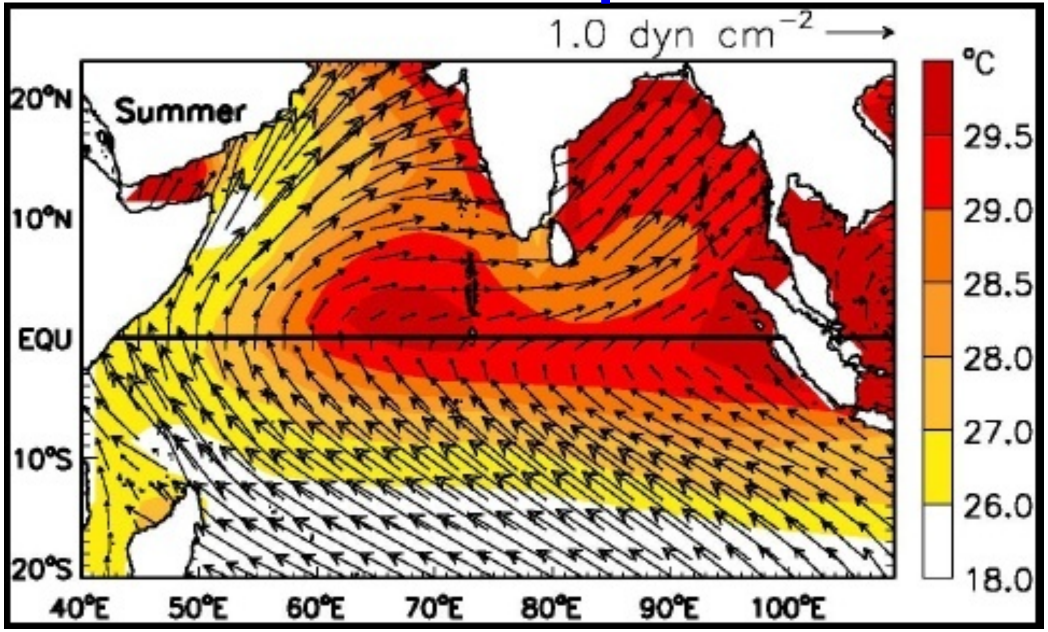
Indian Ocean Warming and its Impact on Indian Summer Monsoon and Global Hiatus

Suryachandra A. Rao
Associate Mission Director, Monsoon Mission
Indian Institute of Tropical Meteorology



Collaborators: H.S.Chaudari, S. Pokhrel, Asish Dhakate, Kiran Solunke, S. Saha and others

Outline

1. Why Indian Ocean is Warming Consistently?
2. What is its impact on Indian Summer Monsoon
   a. Seasonal Mean
   b. Intraseasonal Oscillations
   c. Extreme Rainfall Events
   d. Global warming Hiatus

Data and Model

- TMI & Reynolds SST
- Merged Sea Surface Height data
- NCEP/NCAR and SODA/GODAS/ECCO reanalysis
- ECHAM-5 AGCM (T106L19)
- Data from CMIP5 Models

Indian Ocean Warm Pool

70% of the World Ocean Heat gain is in IO

Springer Link

Why is Indian Ocean warming consistently?

Climatic Change
February 2012, Volume 110, Issue 3, pp 709–719

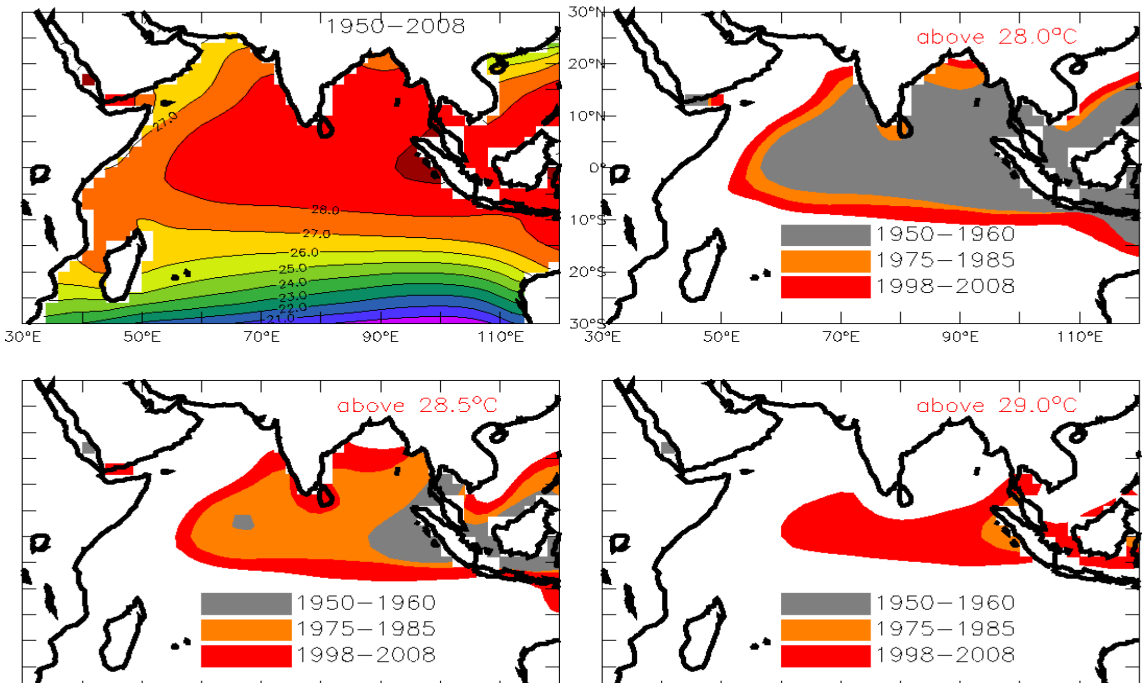


Table 1. The Boreal Summer (JJAS) SST Warming Trend of Global (60°S–60°N, 0°–360°E) and Central Tropical Indian Ocean (15°S–6°N, 60°E–95°E) Over Two Different Periods (1900–2010 and 1979–2010) for Two Distinct Data Sets[a]

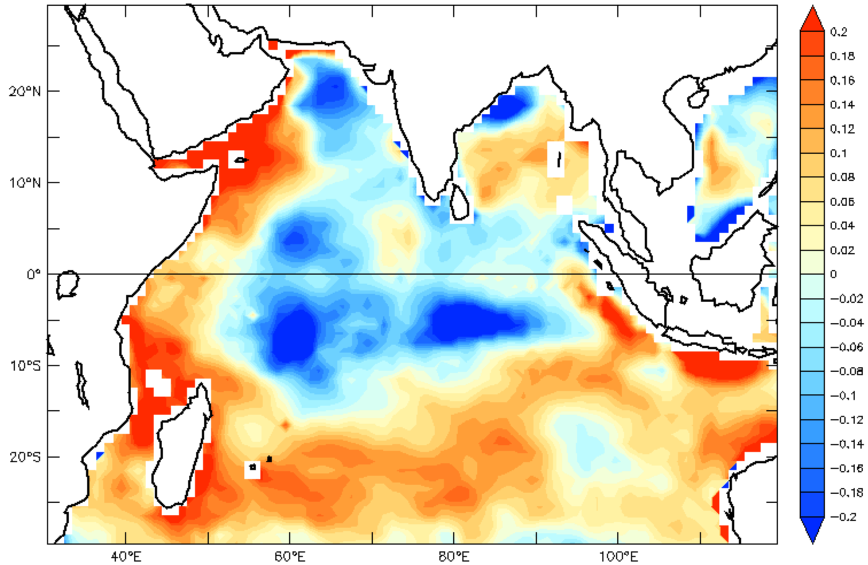
	HadISST		ERSST V3b	
Period	Global	Central Tropical Indian Ocean	Global	Central Tropical Indian Ocean
1900–2010	0.58°C/century	0.65°C/century	0.74°C/century	0.85°C/century
1979–2010	0.96°C/century	1.32°C/century	1.22°C/century	1.61°C/century

[a]Global: 60°S–60°N, 0°–360°. Central Indian Ocean: 15°S–6°N, 60°E–95°E.

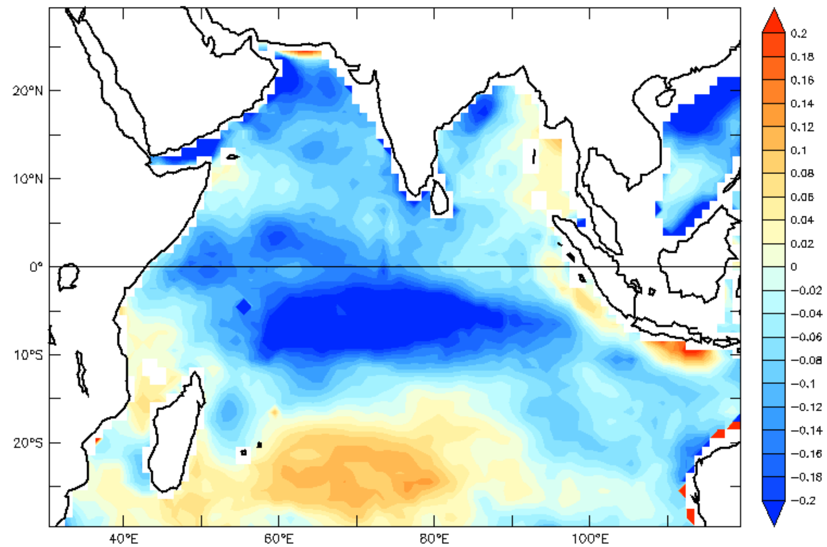
Relative Role of surface heat fluxes and Ocean Dynamics for warming/expansion of warm pool

$$\frac{\partial T}{\partial t} + \mathbf{u}\cdot\nabla T + \frac{w\Delta T}{h} + \frac{1}{h}\frac{Q_{net}}{\rho_o c} = 0,$$

Role of net surface heat fluxes on SST trend

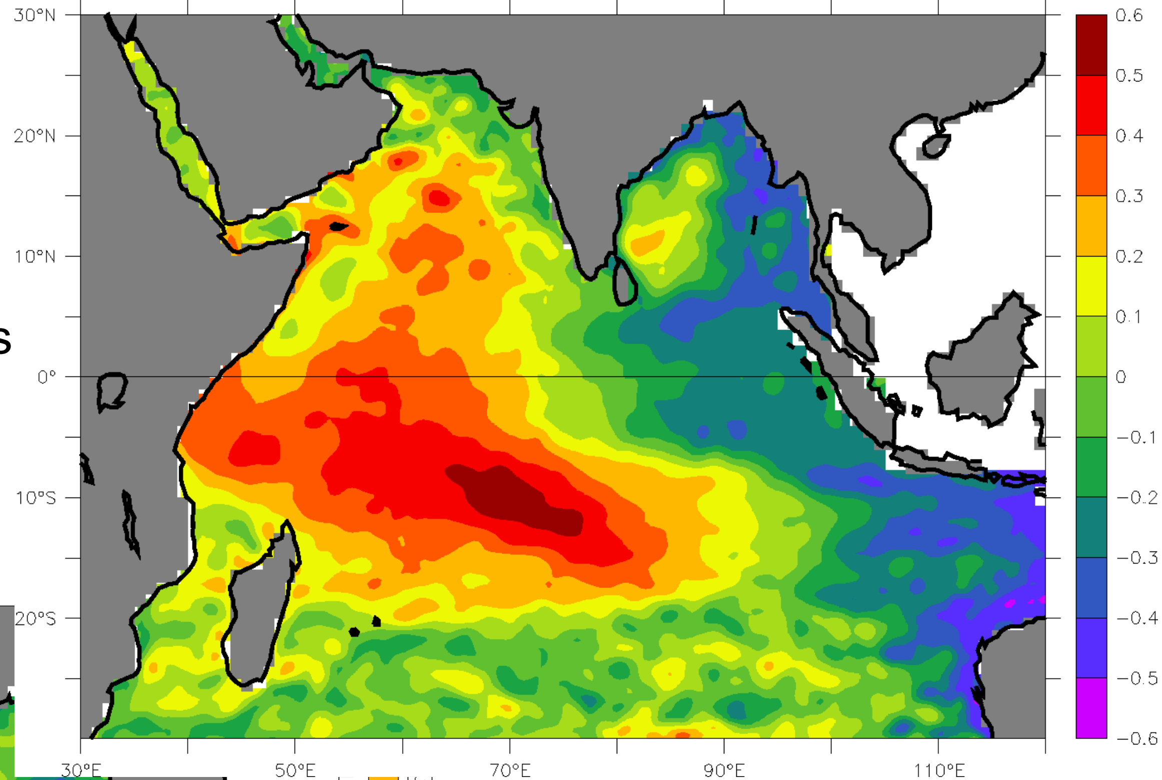


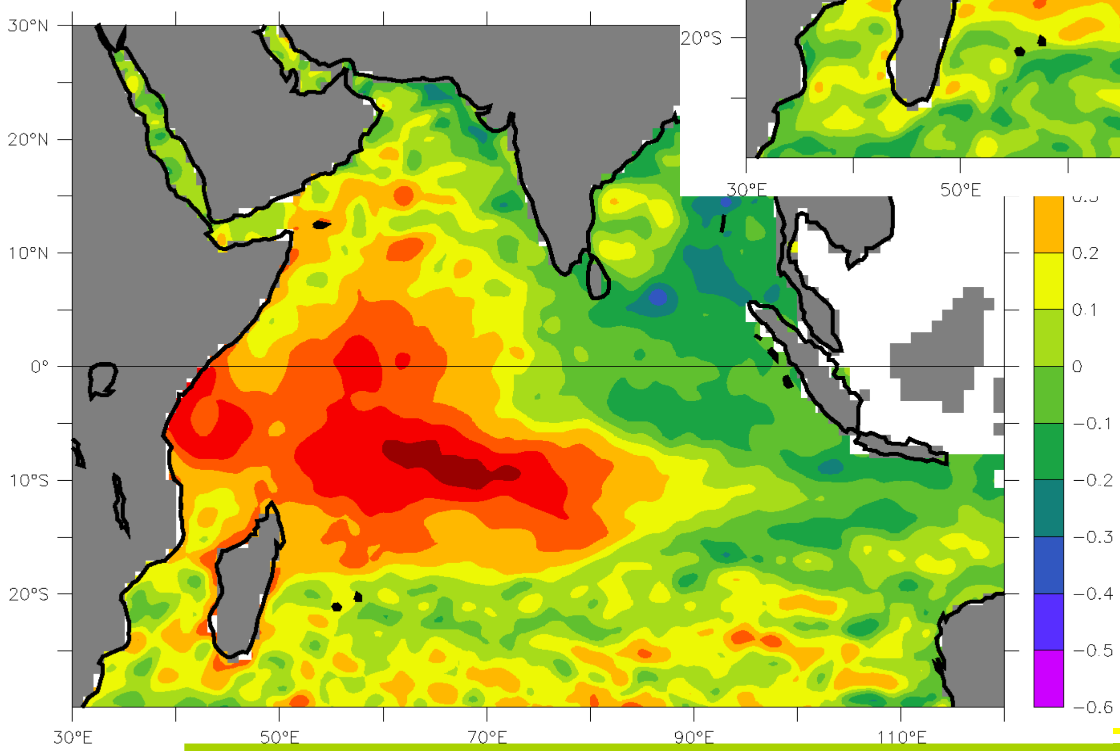
Role of latent heat fluxes on SST trend



Net heat Fluxes (dominated by latent heat flux) try to cool the Ocean, particularly in the central tropical IO

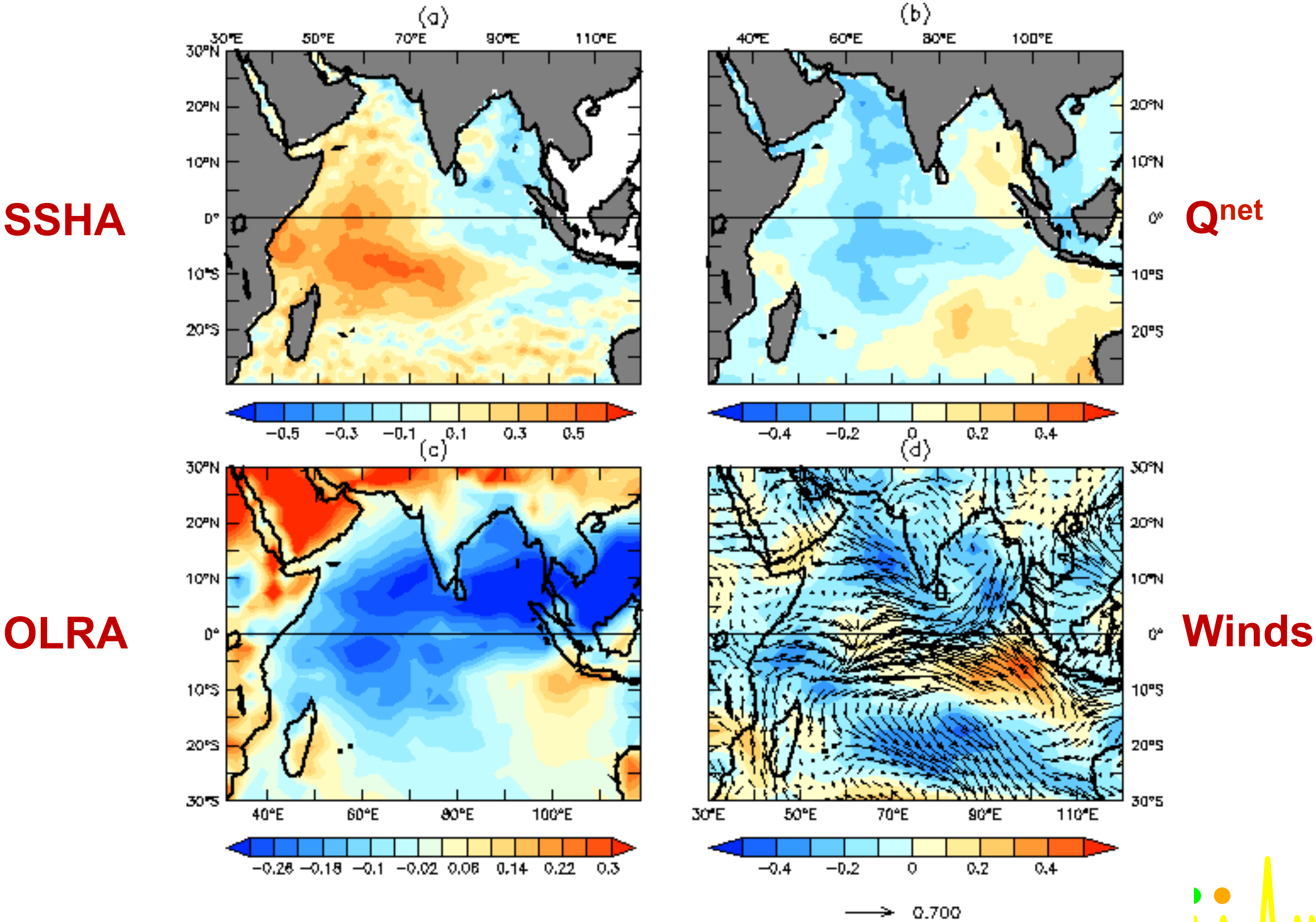
Reynolds area anomalies
Vs. Merged SSH anomalies

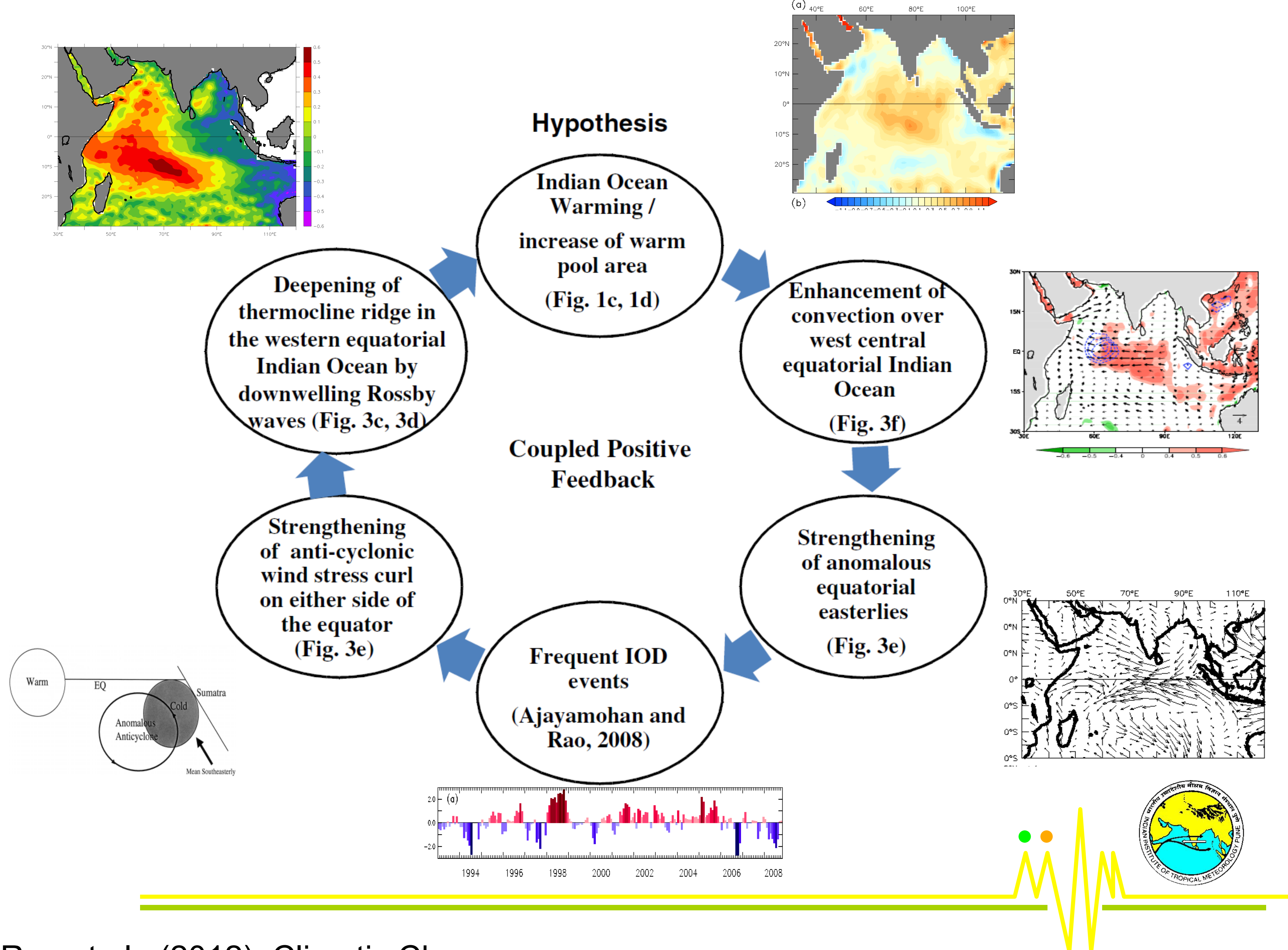




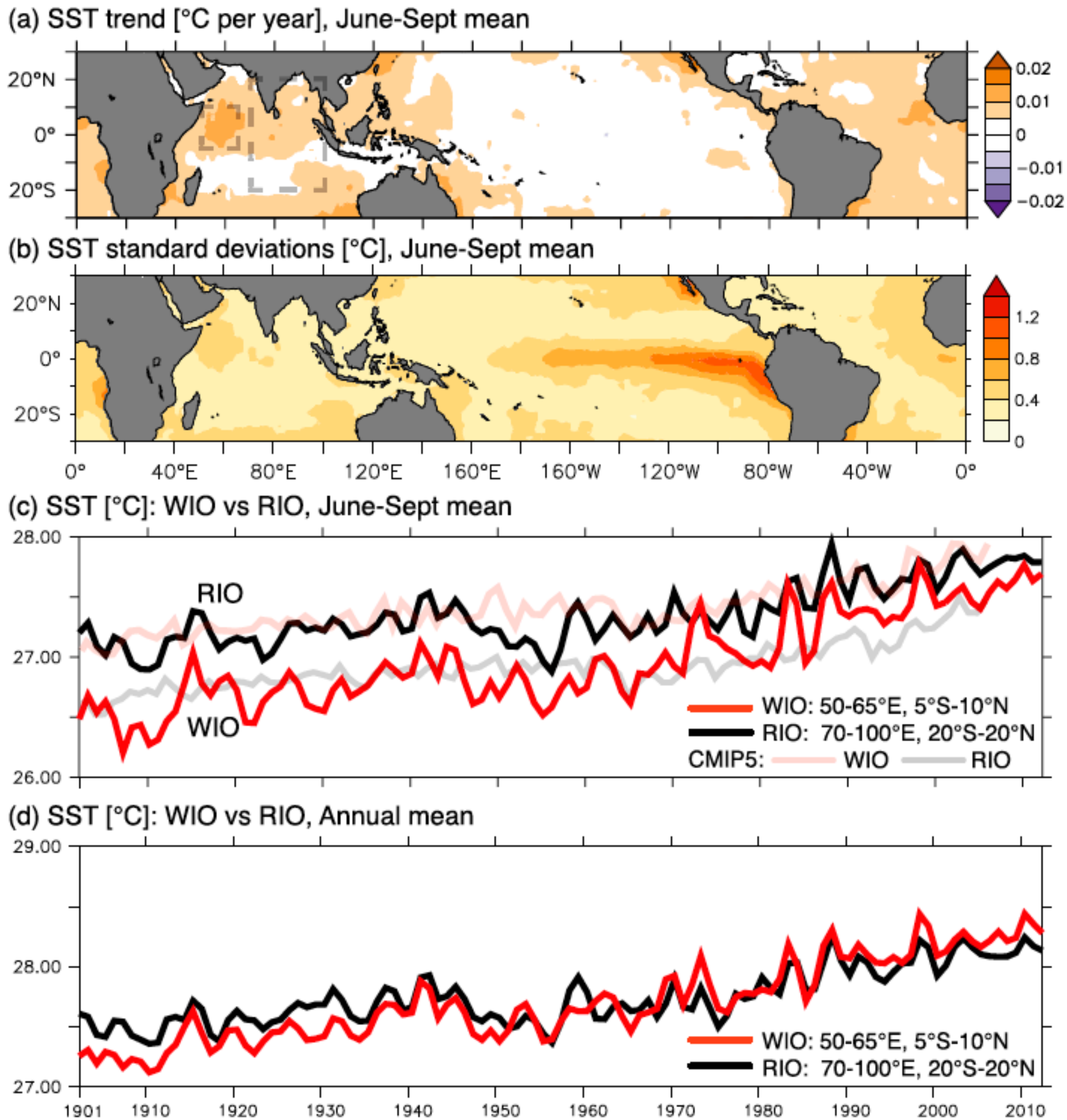
TMI area anomalies
Vs. Merged SSH anomalies

Relation between area anomalies and other parameters





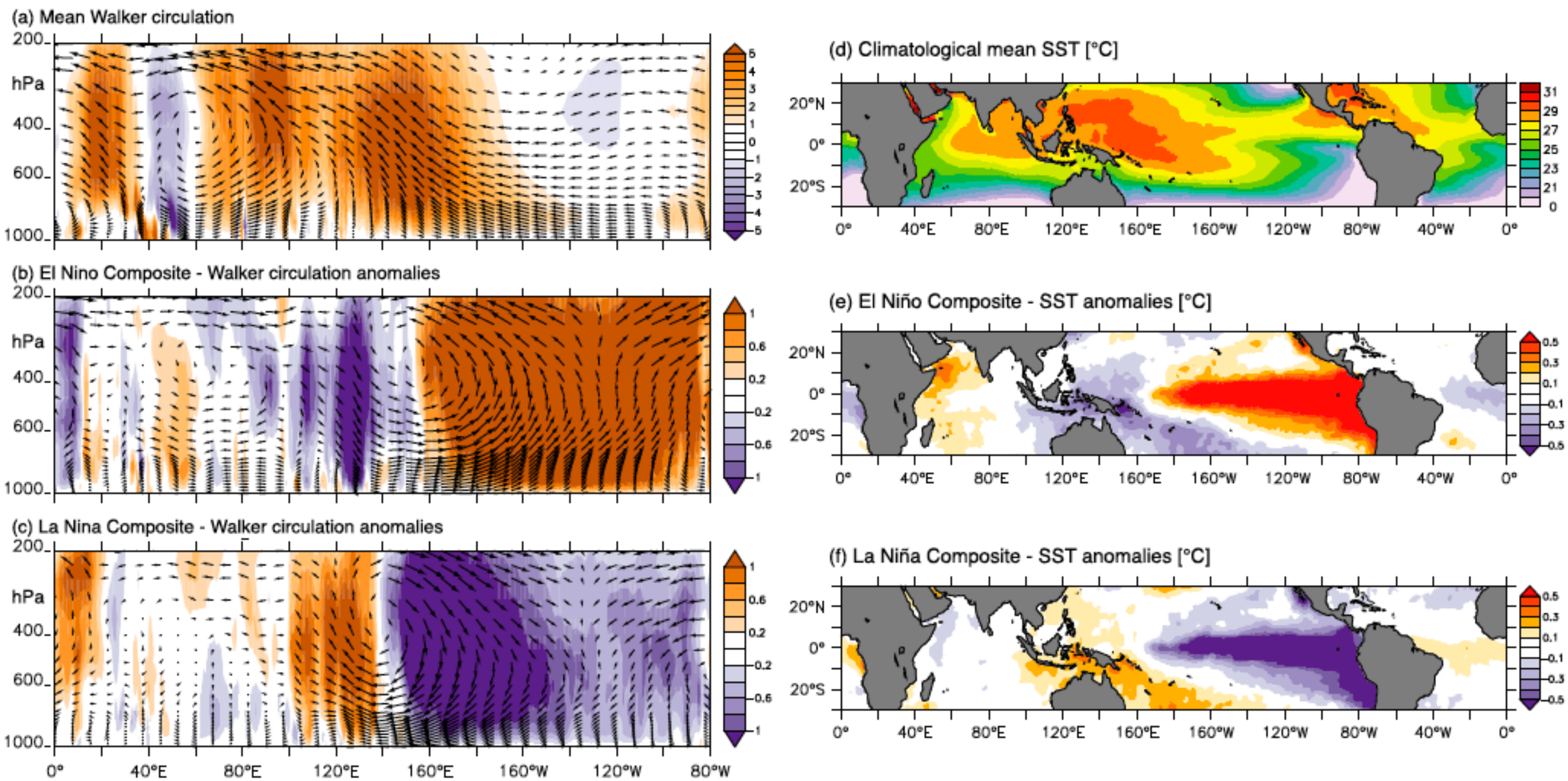
Rao et al., (2012). Climatic Change



Roxy et al., (2014)

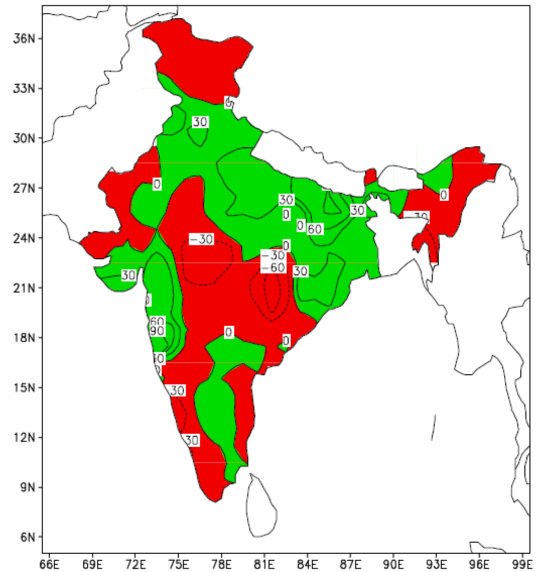
CMIP5 Models get much less warming than Observed in the Rest of the Indian Ocean.
WIO warming is Overestimated.

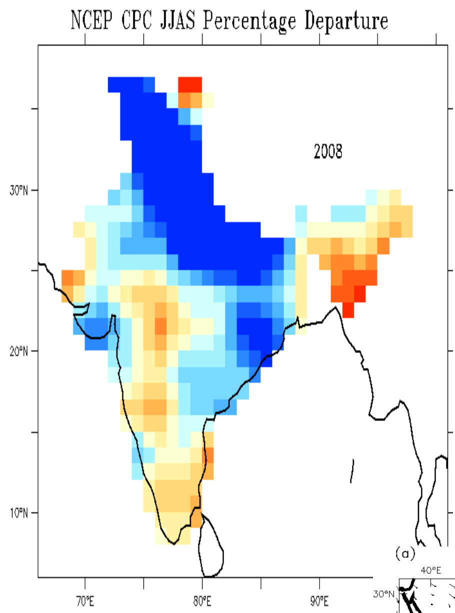
Indian Ocean Warming, Walker Circulation & El Nino: Skewness

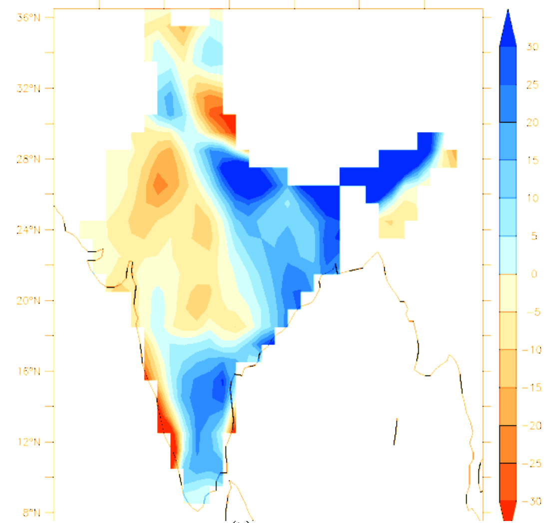


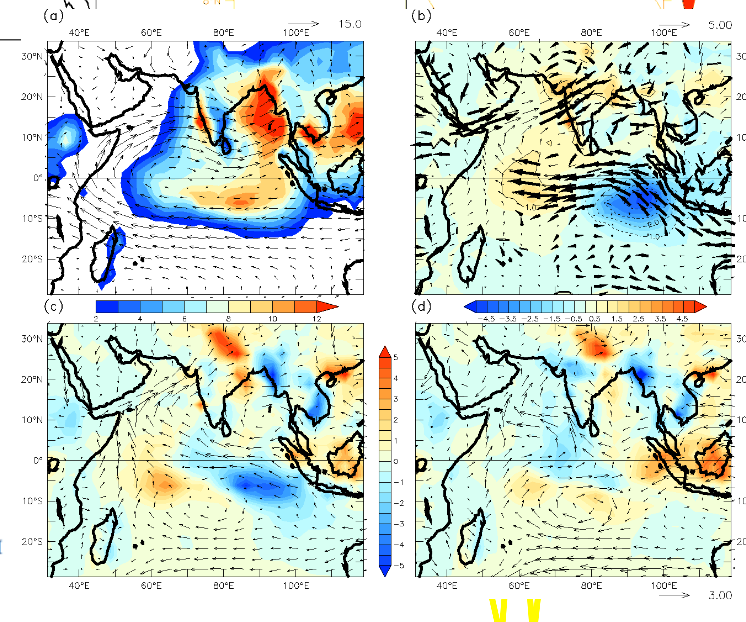
El Nino warms Western IO significantly, however Lan Nina do not cool the WIO with Same magnitude.

2008 Indian Monsoon Rainfall anomalies and deviations from normal IOD









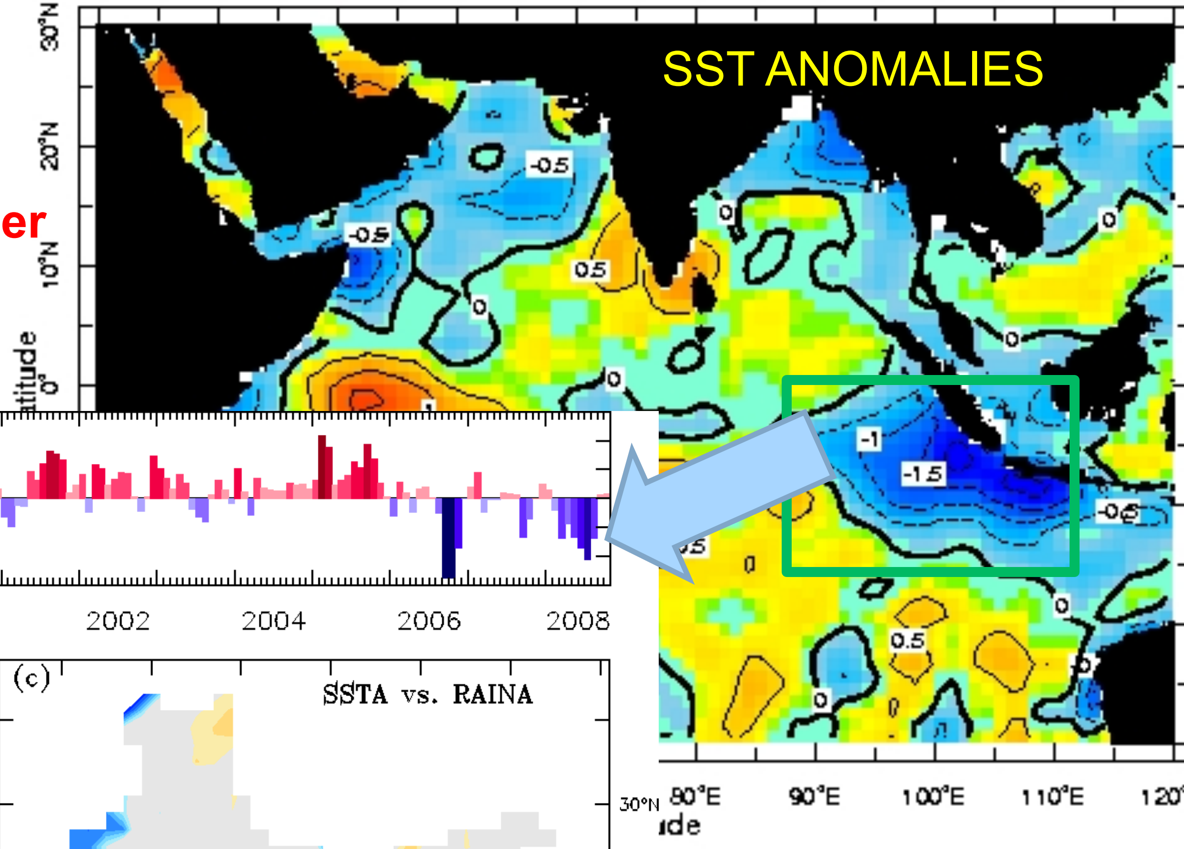
Unusual Central Indian Drought of Summer Monsoon 2008: Role of Southern Tropical Indian Ocean Warming

SURYACHANDRA A. RAO, HEMANTKUMAR S. CHAUDHARI, SAMIR POKHREL, AND B. N. GOSWAMI

Indian Institute of Tropical Meteorology, Pune, India

(Manuscript received 22 May 2009, in final form 28 April 2010)

Indian Ocean Dipole and Its influence on Indian Summer Monsoon



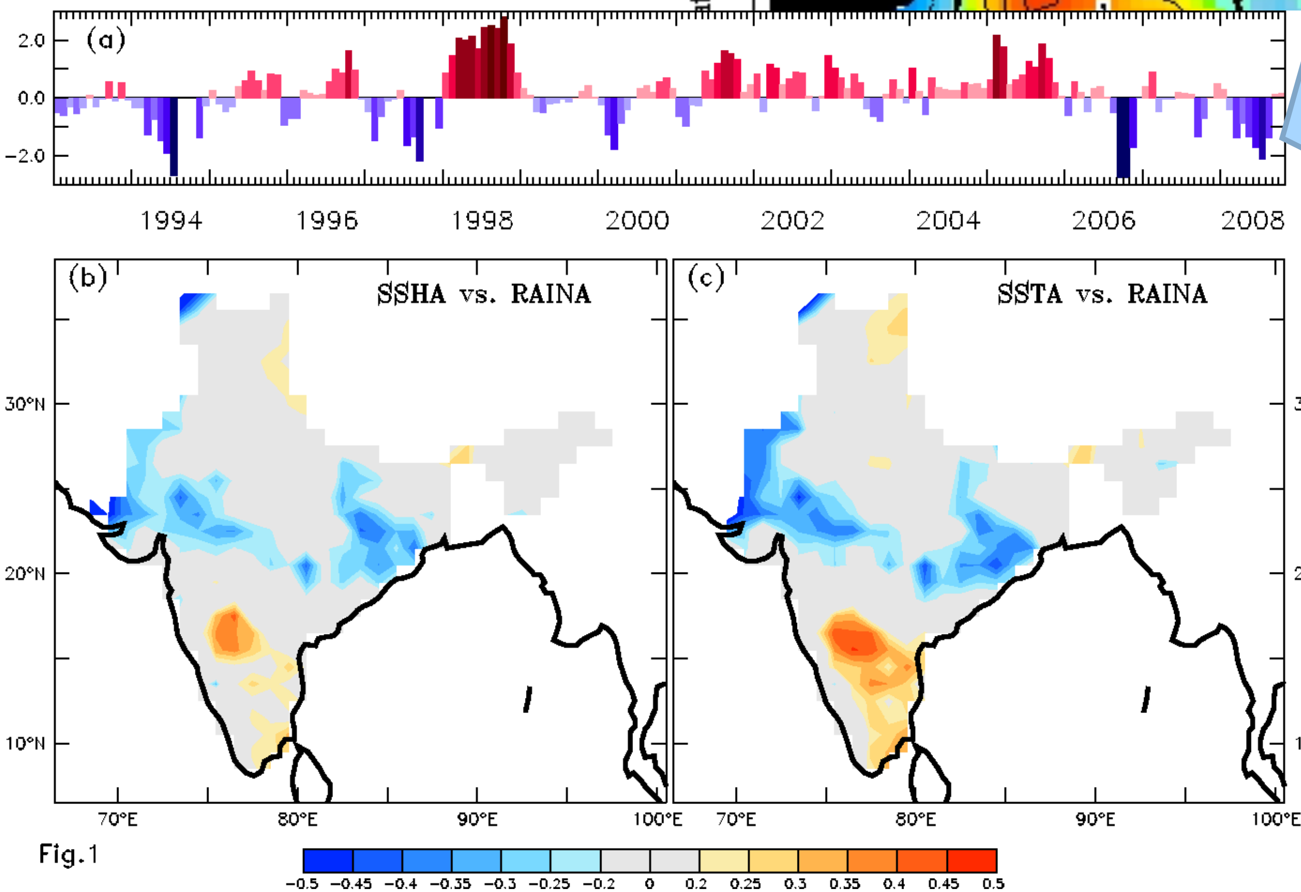
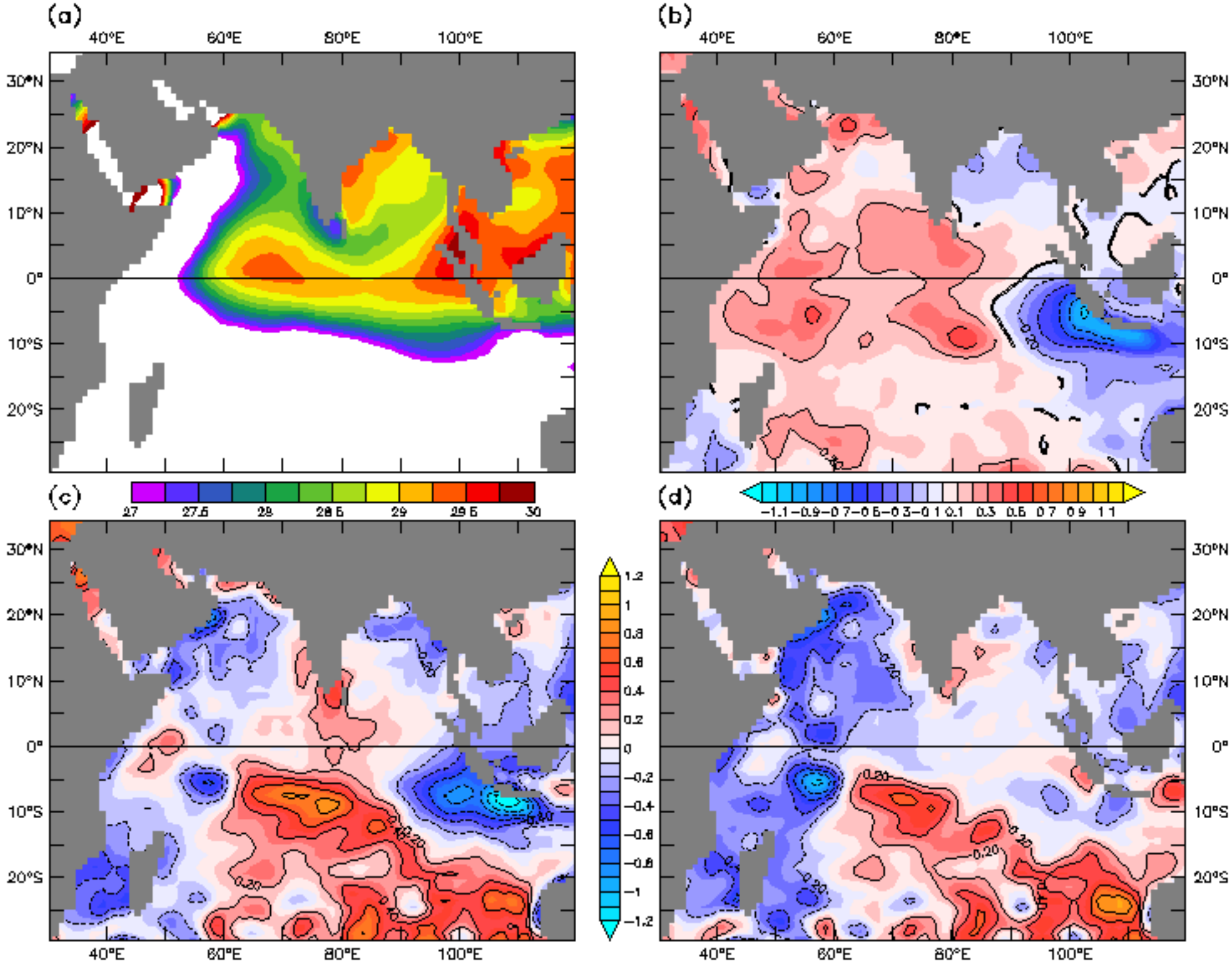
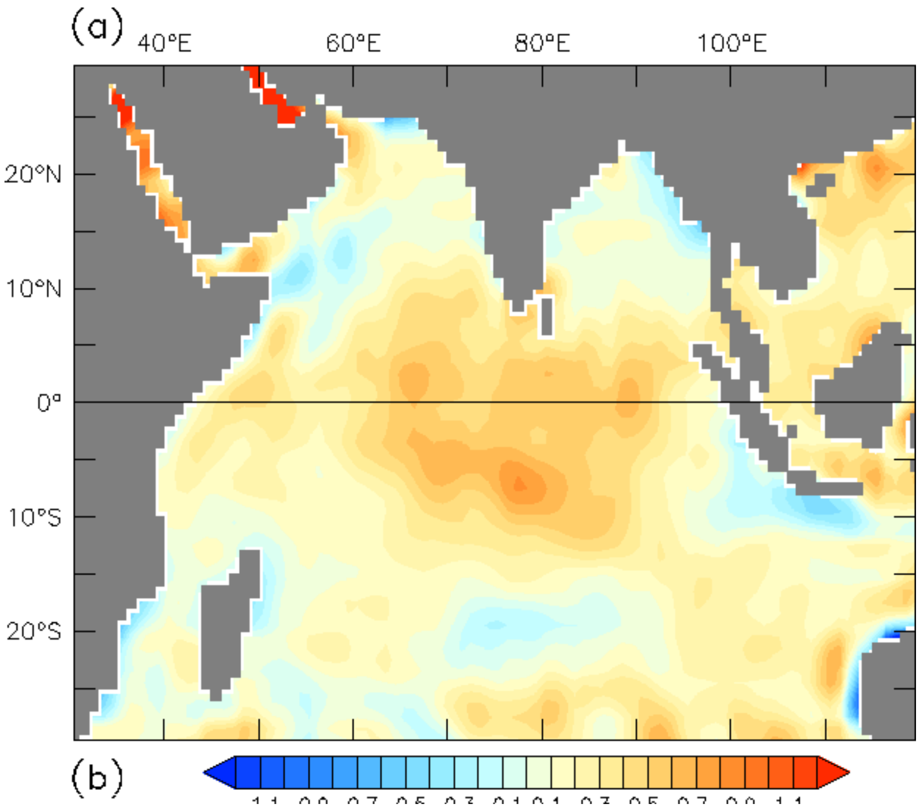


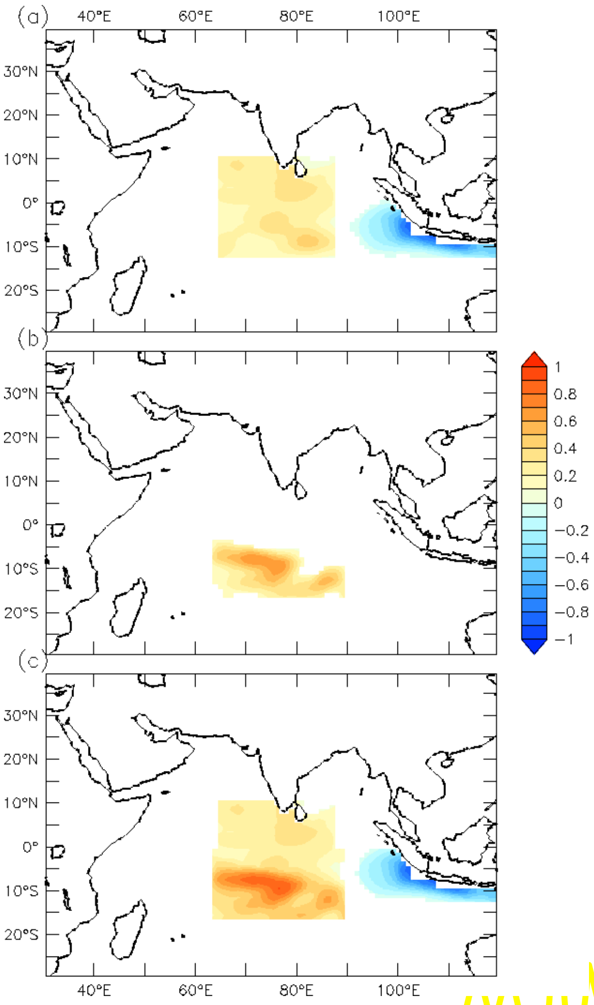
Fig.1

SST Differences in 2008

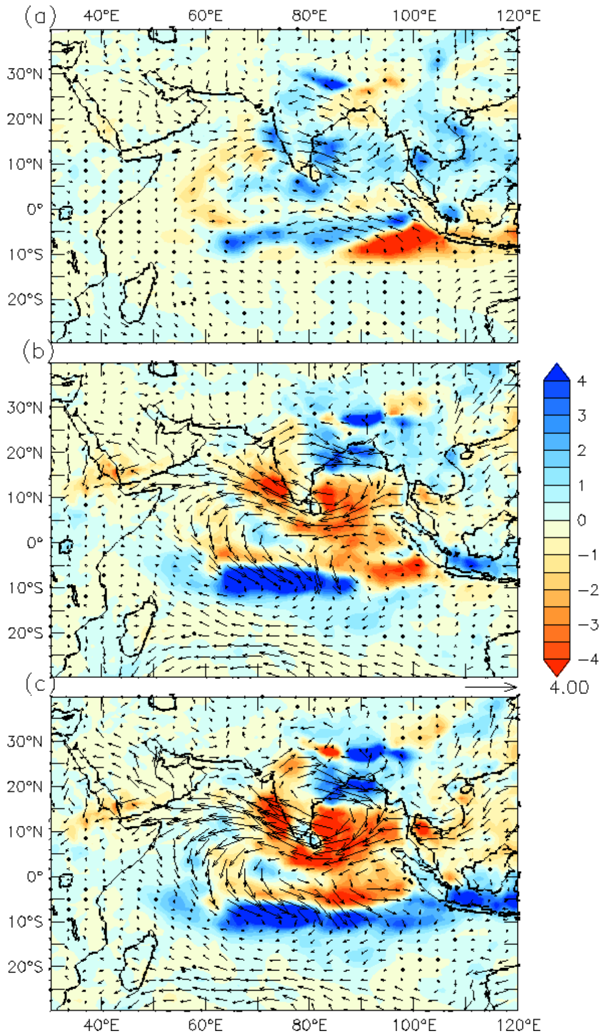


Indian Ocean warming trend and Monsoon Rainfall





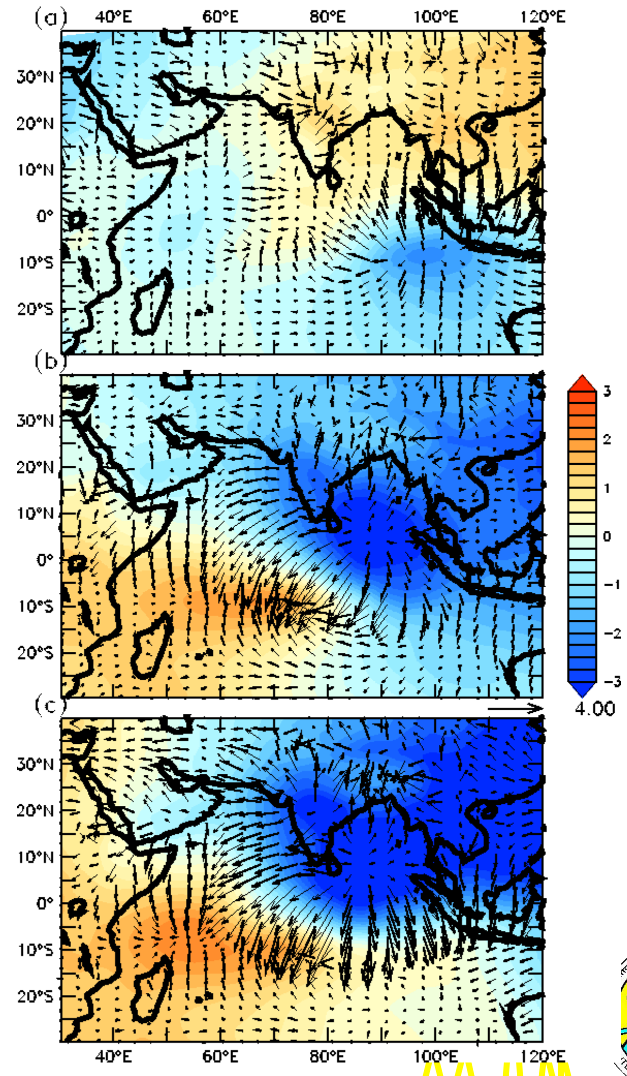
Model response to different SSTA forcings



IOD run

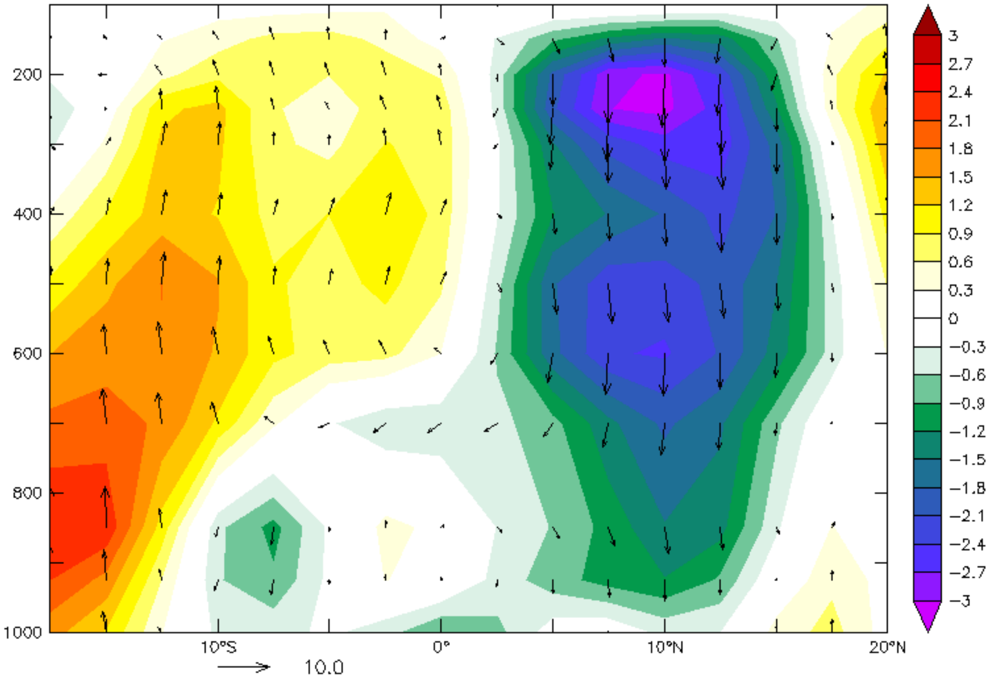
IOD +SIO Warming run

SIO response

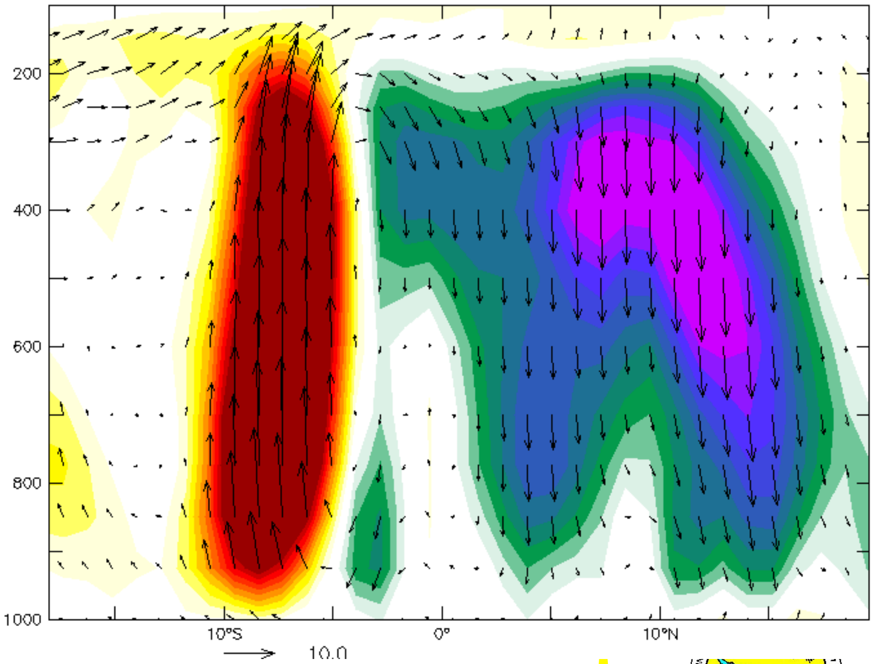


Modulation of Local Hadley Circulation (Vertical Velocities averaged between 70°E-90°E)

Observations

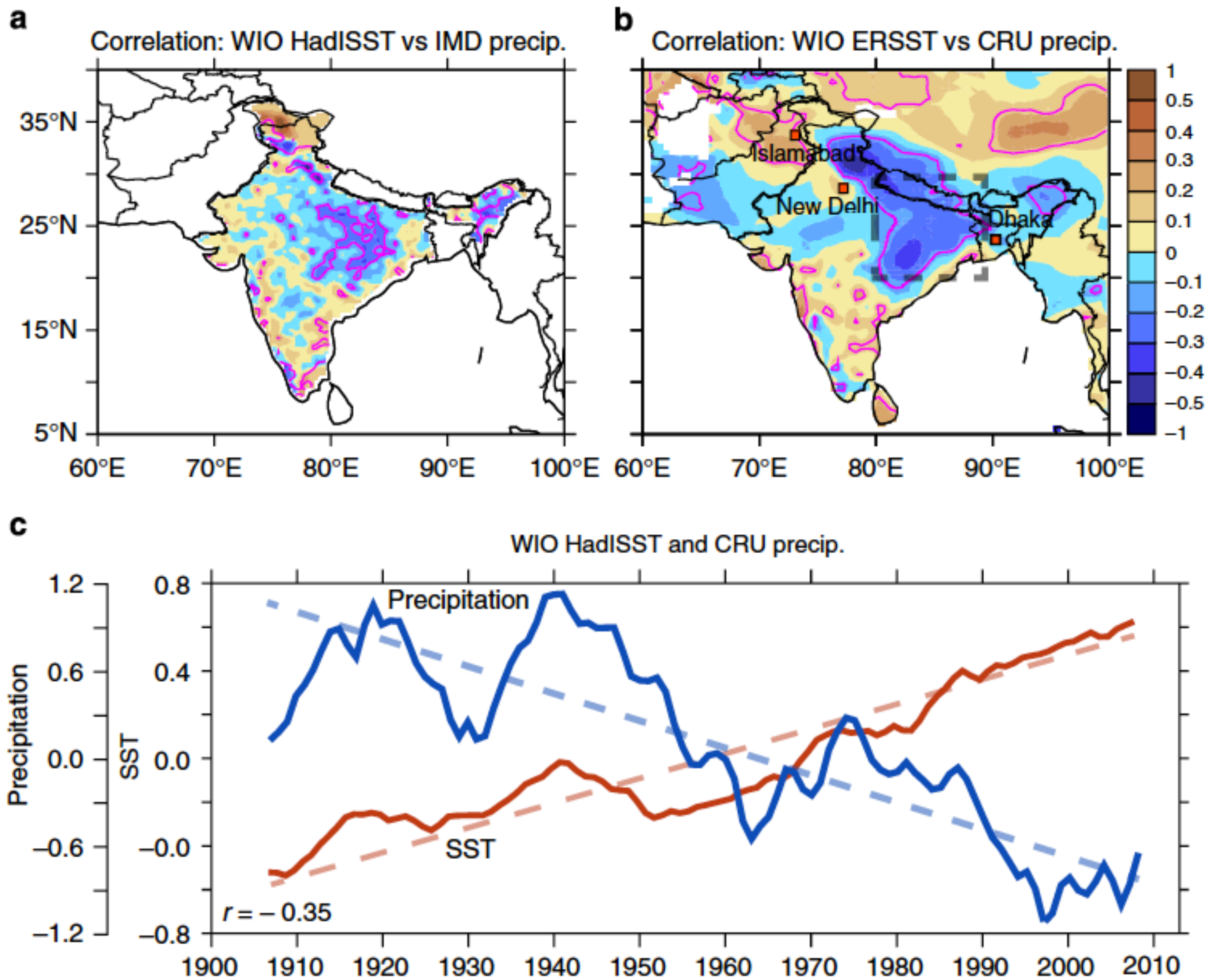


Model



Rao et al., (2010). Journal of Climate

Indian Ocean Warming weakens Monsoon

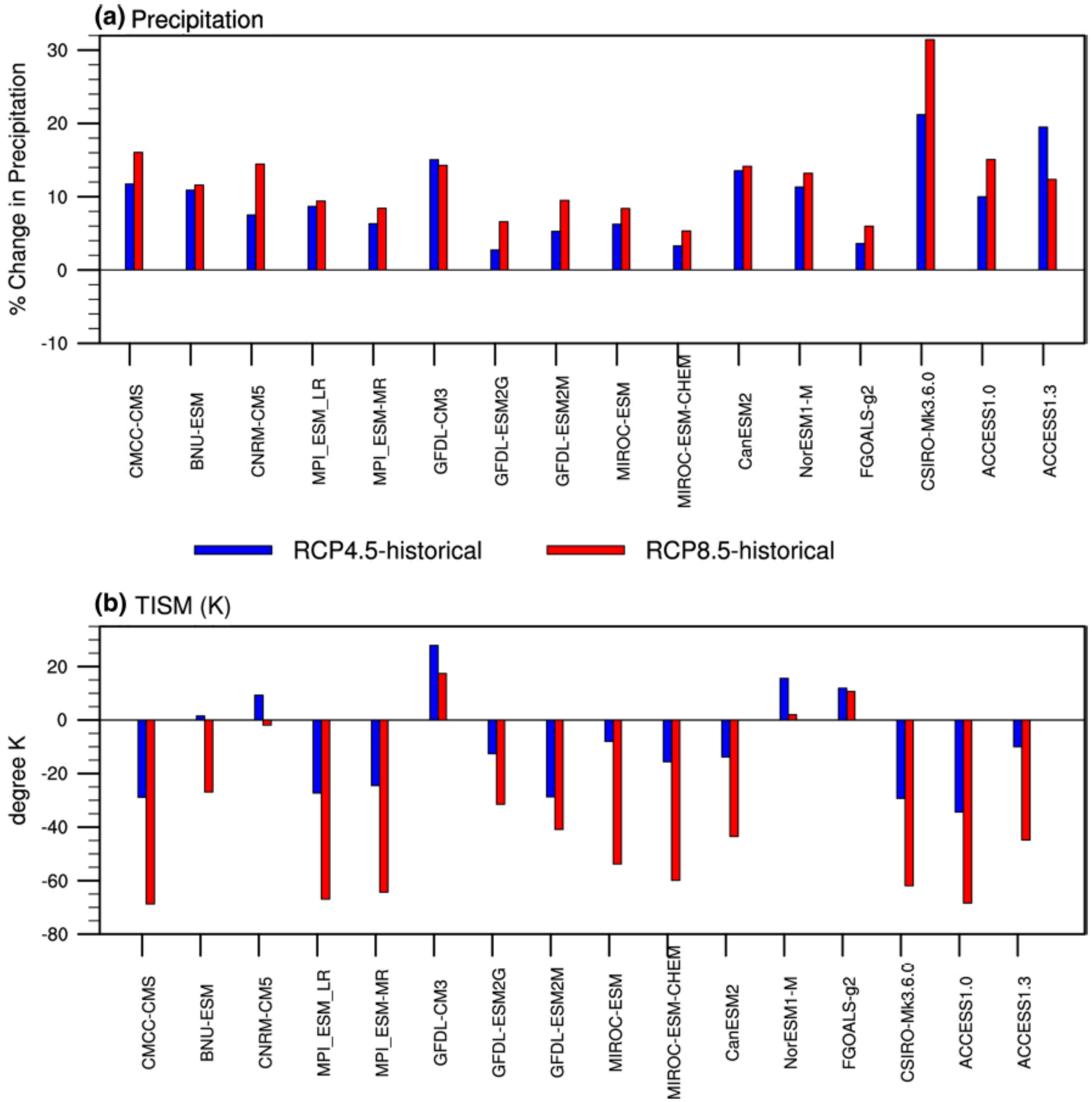


Roxy et al., (2014)

CMIP5 Models Projections

Why ensemble mean projection of south Asian monsoon rainfall by CMIP5 models is not reliable?

C. T. Sabeerali · Suryachandra A. Rao · A. R. Dhakate · K. Salunke · B. N. Goswami



RESEARCH ARTICLE
10.1002/2013JD021261

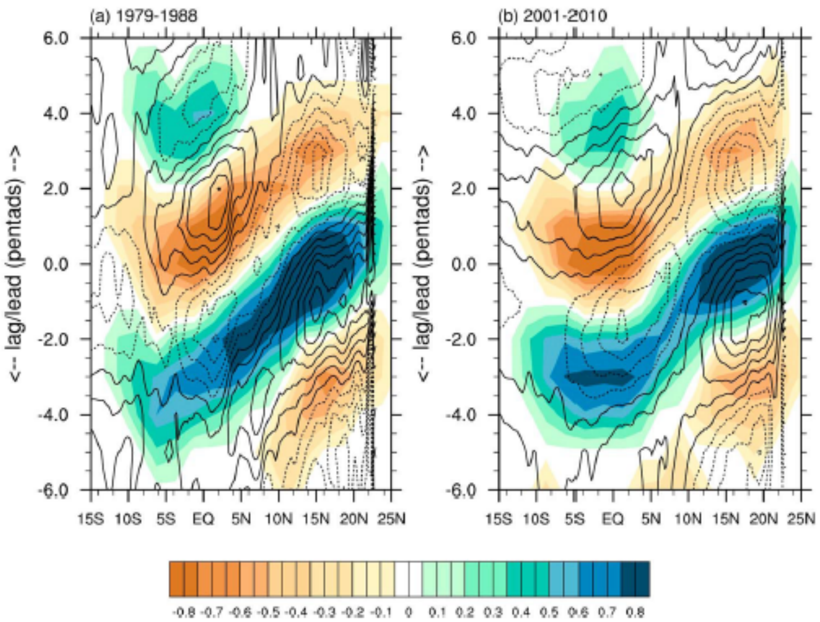
Key Points:
- MISO variance has increased over ISMR region in the warming period
- Northward propagation has slowed down in the warming period
- Mean SST increase over the Indian Ocean are responsible for these change

Modulation of monsoon intraseasonal oscillations in the recent warming period

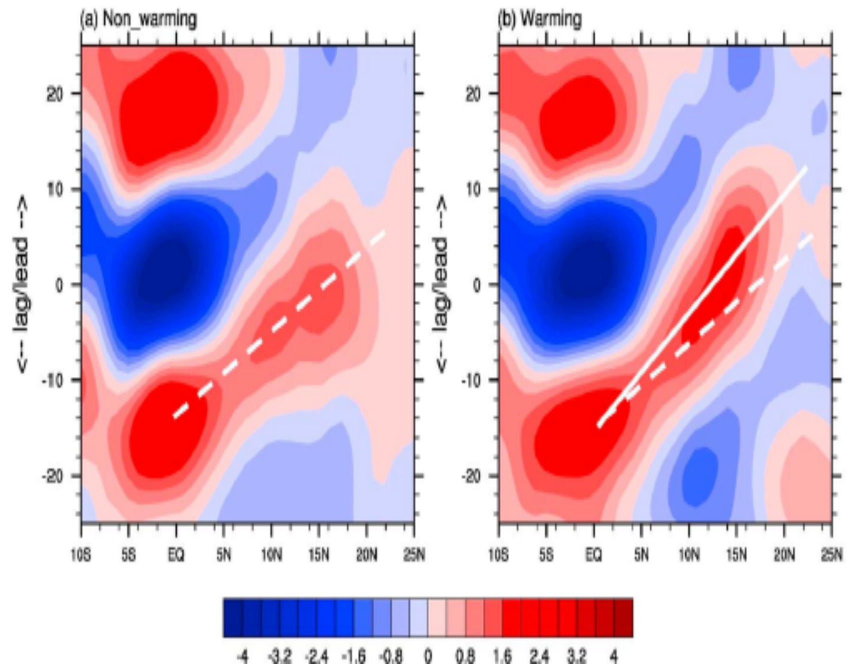
C. T. Sabeerali[1], Suryachandra A Rao[1], Gibies George[1], D. Nagarjuna Rao[1], S. Mahapatra[1], A. Kulkarni[1], and Raghu Murtugudde[2]

[1]Indian Institute of Tropical Meteorology, Pune, India, [2]Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland, USA

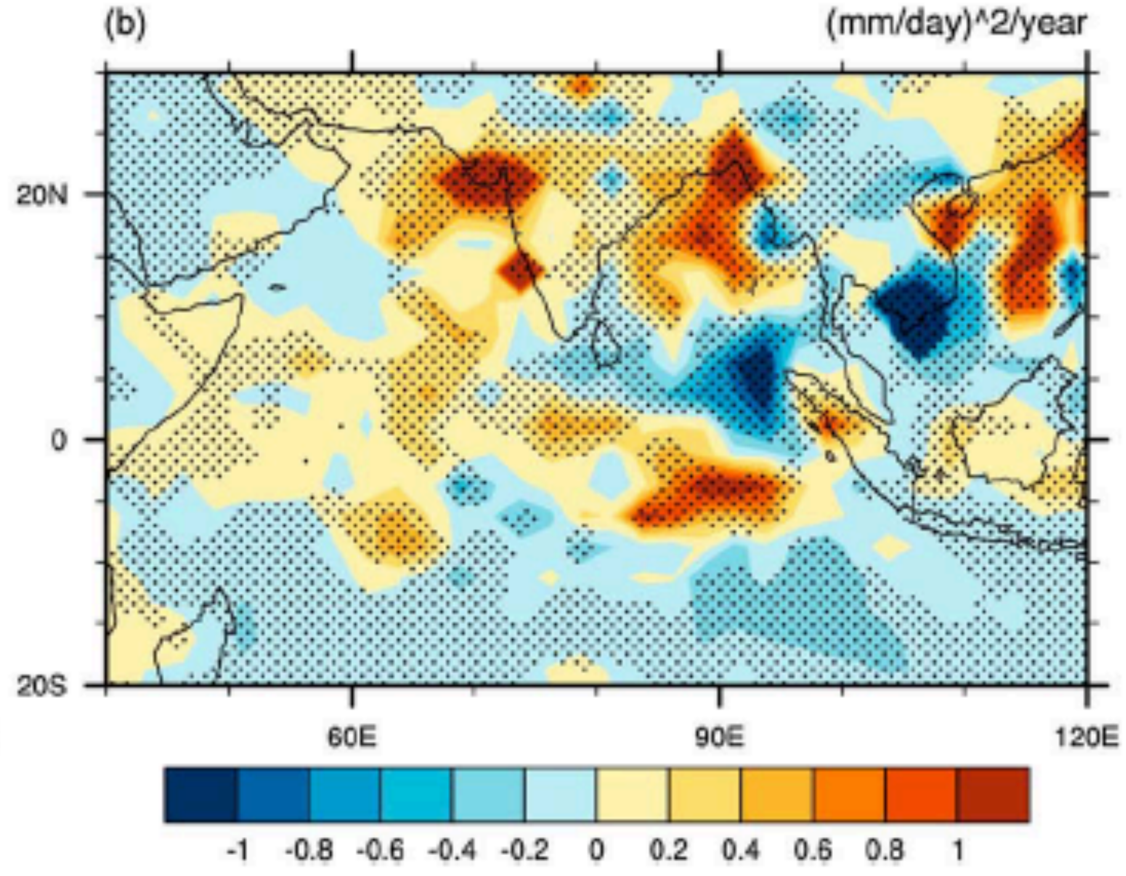
Observations



Model Expt.

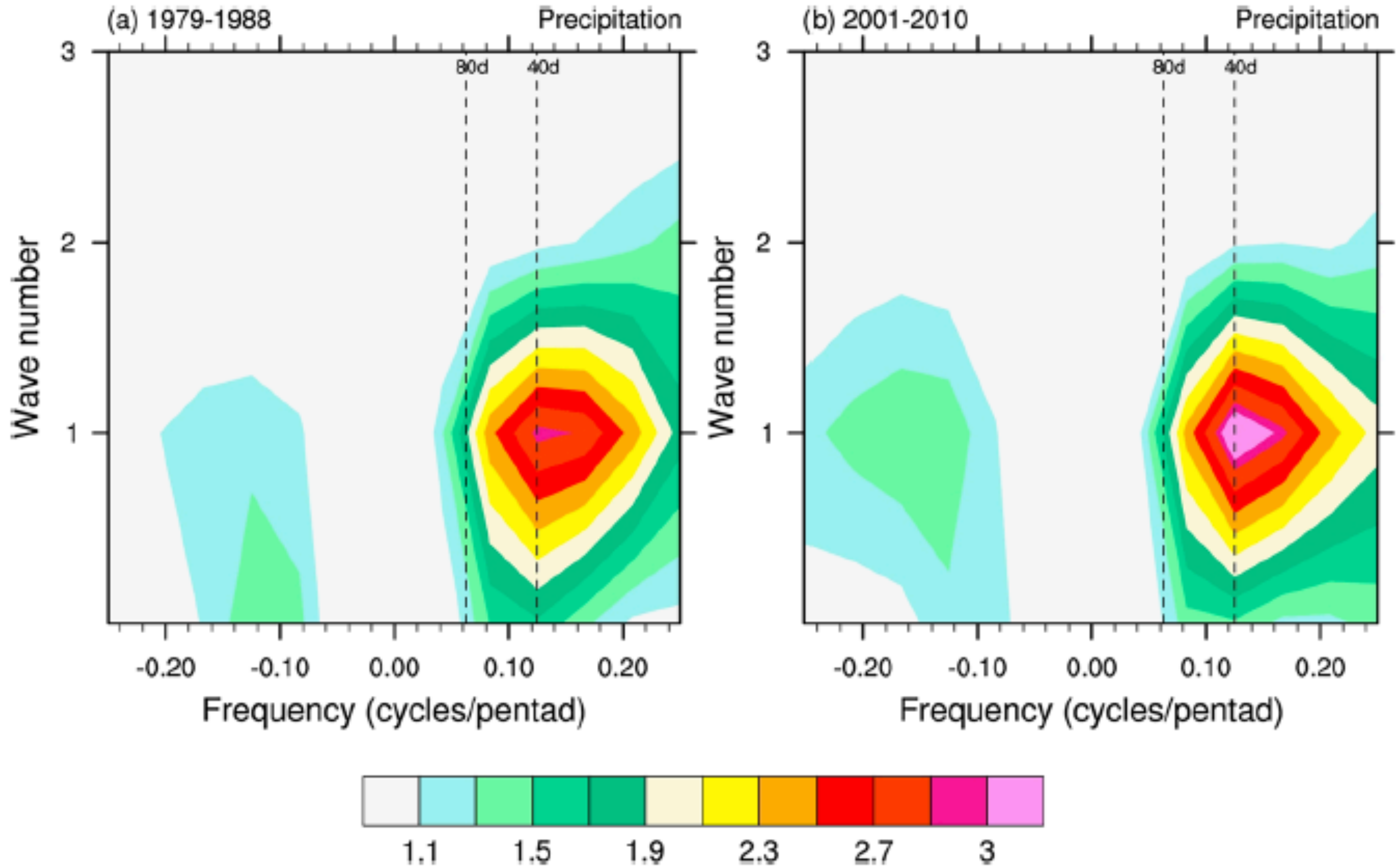


ISO Variance Trend (1970-2012)



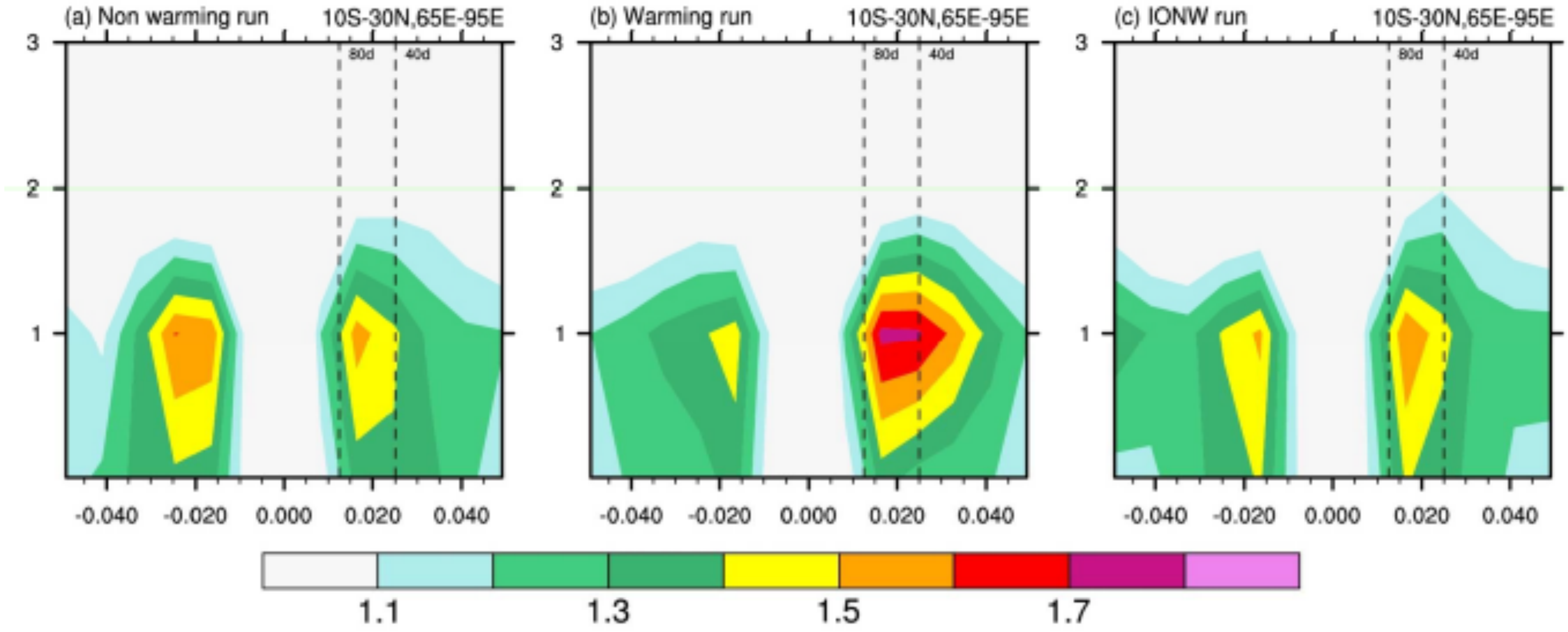
ISO variance is increasing over Indian land mass and eastern Indian Ocean

Space-Time Spectra of Rainfall (10°S- 30°N, 65°E-95°E)



ISO variance is increasing & Propagation speed is slightly decreasing

Space-Time Spectra of Rainfall (10ºS- 30ºN, 65ºE-95ºE) in Model Expts.



ISO variance is increasing & Propagation speed is slightly decreasing

Mechanism to modulate ISO variance

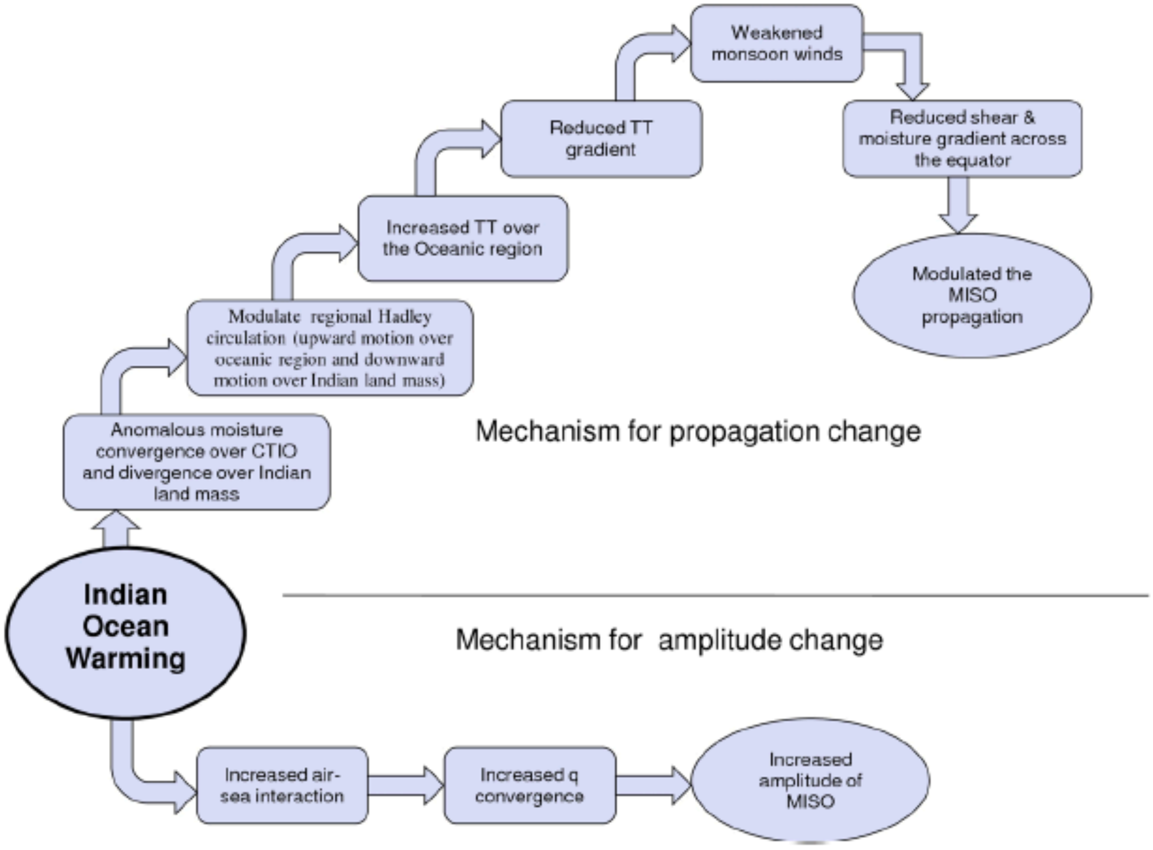
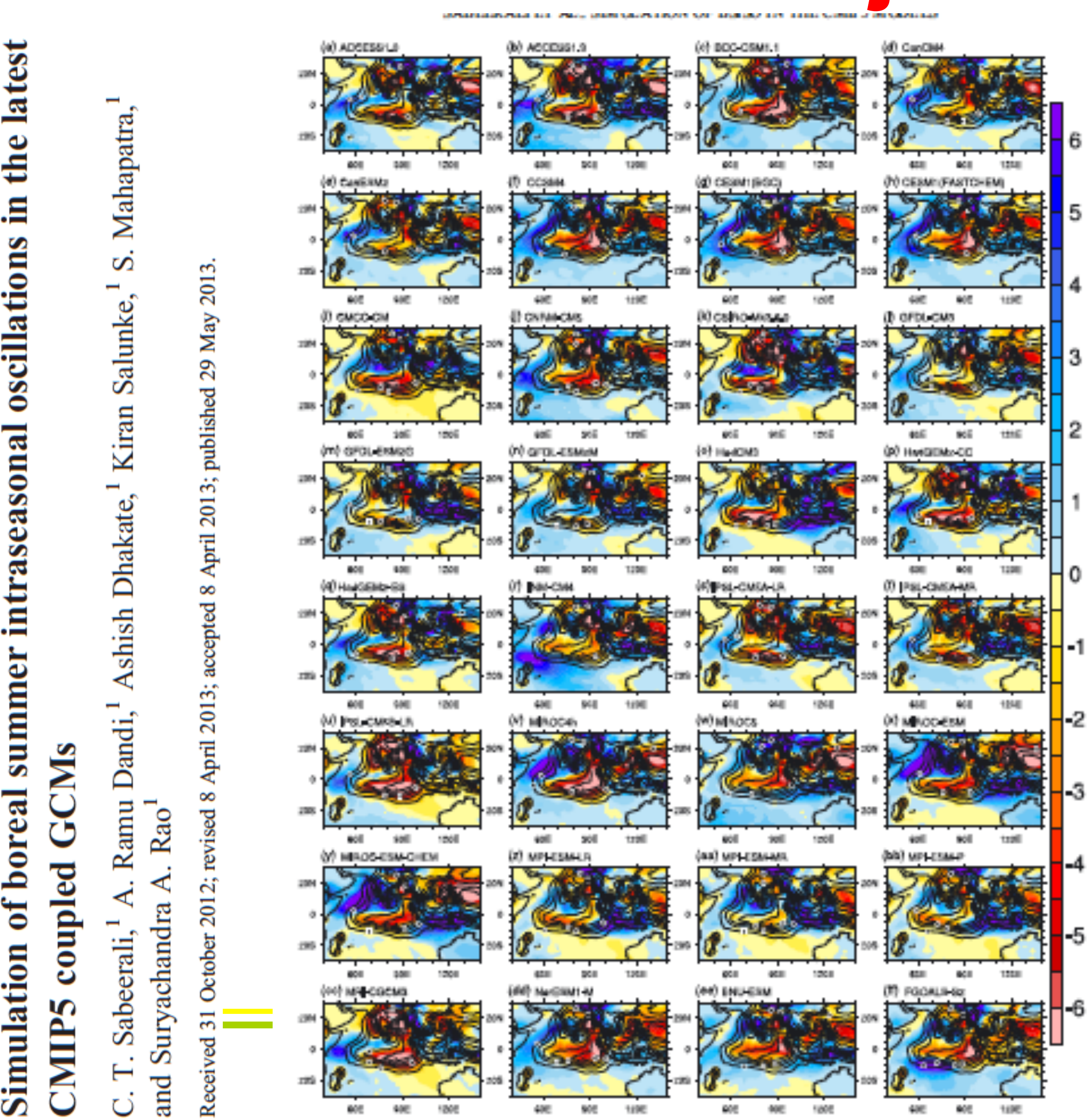


Figure 14. Schematic representation of the mechanism proposed for the changes in the characteristics of the MISO.

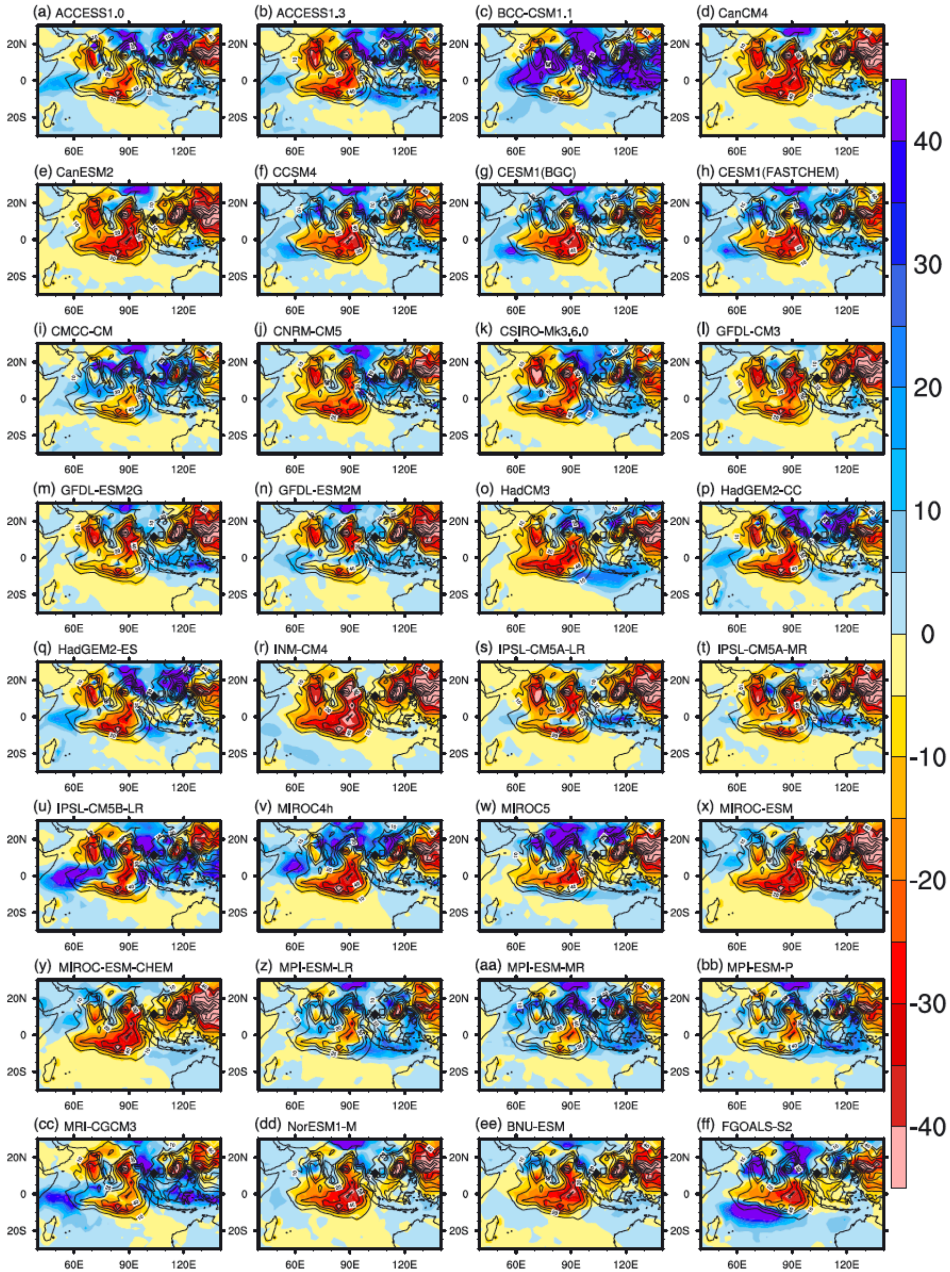
CMIP5 Model Projections of ISO



JJAS Mean Rainfall Bias in CMIP5 models.

Dry Bias over India and Eastern Indian Ocean is a common feature

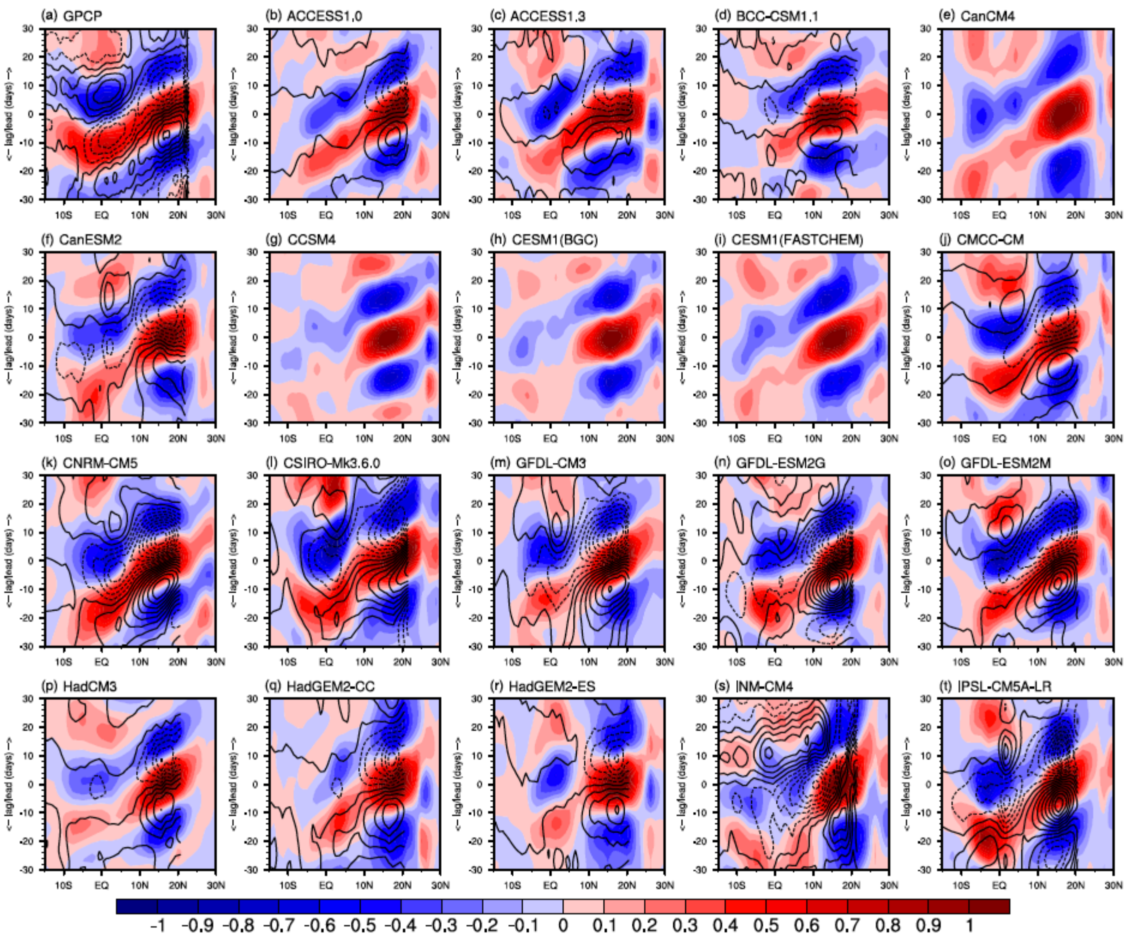
CMIP5 Model Projections of ISO Variance



JJAS ISO Variance bias in CMIP5 models.

Dry Bias over India and Eastern Indian Ocean is a common feature

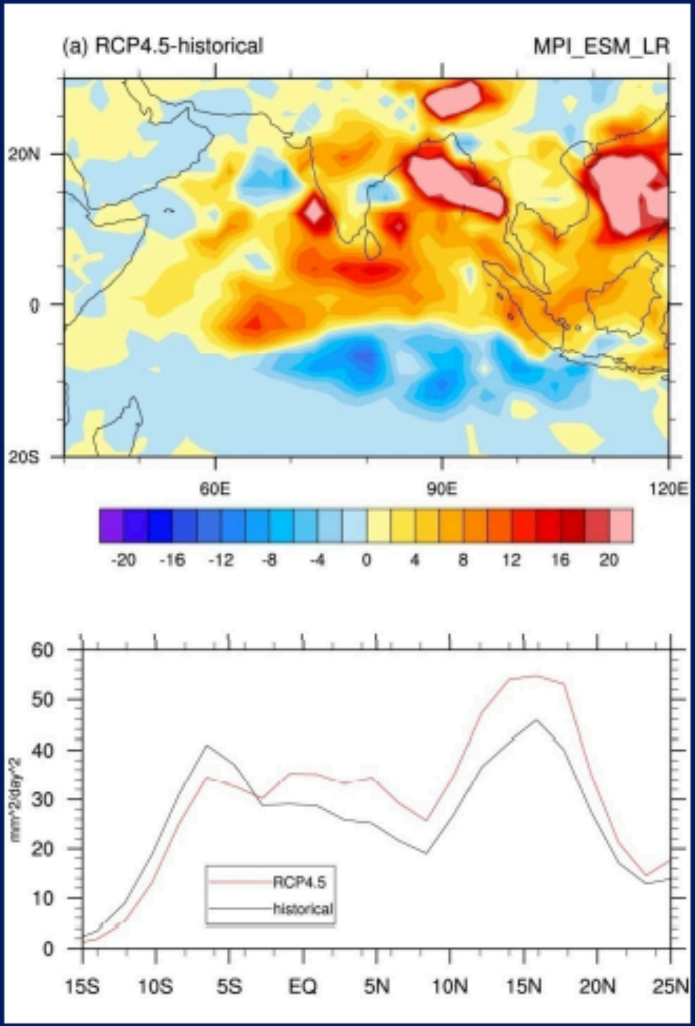
CMIP5 Model Projections of MISO Propagation



JJAS MISO Variance bias in CMIP5 models.

Dry Bias over India and Eastern Indian Ocean is a common feature

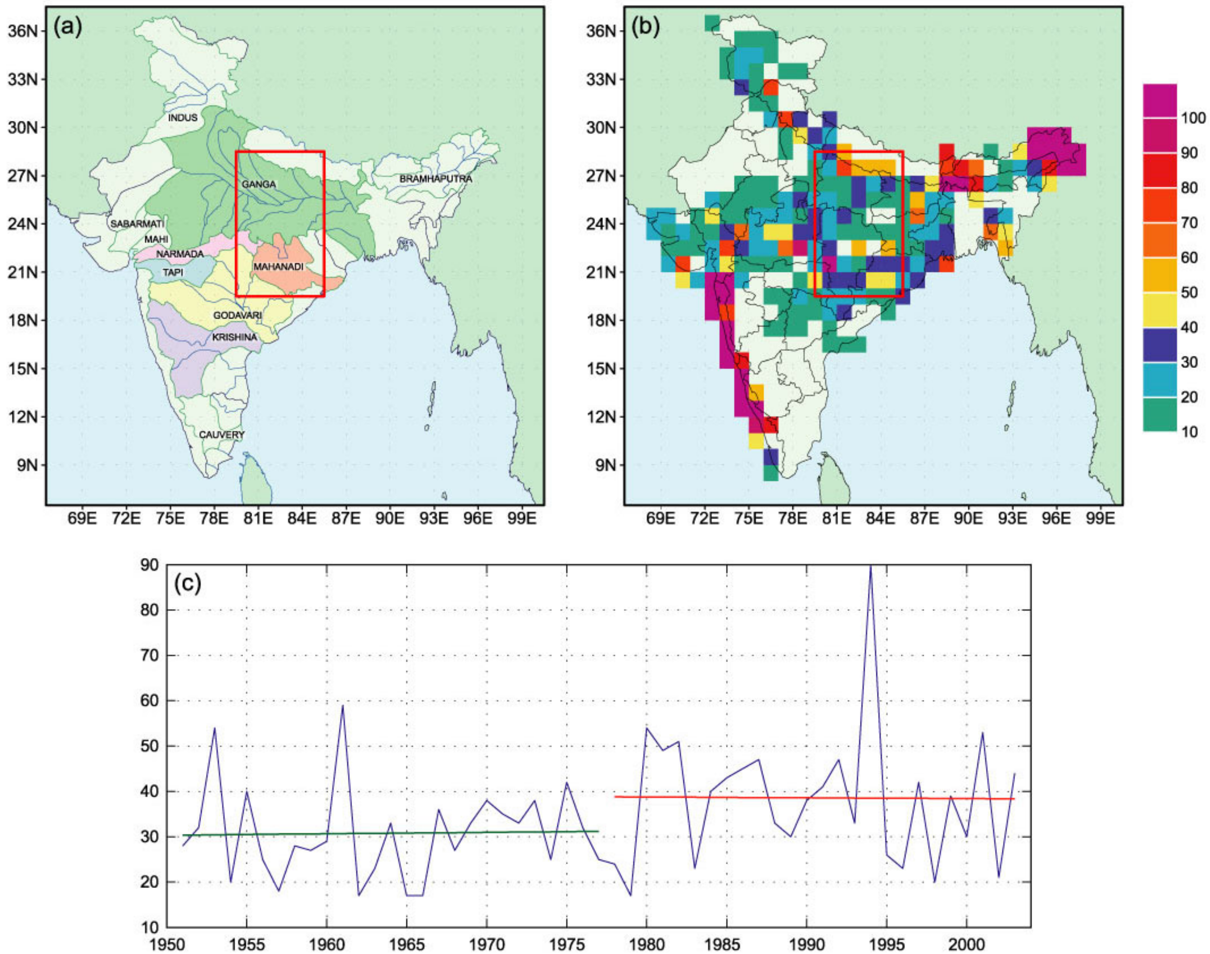
The MISO variance change under the global warming scenario



The MISO variance difference between the RCP4.5 run (2081-2100) and historical run (1986-2005)

Consistent with the observational result, the MISO variance is increased in the Indian summer monsoon region under the global warming scenario

Number of Heavy Rainfall Events



Journal of the Meteorological Society of Japan. Ser. II
Vol. 86 (2008) No. 1 P 245-252
http://doi.org/10.2151/jmsj.86.245
Notes and Correspondence

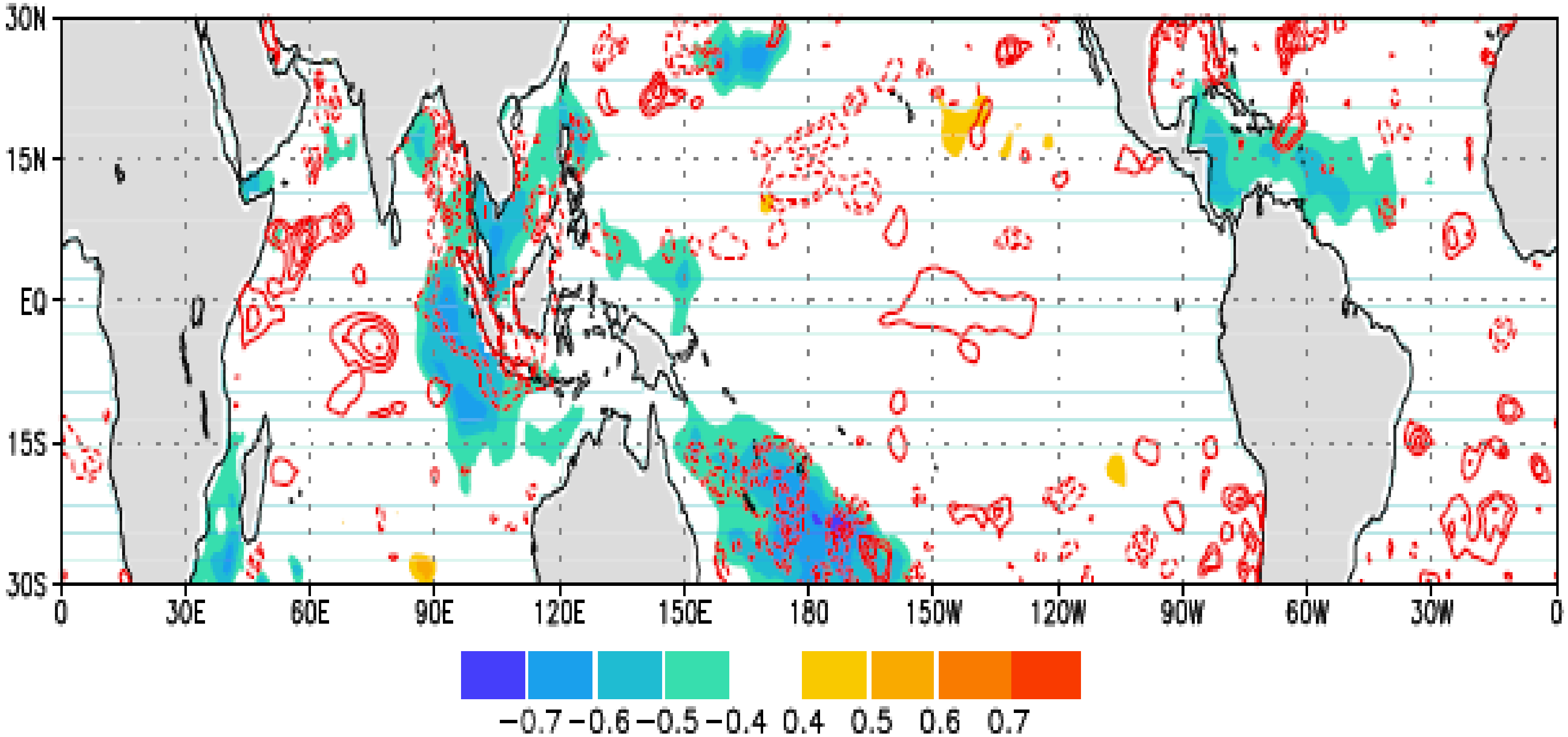
Journal
Language: English
Previous Article

Indian Ocean Dipole Modulates the Number of Extreme Rainfall Events over India in a Warming Environment

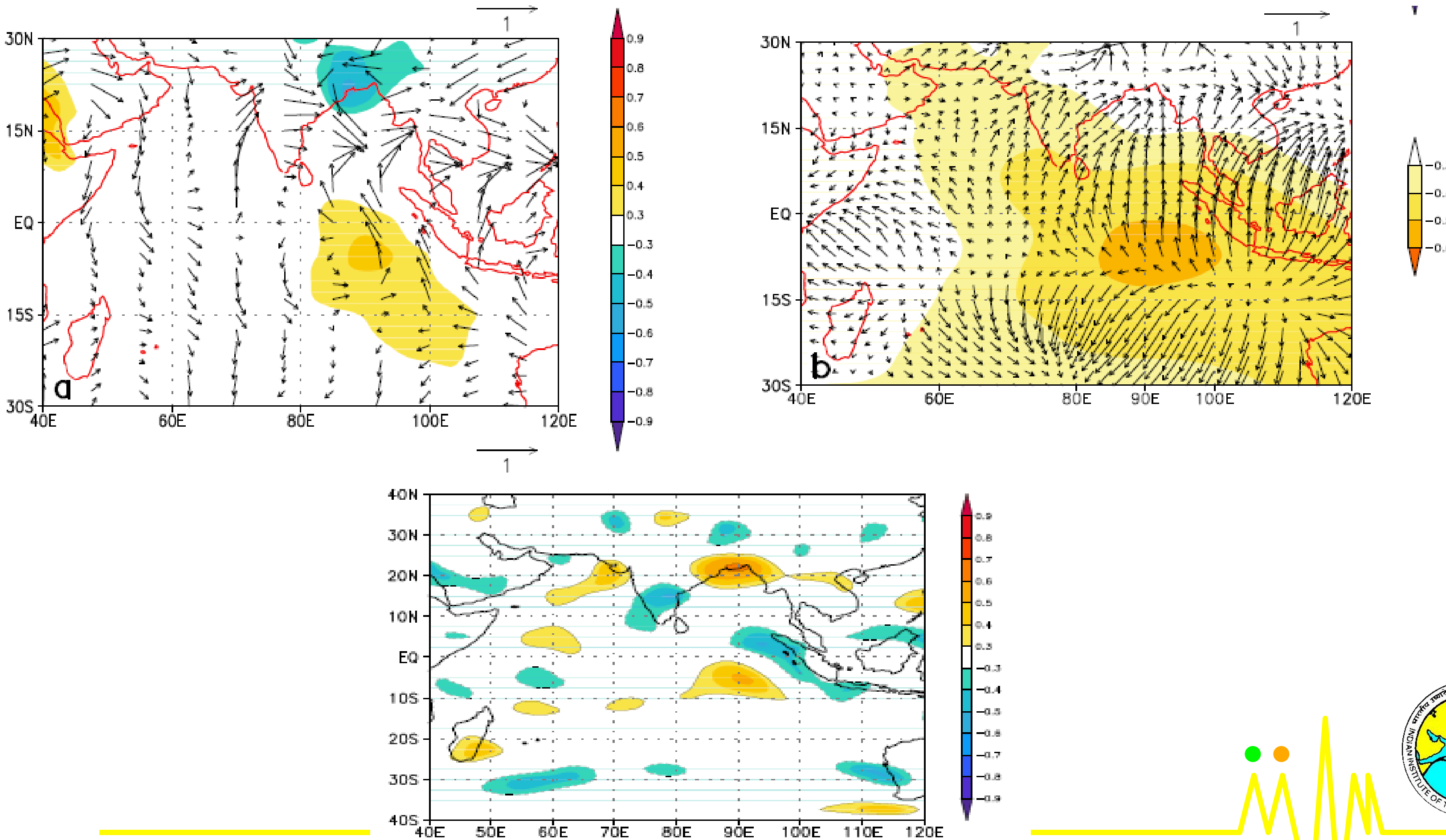
R.S AJAYAMOHAN[1], Suryachandra A. RAO[1]
1) FRCGC, Japan Agency for Marine-Earth Science and Technology

Released 2008/05/12

Correlation between number of heavy rainfall events and SST(SSH) anomalies



Correlation between Extreme Rainfall events with SLP, Moisture Divergence and vorticity



Ajayamohan and Rao , (2008). JMSJ

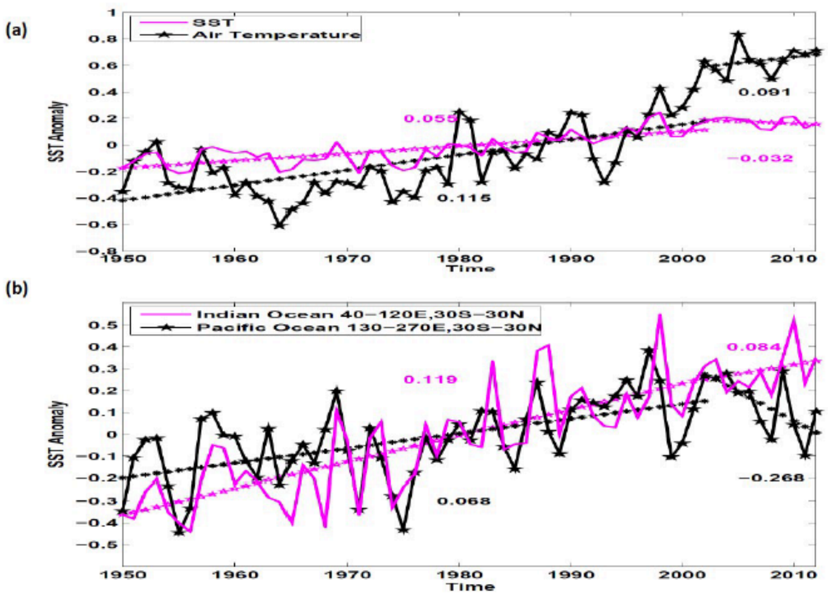
Global Warming Hiatus

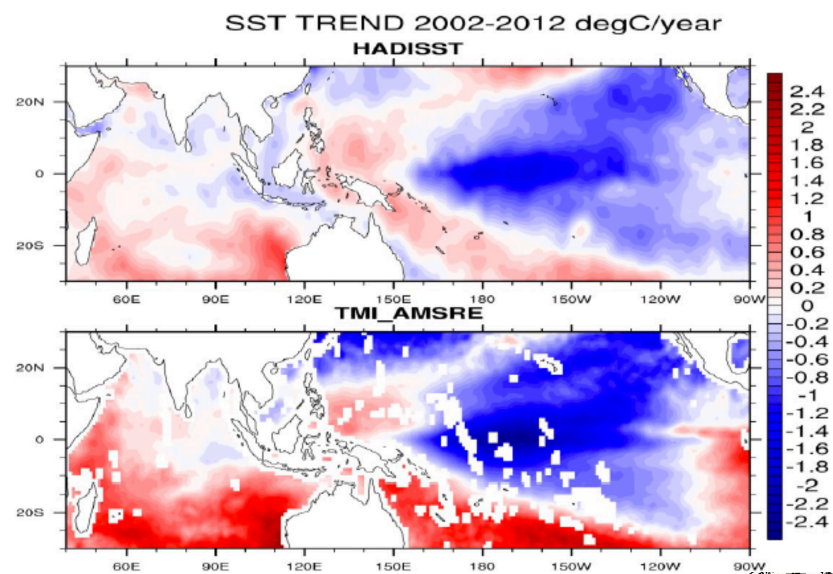
Global and Planetary Change
Volume 143, August 2016, Pages 21–30

Role of Indian Ocean SST variability on the recent global warming hiatus

Anika Arora[a], Suryachandra A. Rao[a], , R. Chattopadhyay[a], Tanmoy Goswami[a], Gibies George[a], C.T. Sabeerali[a, b]

Trend in SST/Air. Temp **SST Trend during hiatus**

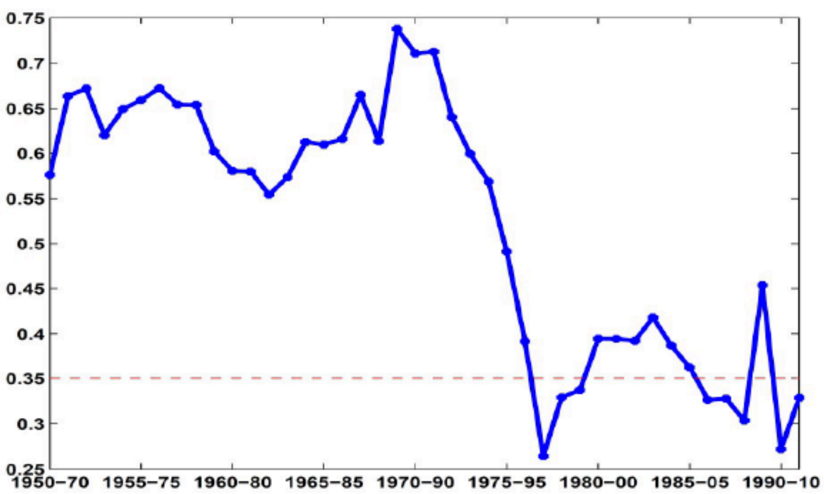




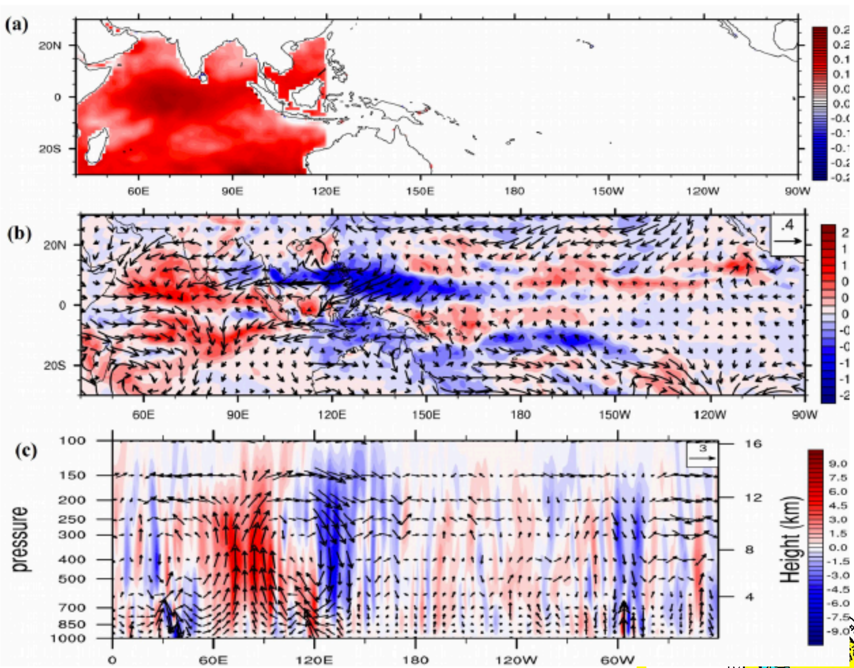
Global Warming Hiatus

Indian Ocean vs Pacific Relation weakening?

AGCM expt.

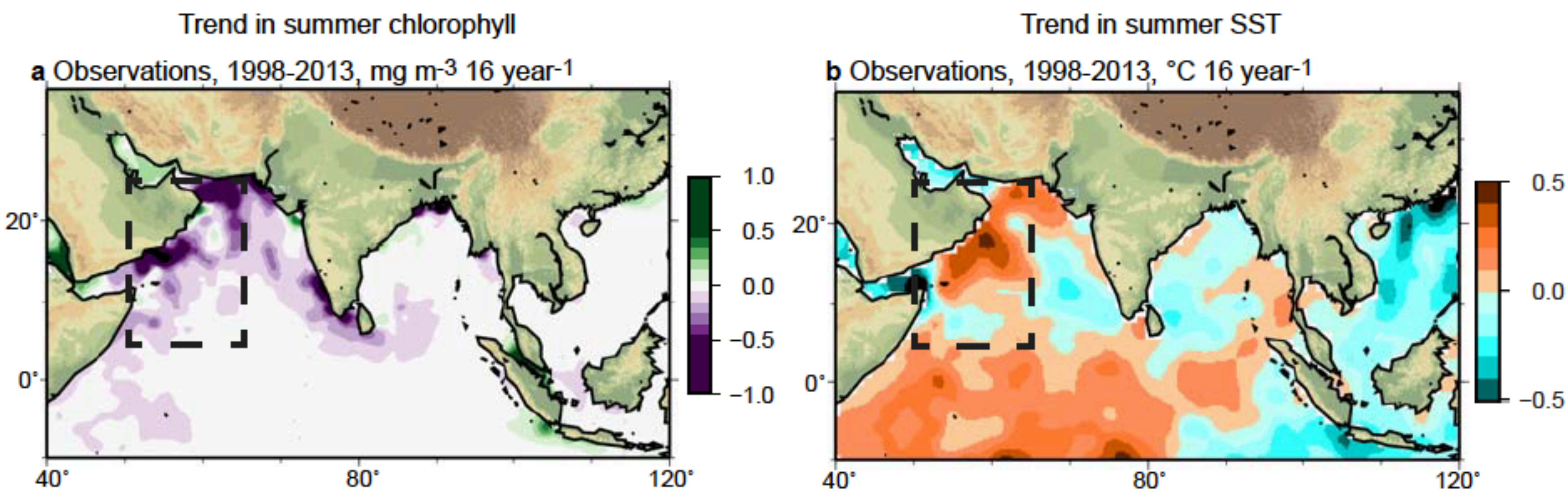


11-year running correlation between Nino 3.4 and IO SST



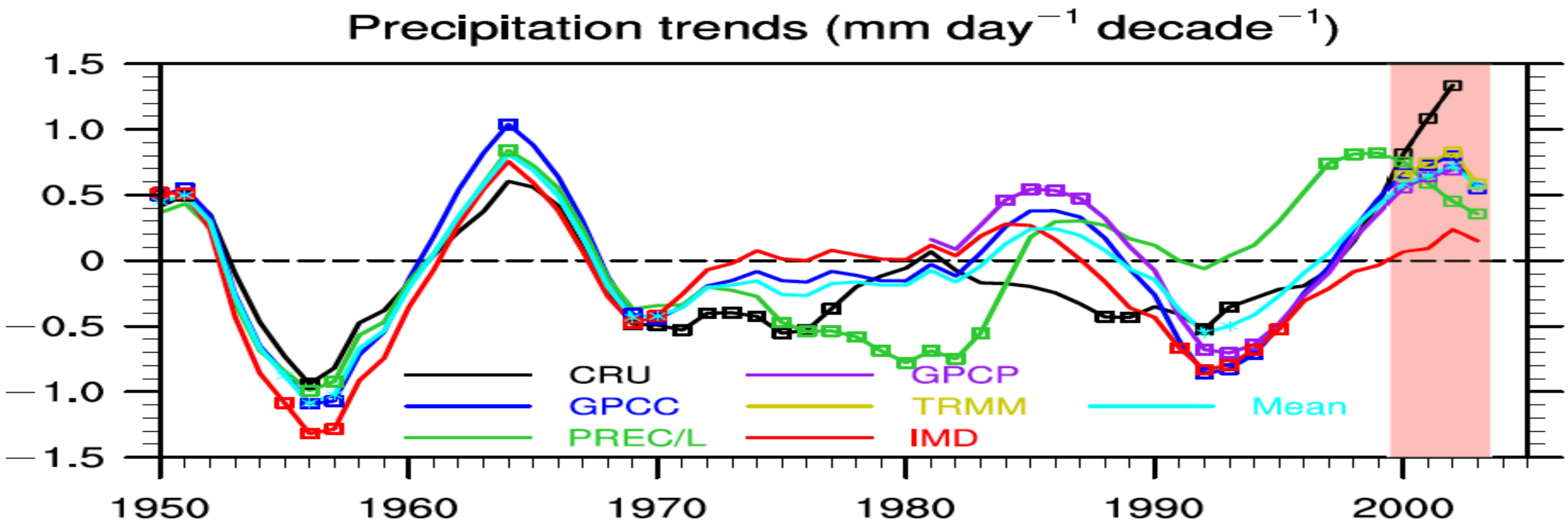
Other Aspects of Indian Ocean Warming and recent trends

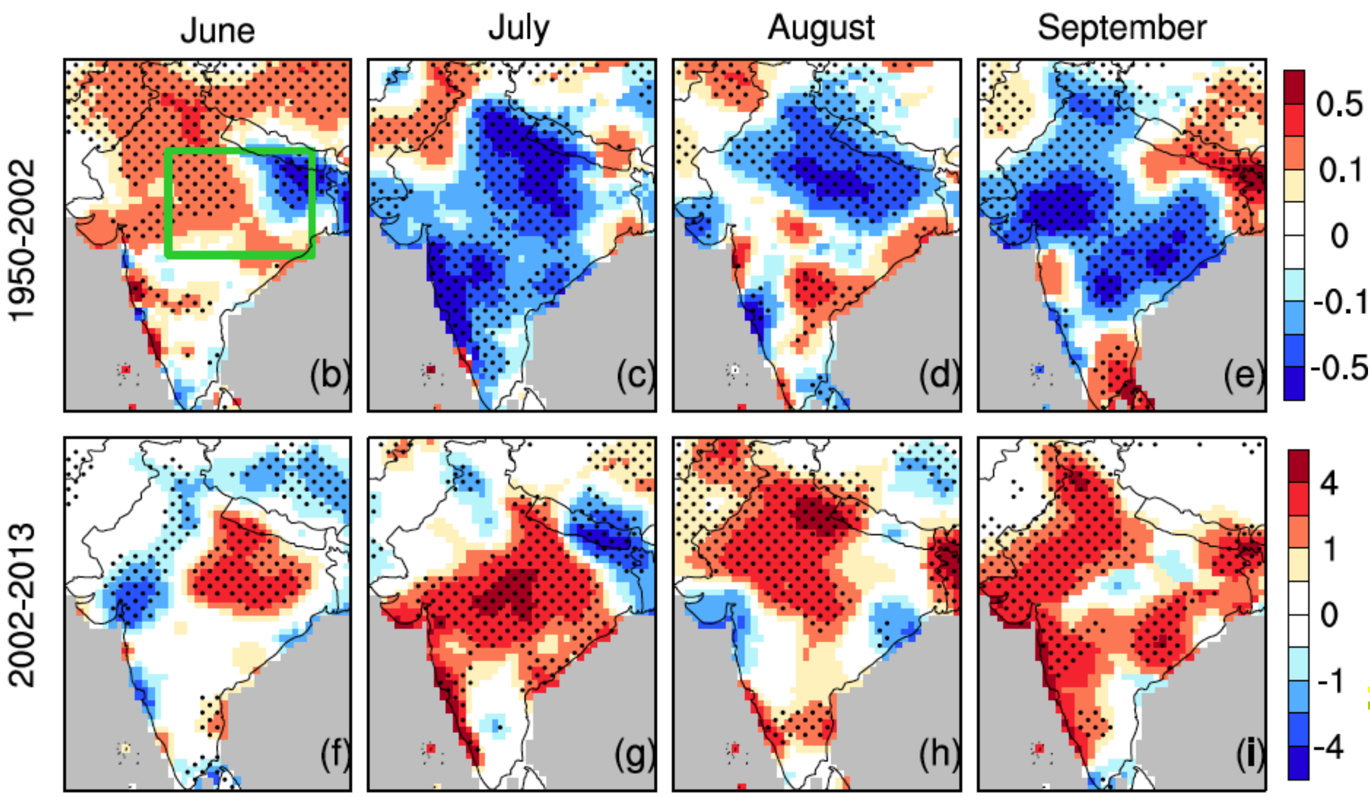
Indian Ocean Warming and Primary productivity



Primary productivity is decreasing rapidly in recent periods.

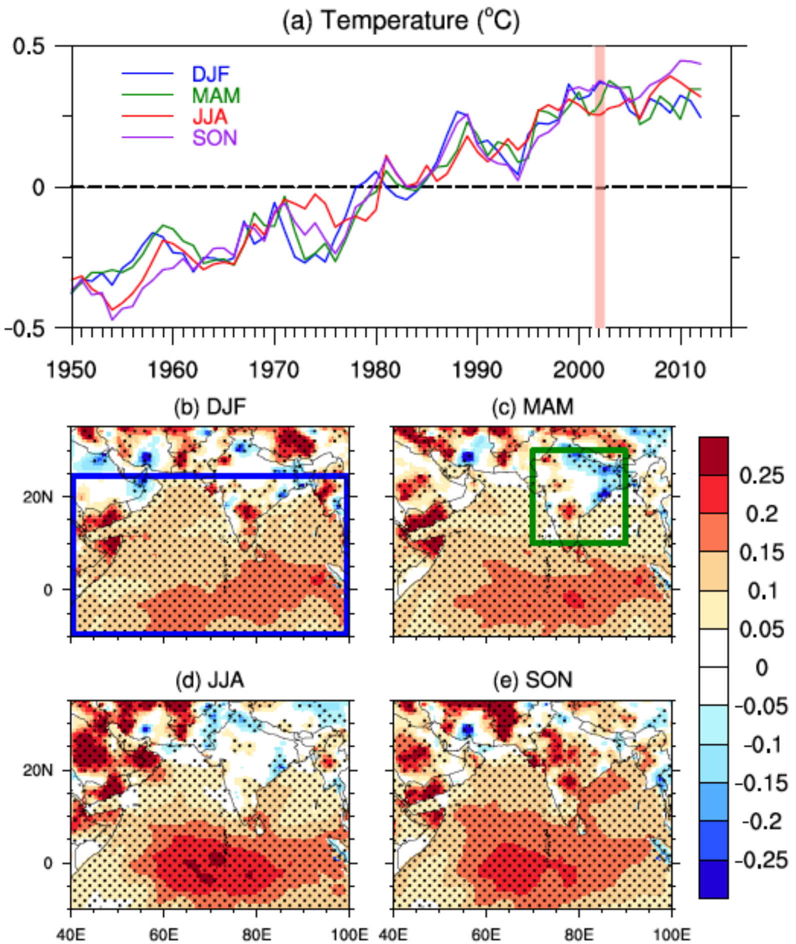
Roxy et al., (2016)



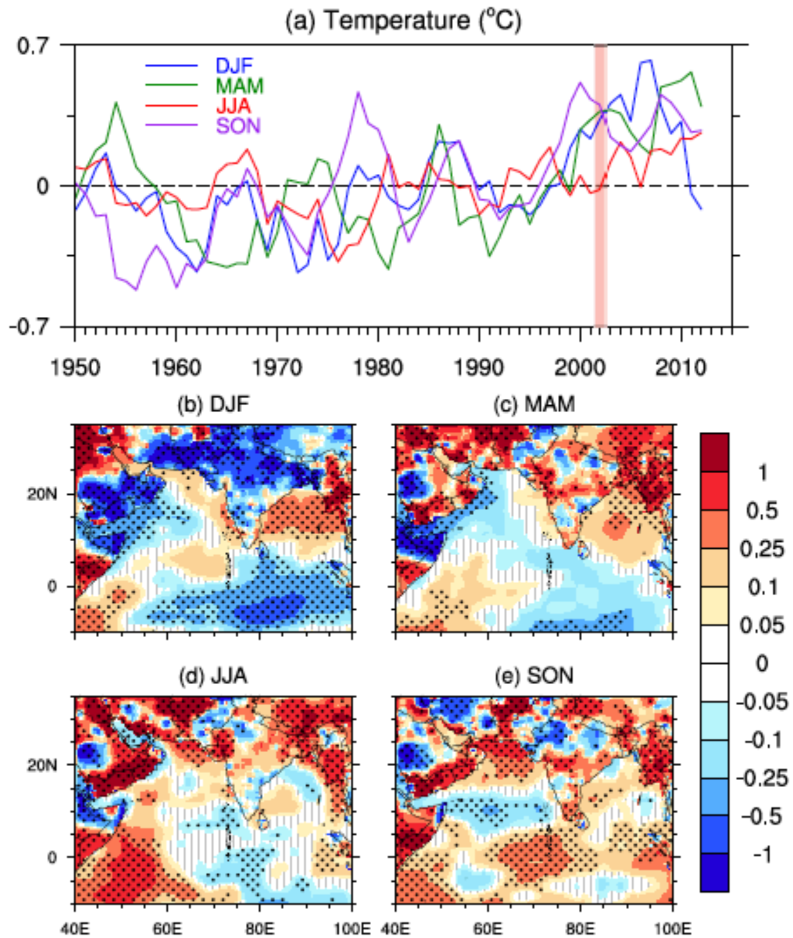


Jin & Wang, 2017

Monsoon Rainfall Decreasing trend is Revived after 2002



I950-2002 Trends



2002-2012 Trends

Conclusions

- Indian Ocean is warming consistently for last 50 years
- Coupled Positive feedback is responsible for the above observation
- Monsoon rainfall over central India may reduce considerably in the above scenario
- Monsoon Intraseasonal Oscillations are modulated considerably under warming.
- Number of extreme rainfall events may increase due to Indian Ocean warming
- Global warming Hiatus is partially due to IO warming

Thank You