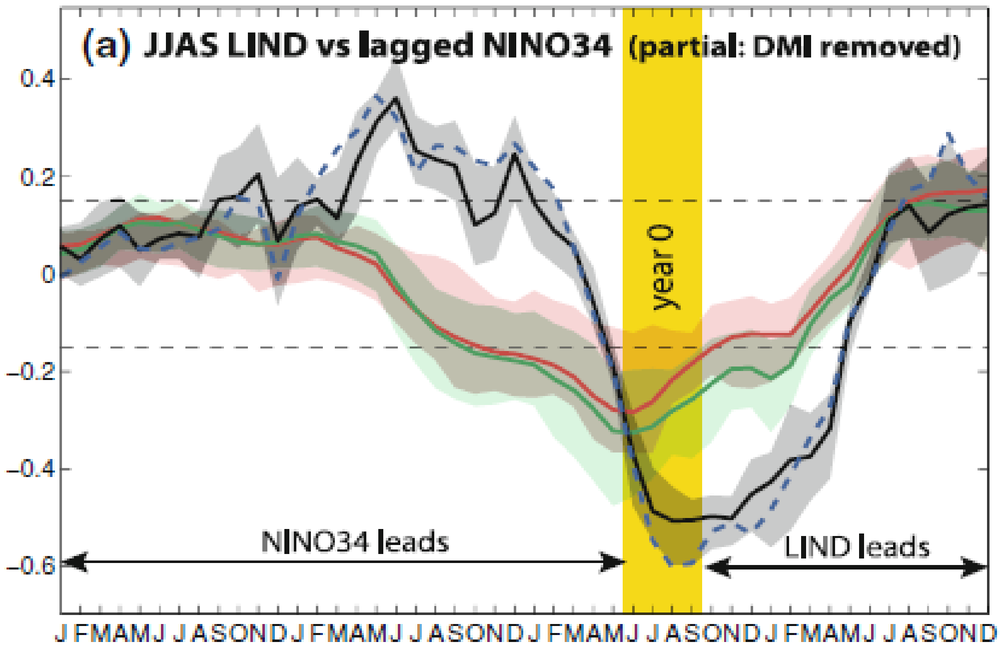
Spread in reanalyses.

Large spread in simulated monsoon rainfall characteristics.

No significant differences between CMIP3 and CMIP5 multi-model means except for the seasonal cycle (slightly better in CMIP5)

Jourdain et al., 2013

Fig.A Lag correlation between Land-Only monsoon rainfall o
monthly NINO3.4 values (months on the X-axis). Thick lines a
(black), CMIP3 (red), and CMIP5 (green). Semi-transparent a
blue thick line represents APHRODITE HadISST. The yellow ar
shows the JJAS months over which each index is averaged. T
of correlation coefficients for a single time-series of 150 yea



Jourdain et al., 2013

- The multimodel mean JJAS Indian monsoon rainfall is under-estimated by ~15 % in the CMIP3 and CMIP5 simulations.
- In both CMIP3 and CMIP5 simulations, the relatively good skill of the multi-model mean hides a wide spread in the mean monsoon rainfall, across individual CMIP models: from nearly no rainfall to twice the observed rainfall. The spread, as estimated by the standard deviation, is 22 % higher in the CMIP5 than the CMIP3
models for LIND

Key points

- Changes in the amplitude of ENSO-driven SST variability in response to global warming are uncertain

- However:
  - Global warming interferes with the impact the El Niño sea-surface temperatures have on rainfall
  - This interference causes robust changes in El Niño's impact on rainfall
  - Changes include an intensification of El Niño-driven west Pacific drying and El Niño-driven rainfall increases in the central and eastern Pacific

- A big surprise!

- Future changes to ENSO clearer than previously thought

Power et al., *Nature*, 2013

Acknowledgements:

-The organizers for hospitality
- relevant (past, present, and prospective) co-authors
-to authors of various papers that I cite in this work
-the authors of the PowerPoint slides availed from the WWW.

Thanks for the attention…

Thank You