Interplay between the Indian Ocean, ENSO and the Monsoon in a warming environment

SPECIAL SECTION

Oceans and climate change

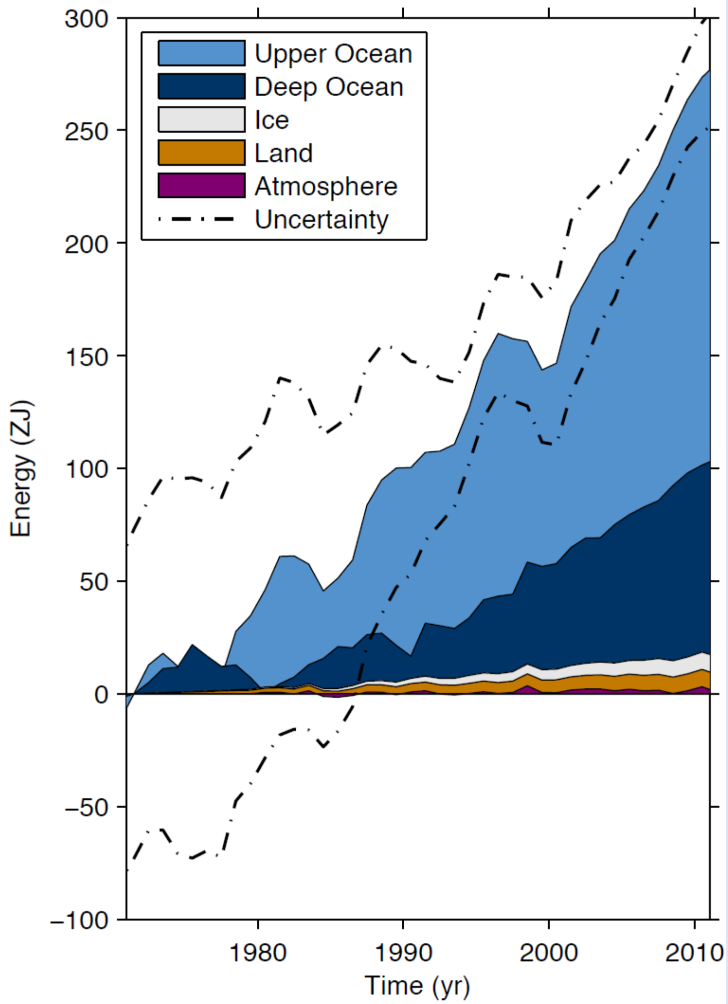
ON THE COVER

Melting water streams from an iceberg in Disko Bay on the western coast of Greenland. The iceberg calved from the Ilulissat Glacier (also known as Sermeq Kujalleq or Jakobshavn Glacier), one the world's fastest-moving and most-studied glaciers. Melting polar ice sheets are one consequence of human-induced global warming and could contribute to a substantial increase in global sea levels in the future. See page 750. *Photo: © Paul Souders/Corbis*

SEE ALSO ▸ EDITORIAL P. 721 ▸ NEWS STORY P. 728 ▸ REPORT P. 809 ▸ REPORT BY J. MOUGINOT *ET AL.* 10.1126/science.aac7111

Roxy Mathew Koll
Indian Institute of Tropical Meteorology, Pune

Ocean warming in a changing climate



During the past century…

1. Where has all the heat gone – Land/Atmos./Ocean?
2. Where in the Ocean?
3. Why is the Indian Ocean warming anomalously?
4. Links to El Niño?

Monsoon:

1. Have the monsoon drivers changed?
2. Is the South Asian Monsoon decreasing? Or increasing?
3. Role of Indian Ocean warming?
4. Aerosols, anyone?

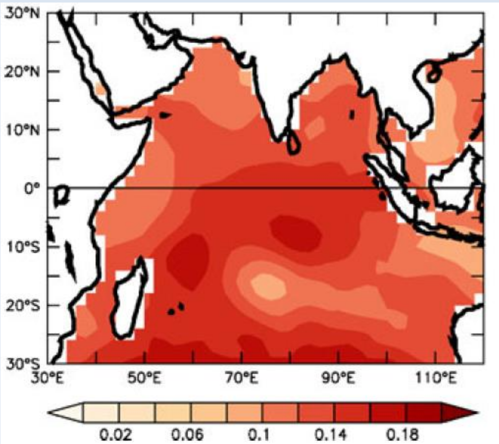
ENSO:

1. Has the ocean warming changed the El Niños?
2. Indian Ocean vs. Atlantic Ocean

IPCC, *AR5*, 2013

Indian Ocean during the past half-century

Basin-wide / Warm-pool warming in recent decades



SST trend during last 50 yrs

Studies note basin-wide warming over Indian Ocean in the last 50 years

Suggested causes:

1. Greenhouse warming (Du and Xie, 2014)
2. Weakening winds causing warming trends (Swapna et al 2013)
3. Warm SST triggers local air-sea coupled interaction (Rao et al 2012, Du et al 2009, Lau et al 2000)
4. Ocean dynamics (Chowdary et al 2007, Rahul et al. 2013)

Warm-pool enlargement in recent years

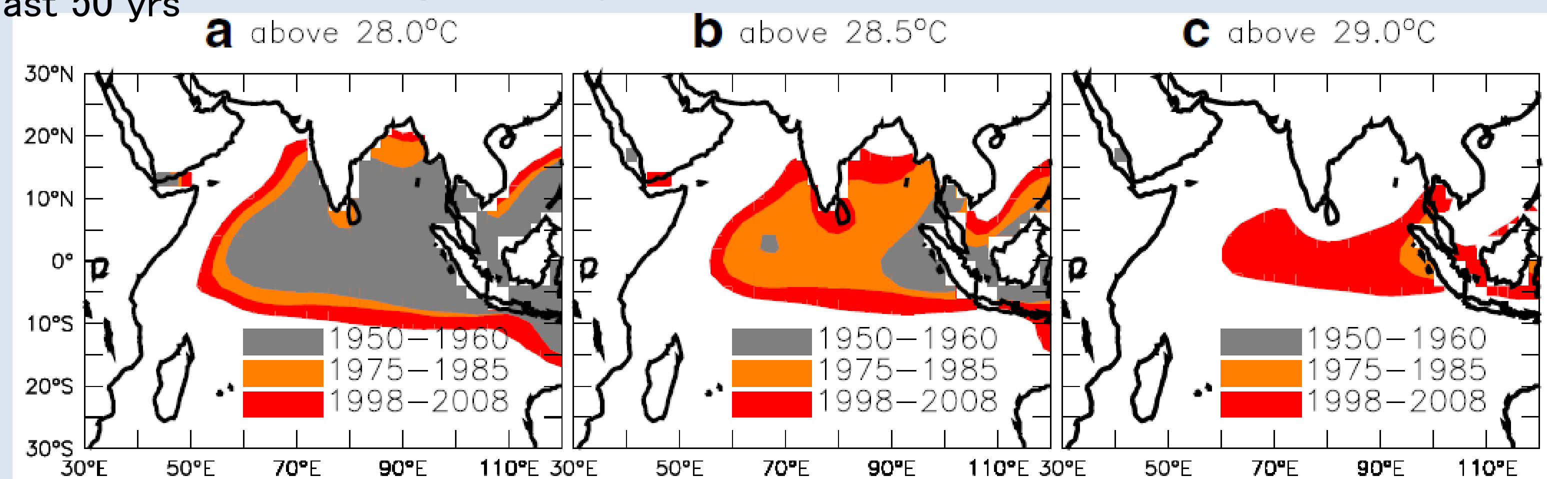
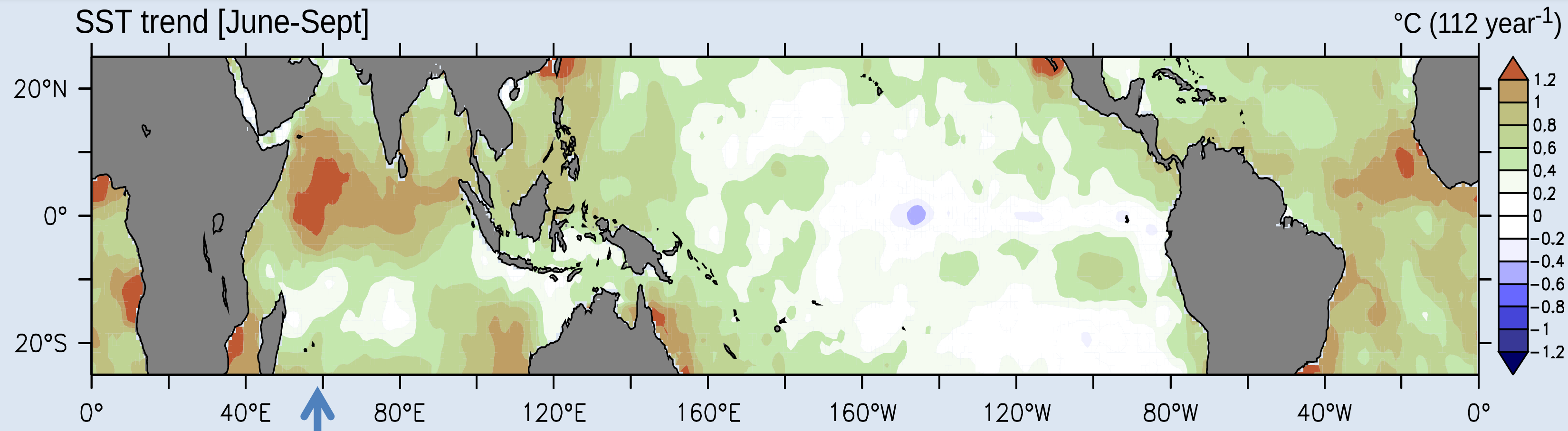


Fig. 2 Warm pool area during 1950–1960, 1975–1985, 1998–2008 with SST **a** above 28.0°C, **b** above 28.5°C and **c** above 29.0°C

Chambers et al. *JGR*, 1999; Alory et al. GRL, 2007; Rao et al. *Climatic Change*, 2012; Swapna et al. *Climate Dynamics*, 2013, Chowdary et al. *IJOC*, 2007

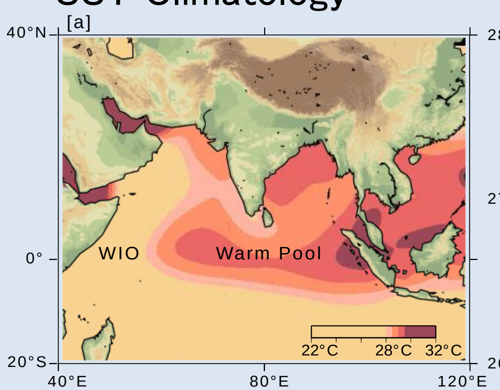
Indian Ocean during the last century

western Indian Ocean warmed up to 1.2degC, in 100 yrs

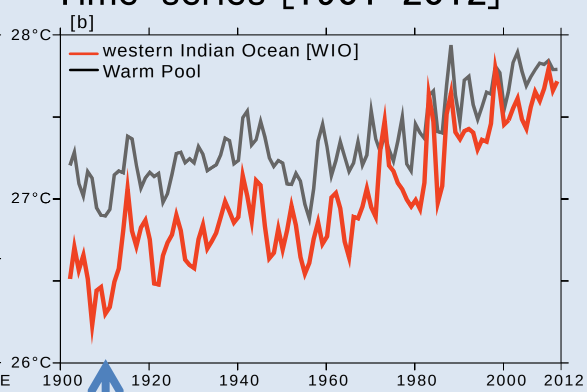


Basin-wide warming, with significant warming over western Indian Ocean.

SST Climatology

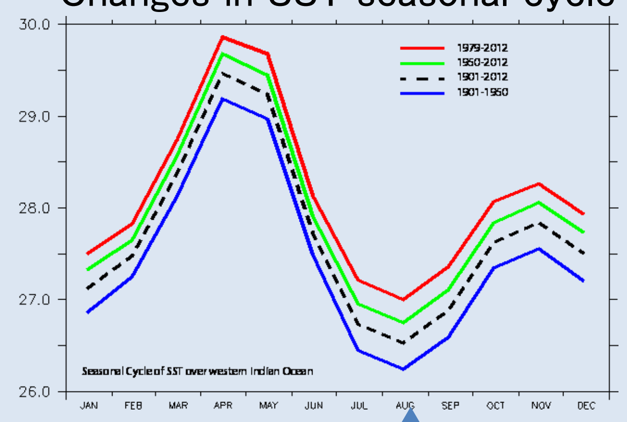


Time-series [1901-2012]



Monotonous **warming over west nullifies zonal SST gradient**

Changes in SST seasonal cycle



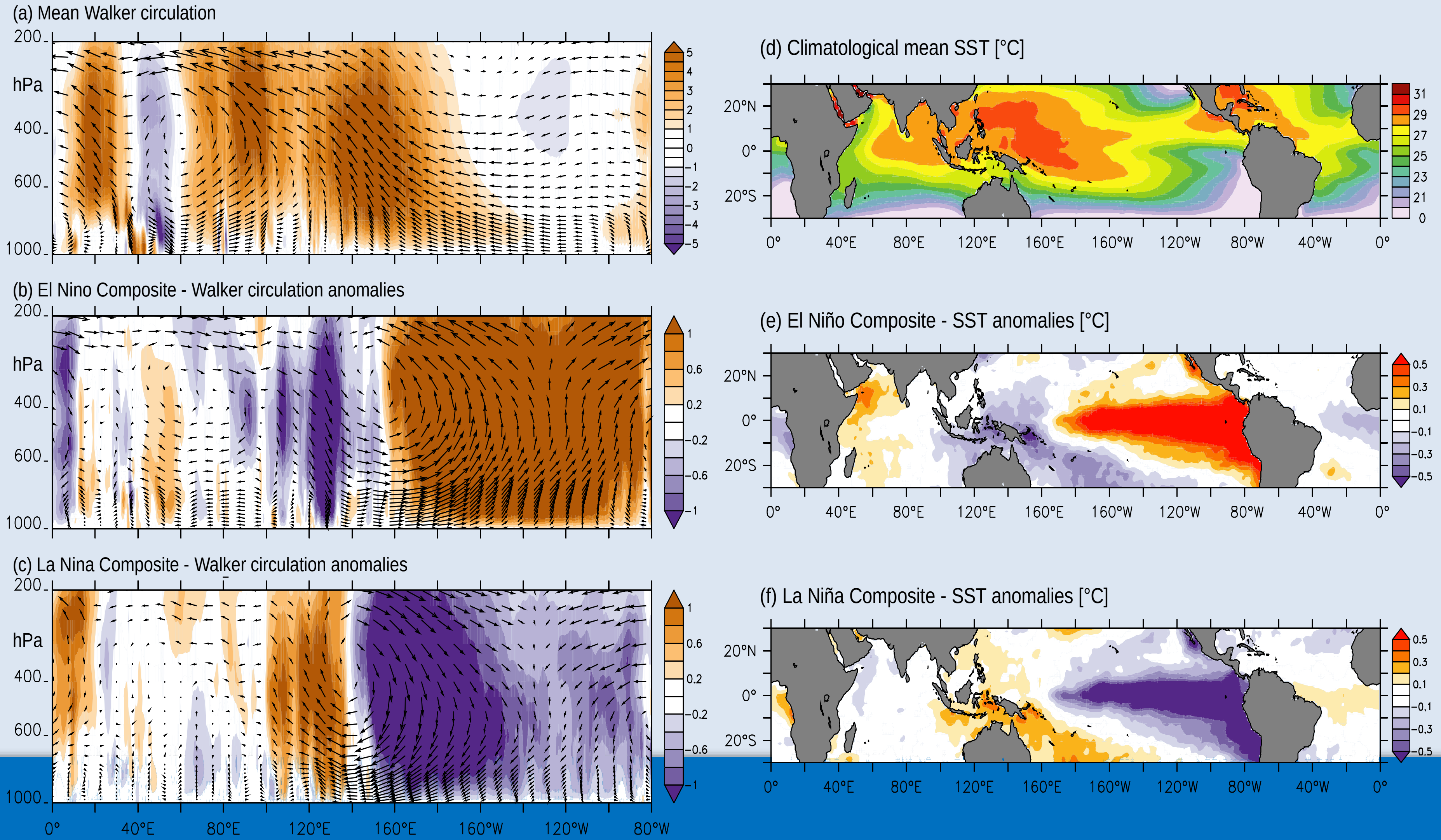
SST change largest in summer

Roxy et al. *J.Climate*, 2014

Asymmetry in ENSO forcing
Influence of El Niño > La Niña

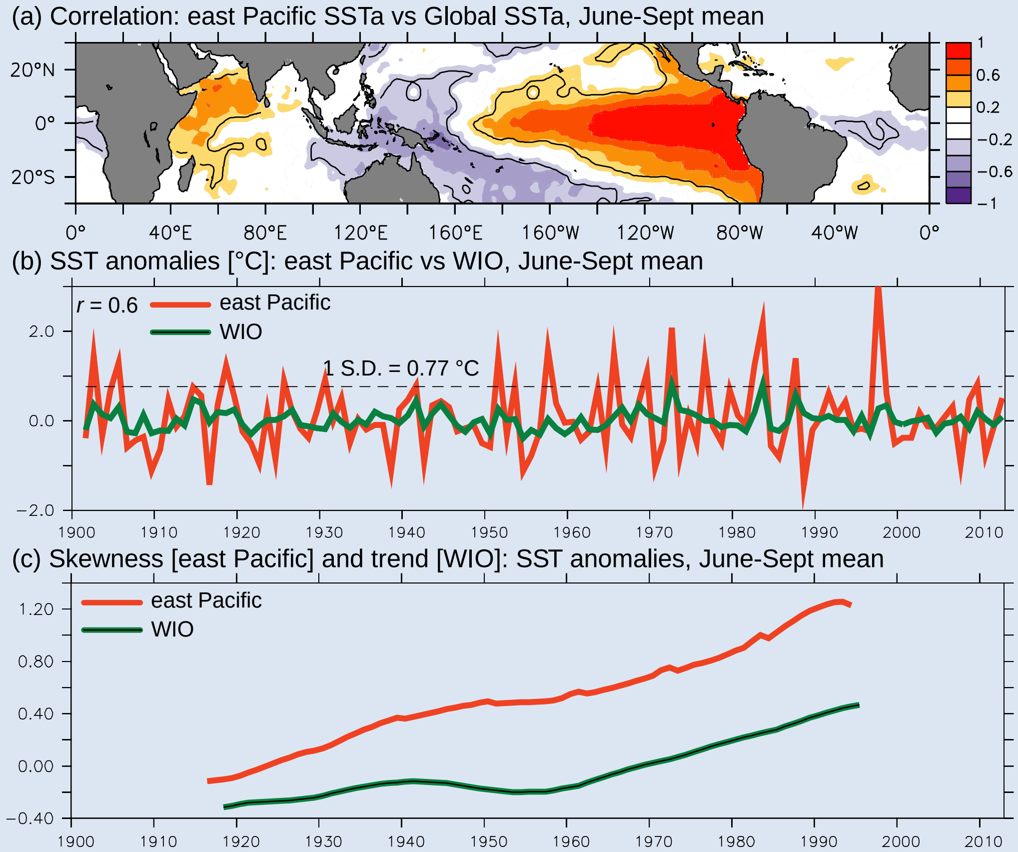
El Niño induce significant easterlies and positive SST anomalies over w.Indian Ocean

but… La Niña events do not result in significant anomalies over the Indian Ocean

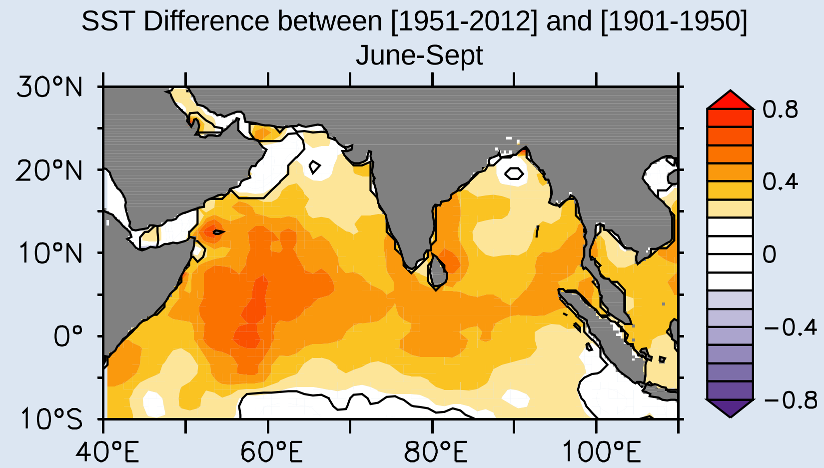


Skewness in El Niño forcing

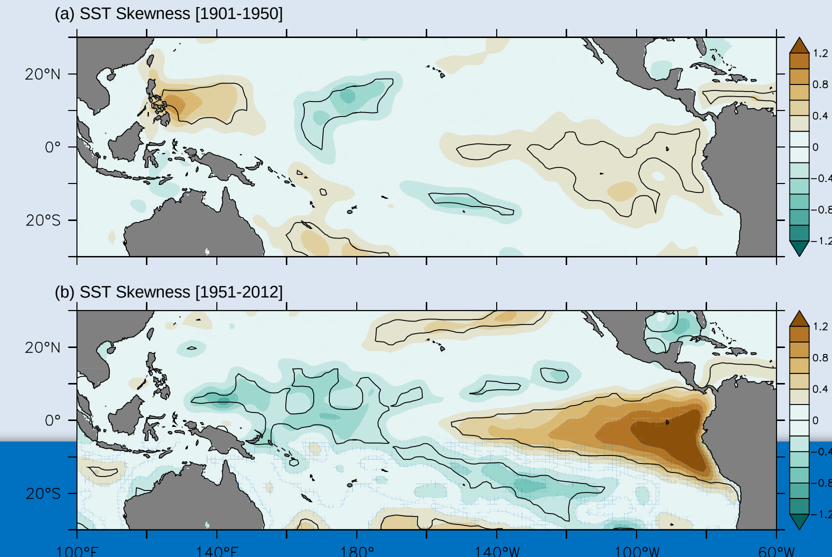
Increase in Frequency and Magnitude of El Niños



Detrended anomalies show increase in frequency and strength of El Niños. The warm events over Indian Ocean also has increased. Occasionally, they cross the El Niño criteria (1 S.D. = 0.77 degC).



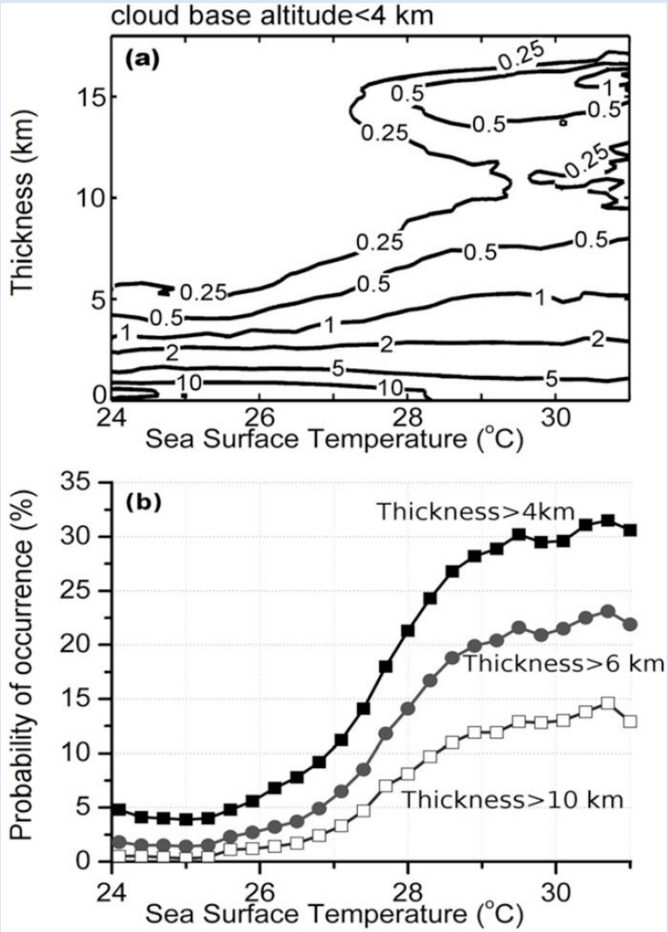
Indian Ocean warming (above) associated with positive skewness over east Pacific (below)

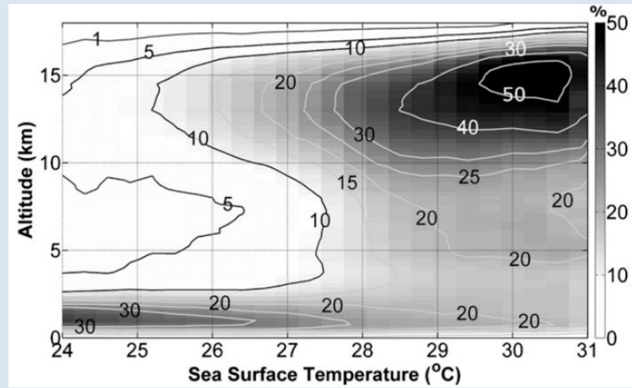


Changes in Monsoon drivers

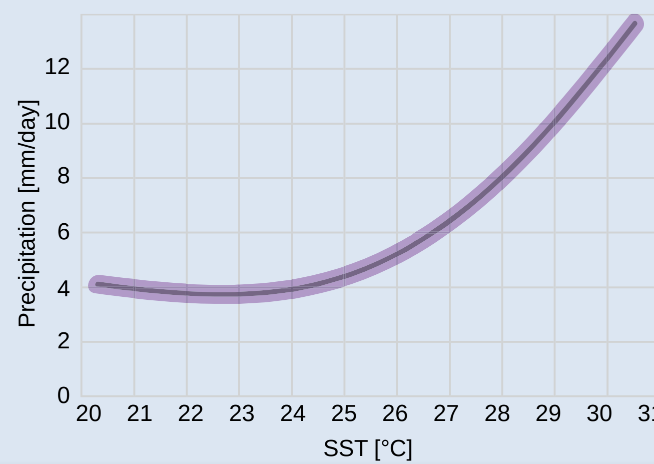
Increased ocean warming enhances convection

Cloud vertical distribution and thickness grows with increased SST (CloudSat and CALIPSO)





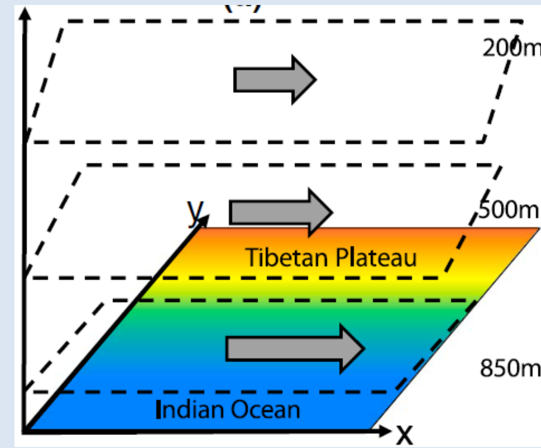
Increased SST enhances precipitation



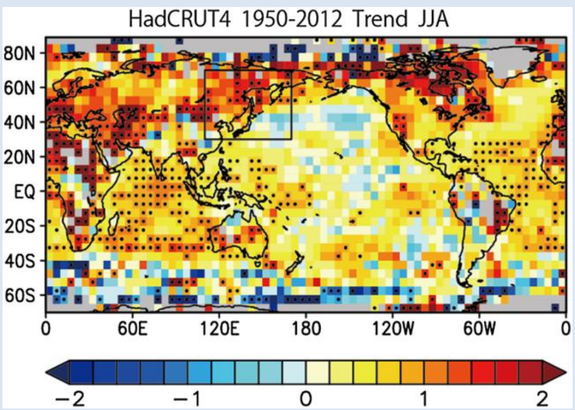
Gadgil et al.,*Nature*, 1984; Roxy,*Climate Dynamics*, 2013; Nair and Rajeev, *J.Climate*, 2013

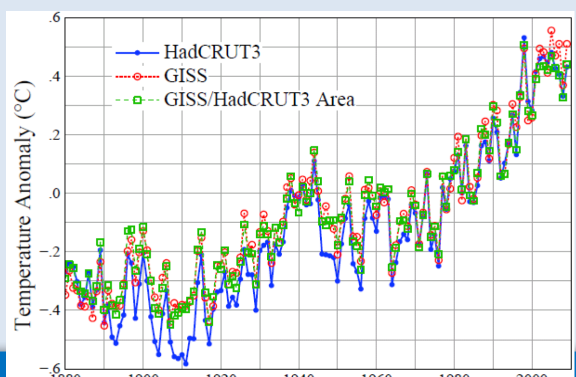
Changes in Monsoon drivers
Increase in land-sea thermal gradient during past century

Observations and climate models suggest an increase in land–sea thermal contrast over Northern Hemisphere during recent decades -as surface temperatures over land increase more rapidly than over sea in response to greenhouse gas forcing.

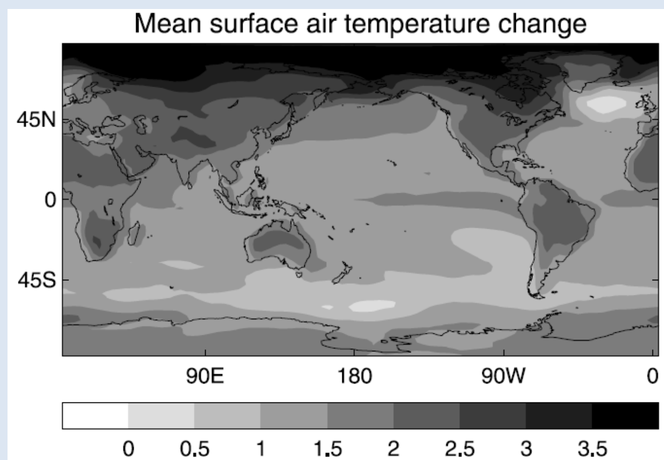


Observations





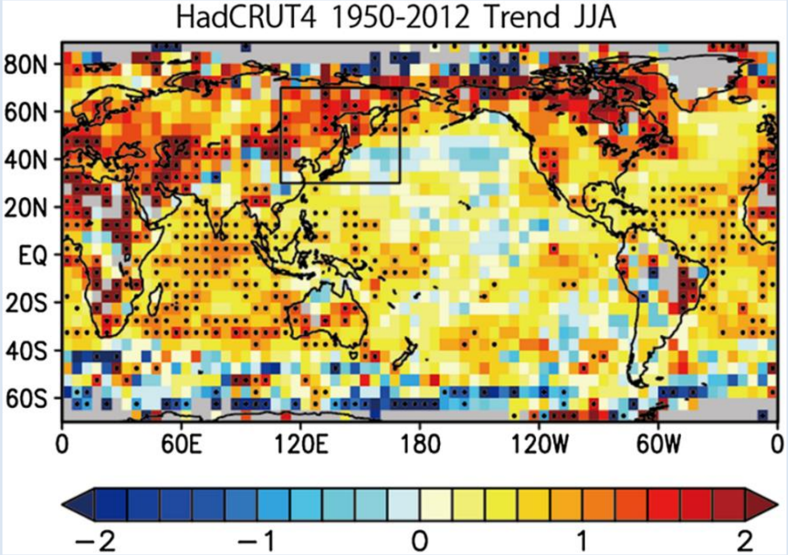
Climate Model response to CO_2 forcing (IPCC AR4 Ensemble)



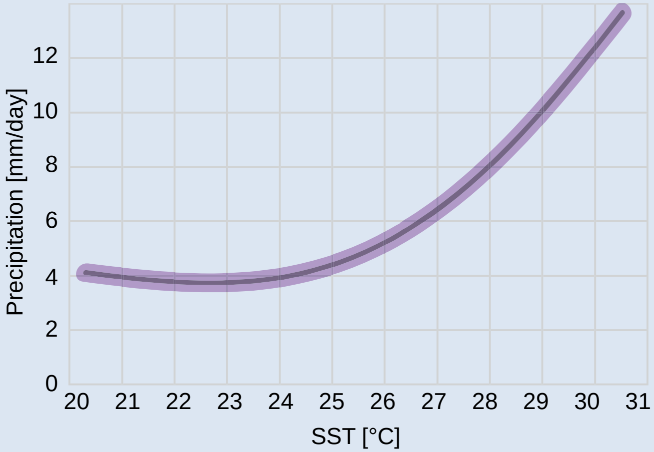
Sutton et al. *GRL*, 2007; Hansen et al. *Rev.Geophys*, 2010

Ideally, Increased land-sea contrast = more rainfall
Increased ocean warming = more rainfall

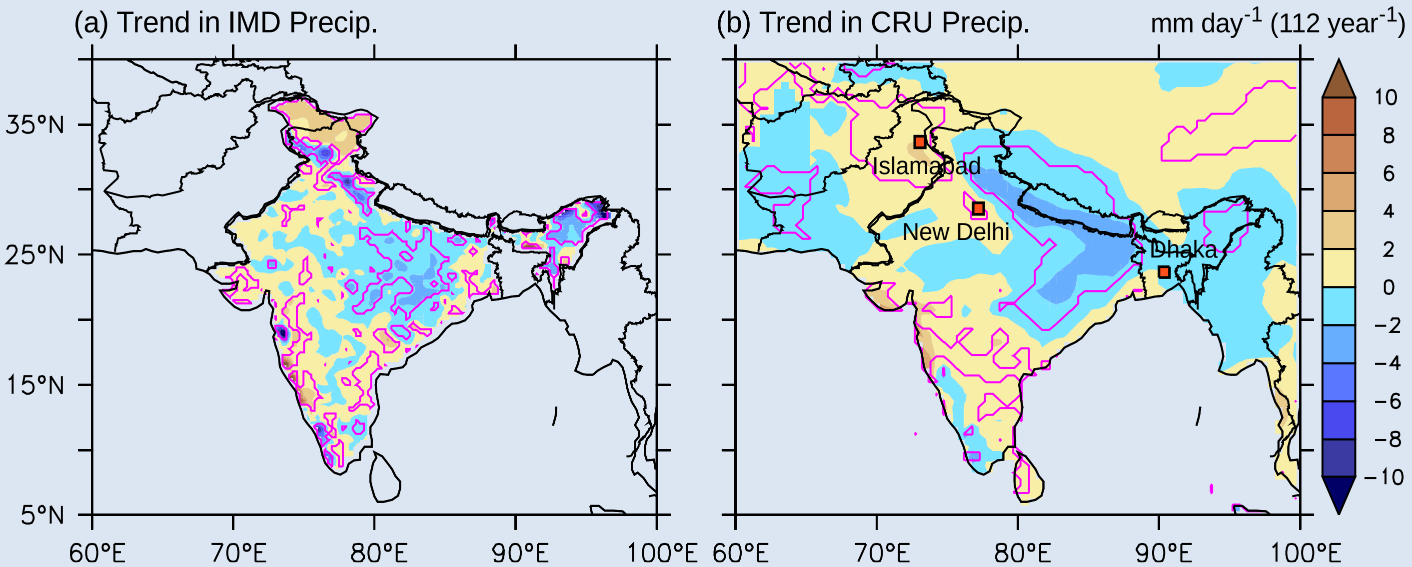
Increased land–sea thermal contrast



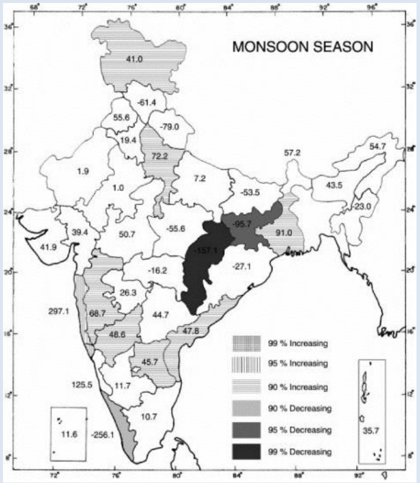
Increased ocean warming



but it's a weak South Asian Monsoon
central India shows significant reduction in rainfall



Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)



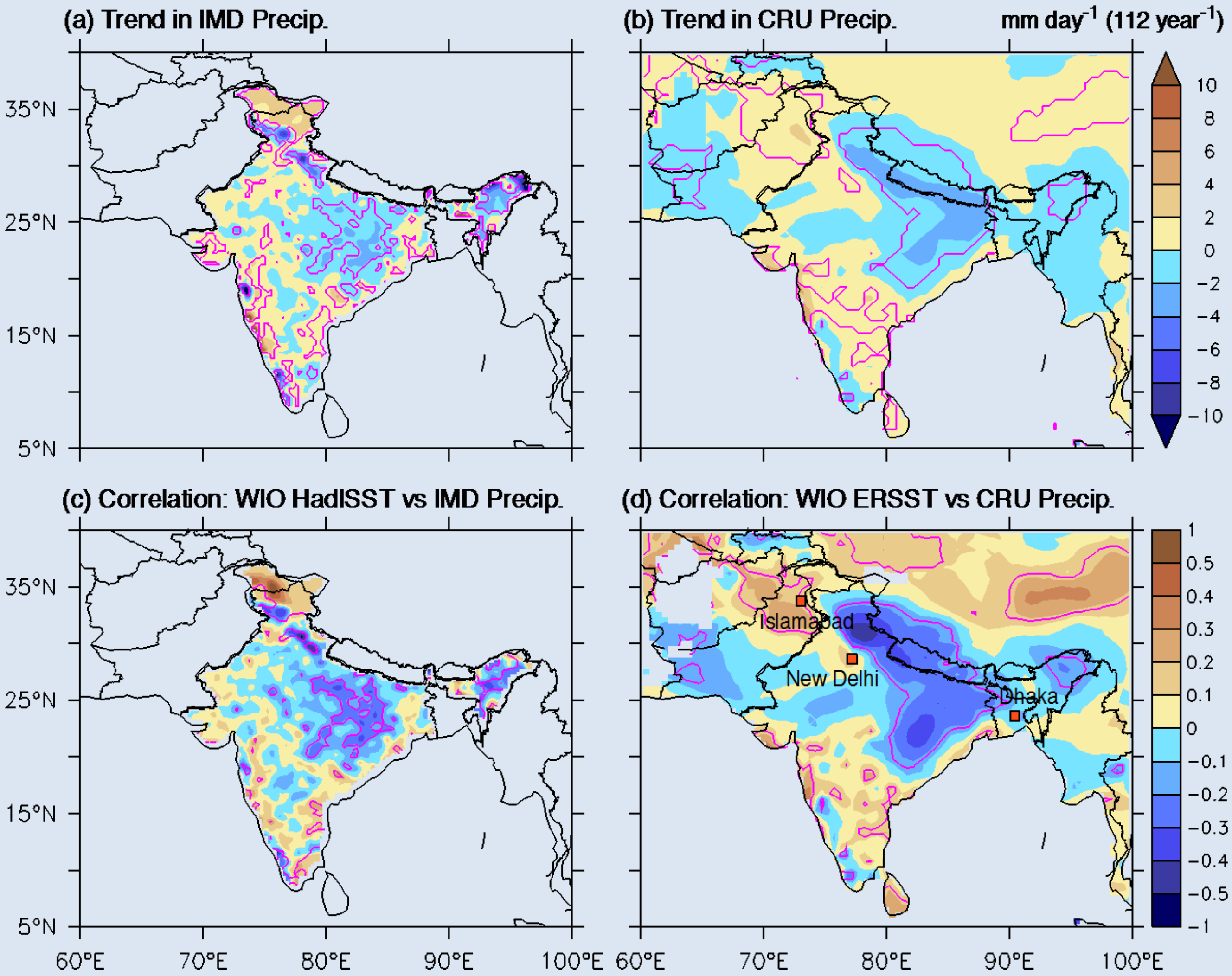
Similar results from subdivisional station data: Guhathakurta and Rajeevan, 2008

Western Ghats show dipole like trends: Sandeep and Ajayamohan 2014

Guhathakurta and Rajeevan, *IJOC*, 2008; Sandeep and Ajayamohan, *Sci.Rep.*, 2014
Roxy et al. *Nature Communications*, 2015

Warm Indian Ocean, Weak south Asian Monsoon

Indian Ocean warming well correlated with weak Precip.



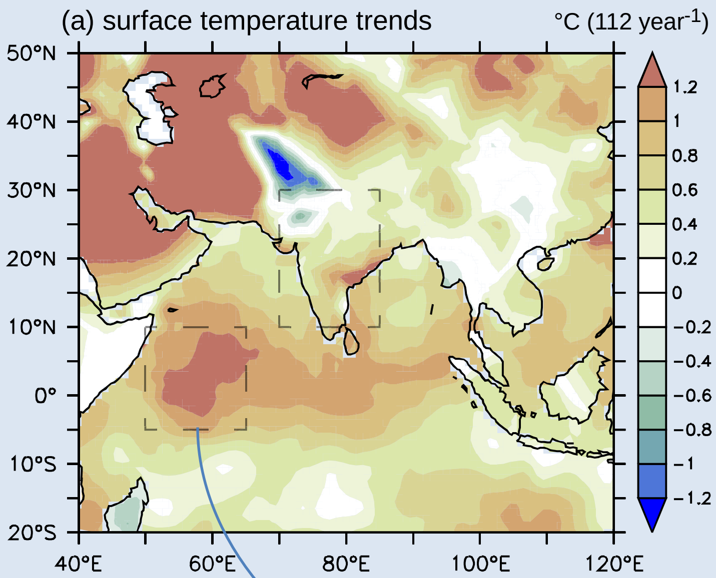
(a) & (b)
Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)

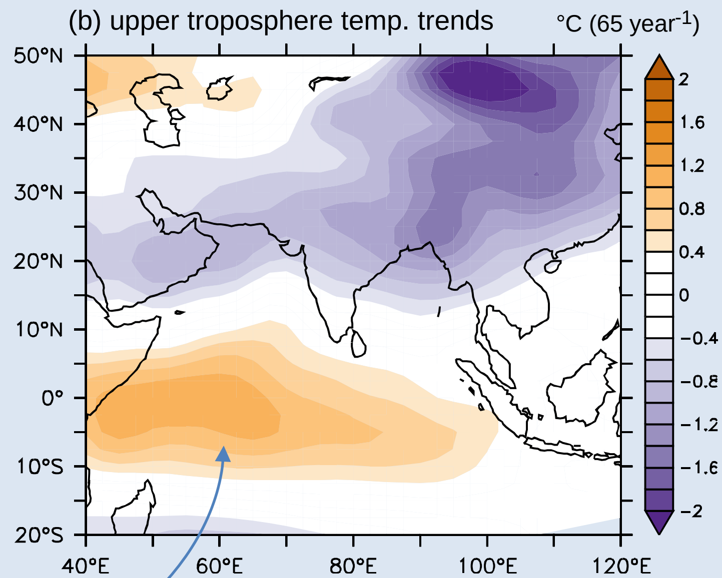
(c) & (d)
Trend and correlation with western Indian Ocean warming has similar patterns!

Land-sea thermal contrast over South Asian domain

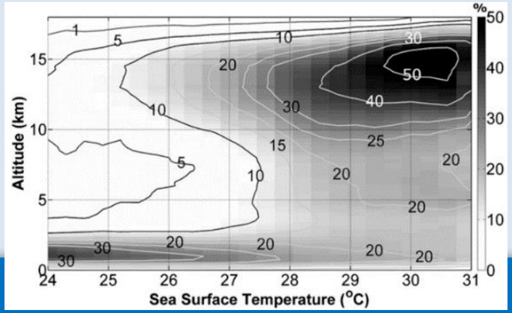
Indian Ocean–large warming, Subcontinent–suppressed warming

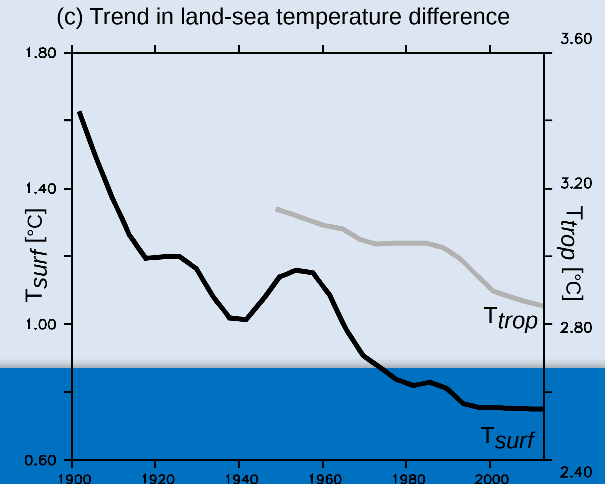
Though models and observations suggest increase in land–sea contrast over Northern Hemisphere due to global warming, it is different over South Asia/Indian Ocean.





Increased SST results in intense vertical development of convection

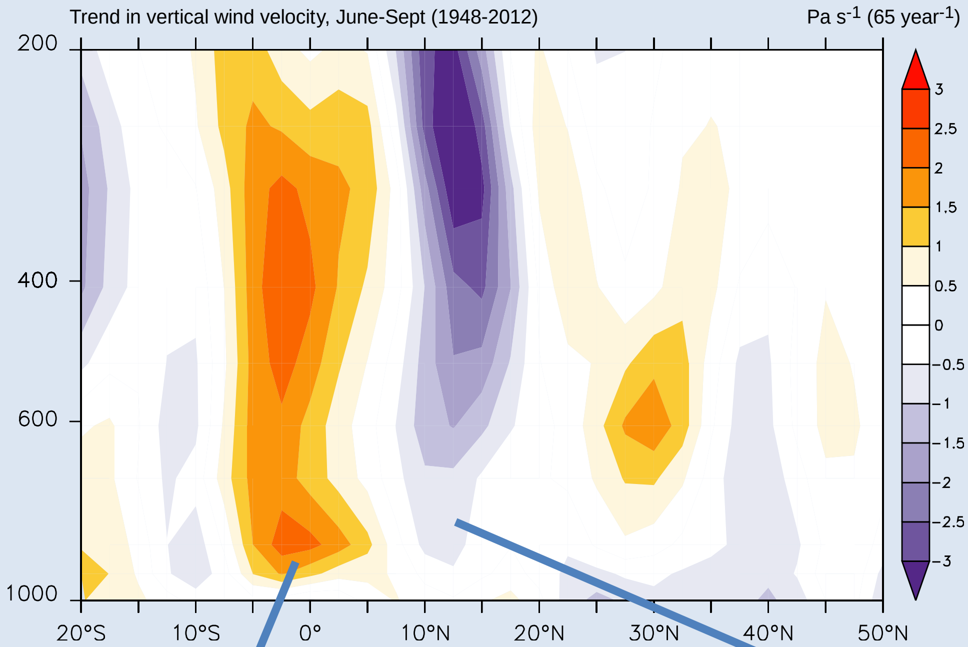


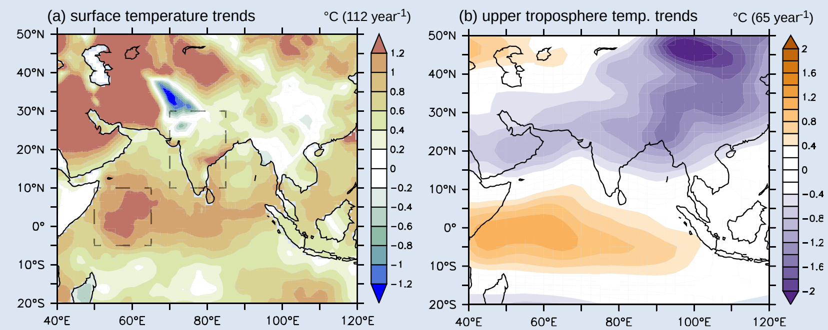


Roxy et al. *Nature Communications*, 2015

Weakening local Hadley circulation: Convection enhanced over ocean and suppressed over land

Observations: trend in vertical velocity (1948–2012)





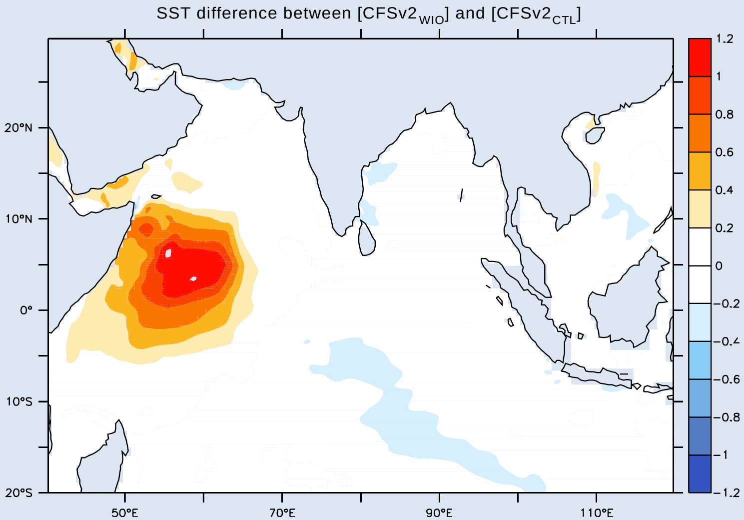
WIO warming extends the warm pool, and increases ocean convection

Large scale upward motion over the Indian ocean (10S–10N), extending up to the upper troposphere and favoring intense local convection.

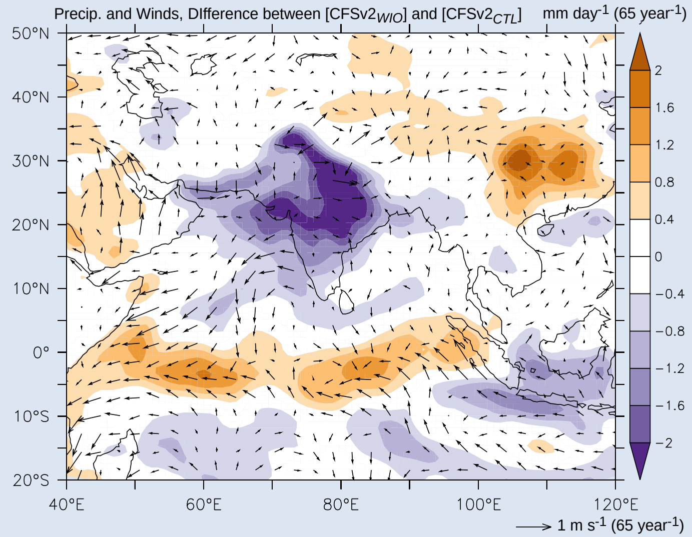
Compensated by subsidence of air over the subcontinent (10–20N), inhibiting convection over the landmass and drying the region.

Weakened Monsoon precip/winds due to warming
Model simulations with Indian Ocean warming

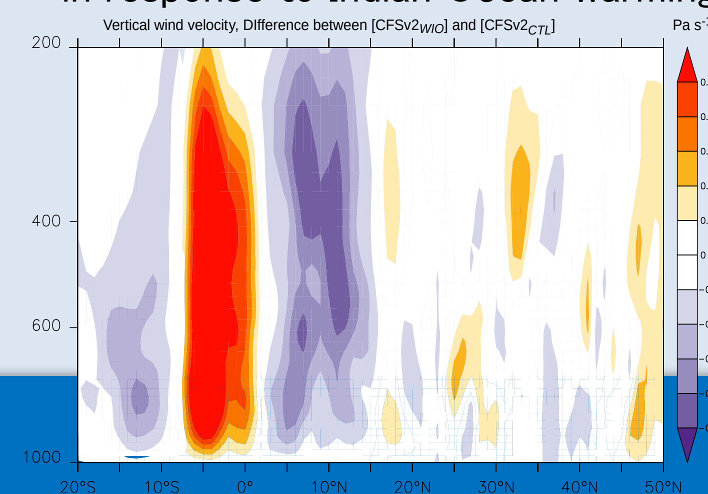
Model simulated warming of WIO



Model simulated response to warming



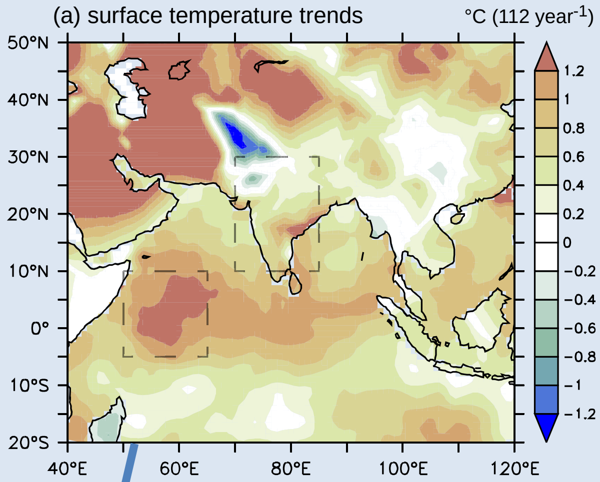
Model simulated vertical velocity in response to Indian Ocean warming



Competition between ocean and land rainfall:
SST warming extends the warm pool, increases ocean rainfall
…but results in decreased rainfall over the subcontinent
– horseshoe pattern in model simulations with increased IO warming

Role of other monsoon drivers
aerosol cooling, stratosphere–troposphere interactions??

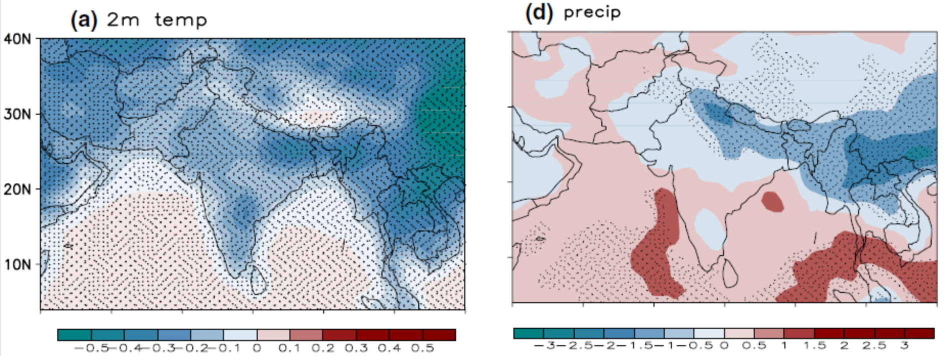
land surface – aerosol cooling?



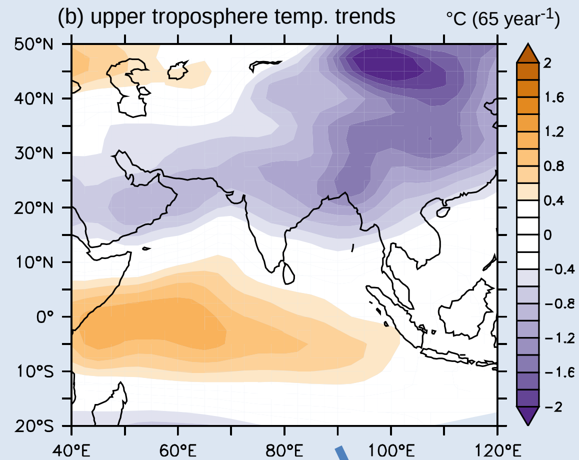
On the response of Indian summer monsoon to aerosol forcing in CMIP5 model simulations

S. D. Sanap · G. Pandithurai · M. G. Manoj

Received: 11 July 2014 / Accepted: 9 February 2015



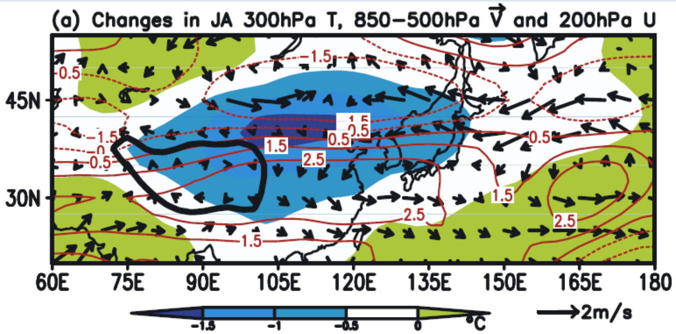
upper troposphere -stratospheric interactions?



Tropospheric cooling and summer monsoon weakening trend over East Asia

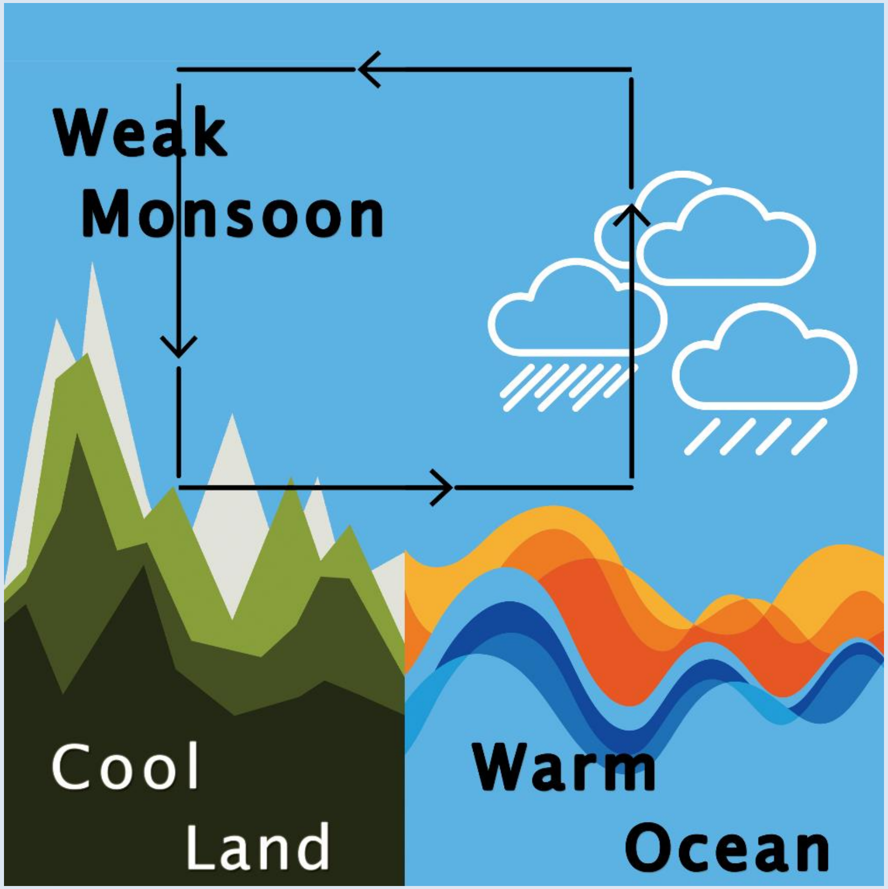
Rucong Yu,[1] Bin Wang,[2,3,4] and Tianjun Zhou[1]

Received 16 August 2004; revised 12 October 2004; accepted 25 October 2004; published 27 November 2004.



Krishnan and Ramanathan, *GRL*, 2002
Sanap et al., *Climate Dynamics*, 2015
Yu et al, *GRL*, 2004

Future?



CMIP5 future projections suggest further warming of the Indian Ocean. Will the monsoon decrease further?

These future projections also suggest increasing monsoon rainfall (Sharmila et al 2015).

However it is to be noted that these models fail to reproduce the present day monsoon (Sabeerali et al 2014, Saha et al 2014)

Roxy et al. *Nature Communications*, 2015

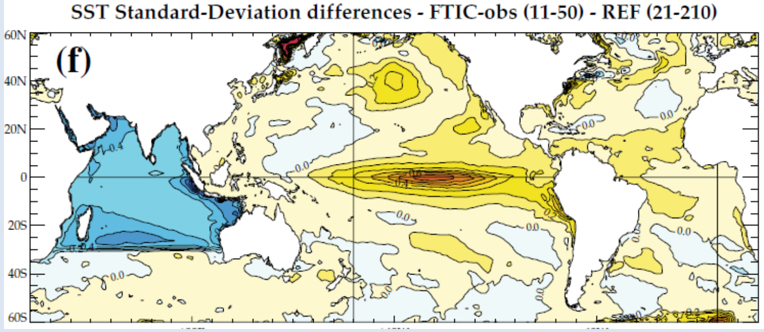
Indian Ocean warming may dampen the El Niño

Table 1 Summary of the numerical experiments with their main characteristics, including length, nudging domain and SST climatology used for the nudging in the Indian or Atlantic oceans decoupled experiments

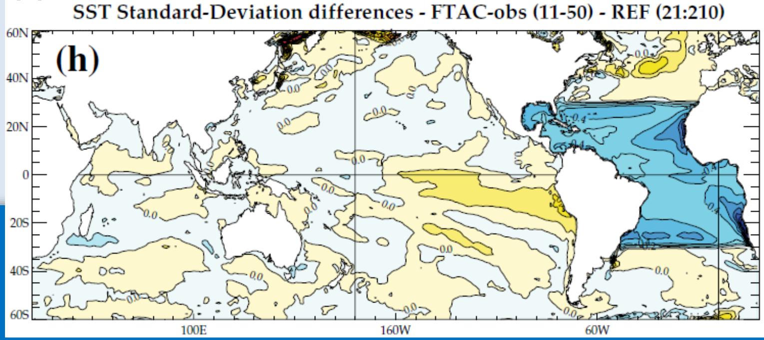
Name	REF	FTIC	FTIC-obs	FTAC	FTAC-obs
Correction area	None	Indian Ocean 30°E–120°E 25°S–30°N	Indian Ocean 30°E–120°E 25°S–30°N	Atlantic Ocean 100°W–20°E 25°S–25°N	Atlantic Ocean 100°W–20°E 25°S–25°N
Smoothing area	None	30°S–25°S	30°S–25°S	30°S–25°S 25°N–30°N	30°S–25°S 25°N–30°N
SST data	None	REF	AVHRR	REF	AVHRR
Time duration (year)	210	110	50	110	50

Suppressing the Indian Ocean SST variability increased the ENSO strength.

Suppressed Indian Ocean variability

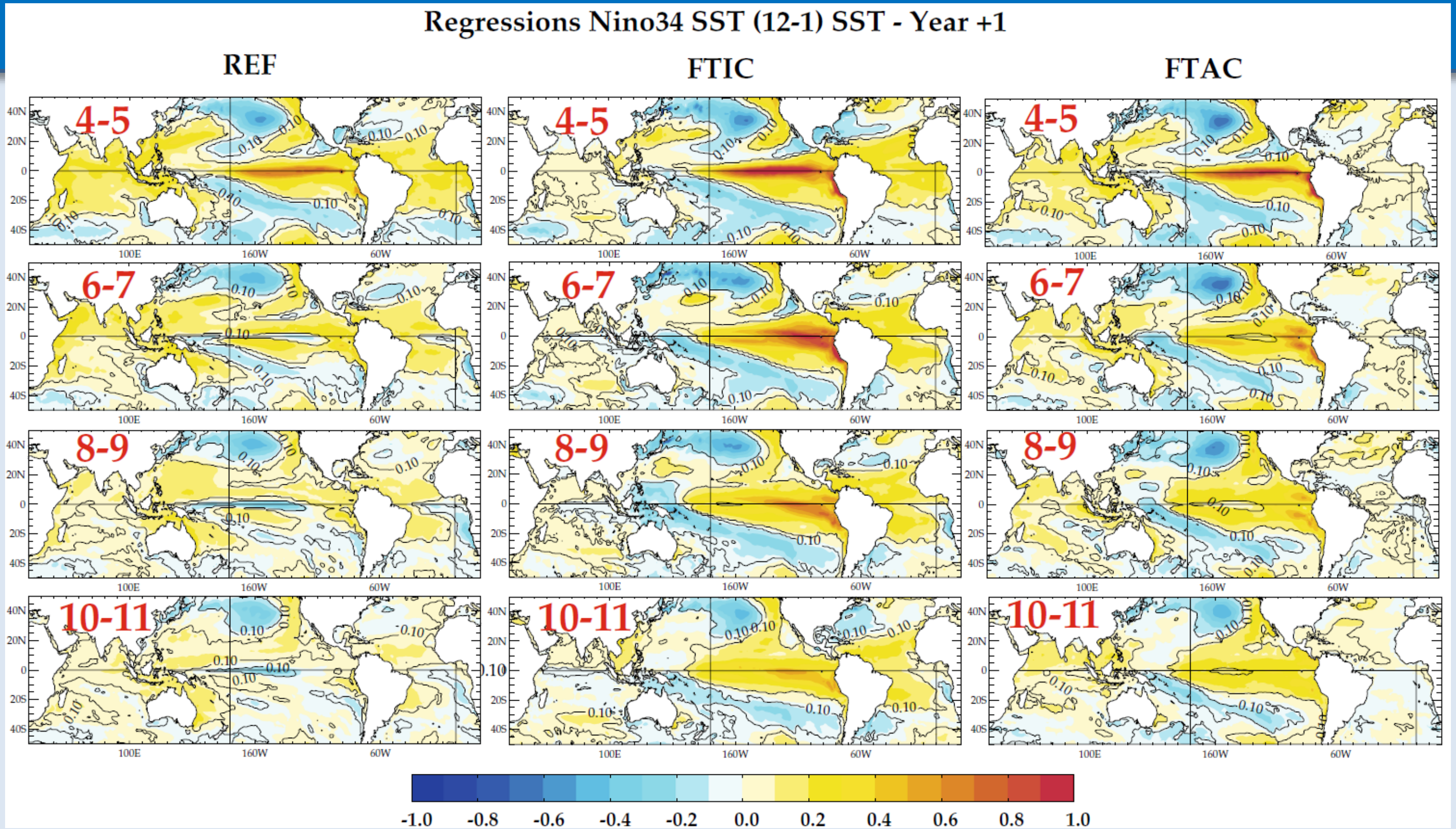


Suppressed Atlantic Ocean variability



Terray et al. *Climate Dynamics*, 2015

Indian Ocean warming shortens the El Niño cycle



Suppressing the Indian Ocean SST variability increased the El Niño decaying period.
i.e. warm Indian Ocean SST kills an El Niño at an earlier state.

Involve modulations of the surface winds in the western equatorial Pacific, which trigger eastward-propagating oceanic Kelvin waves responsible for the turnabout of ENSO (through changes in the thermocline).

Terray et al. *Climate Dynamics*, 2015

Interplay between the Indian Ocean, ENSO and the Monsoon in a warming environment

Indian Ocean warming:

- Strong, monotonous warming during the last century in western Indian Ocean
- Links to asymmetry/skewness in ENSO forcing

Potential Impacts:

- Weakens the South Asian monsoon
- Dampens the ENSO magnitude and the cycle

Thank You!