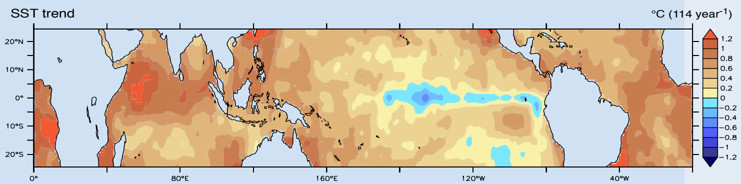
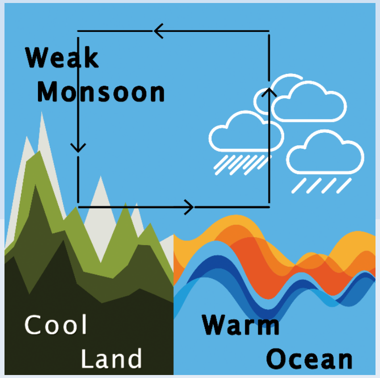
Teleconnections between tropical Indian and Pacific Oceans —in relation to Indian Ocean warming

Indian Ocean warming:

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



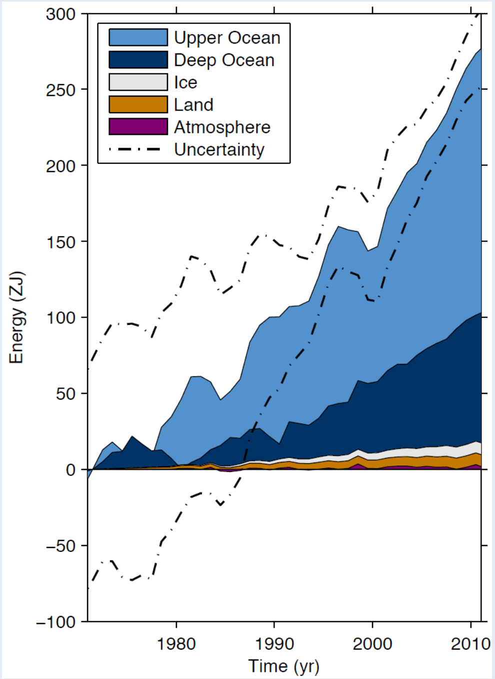


Potential Impacts:

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

Roxy Mathew Koll
Indian Institute of Tropical Meteorology, Pune

Heat gain is uneven among earth system components —Ocean gaining more than 90% of the heat



Oceans are a big deep reservoir of a liquid with high heat capacity.

Almost all (more than 90%) of Earth's heat gain goes into the oceans.
Rate is 8×10^{21} J/yr, or 2.5×10^{14} J/sec.

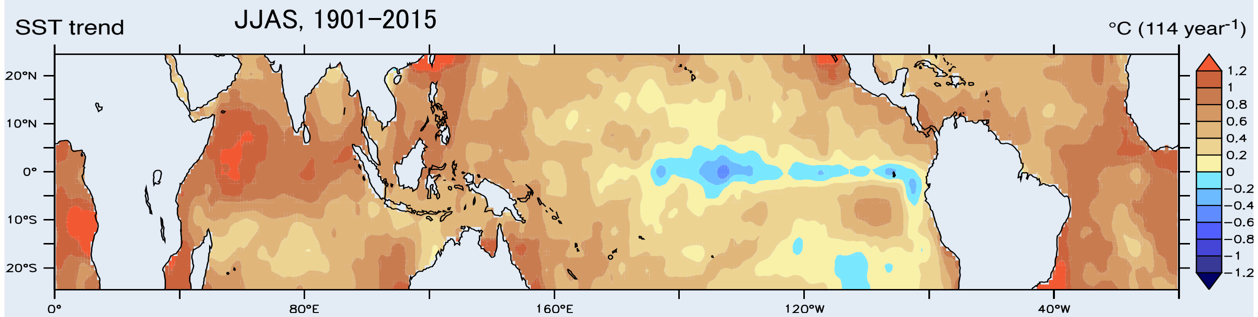
≈ 4 Hiroshima atomic bomb detonation per second
(1 detonation = 6.3×10^{13} Joules
So, about 2 billion atomic bombs since 1998)

Atmospheric heat gain is an especially small part of the total.

Atmosphere + Land + Ice accounts for less than 10% of the heat gain.

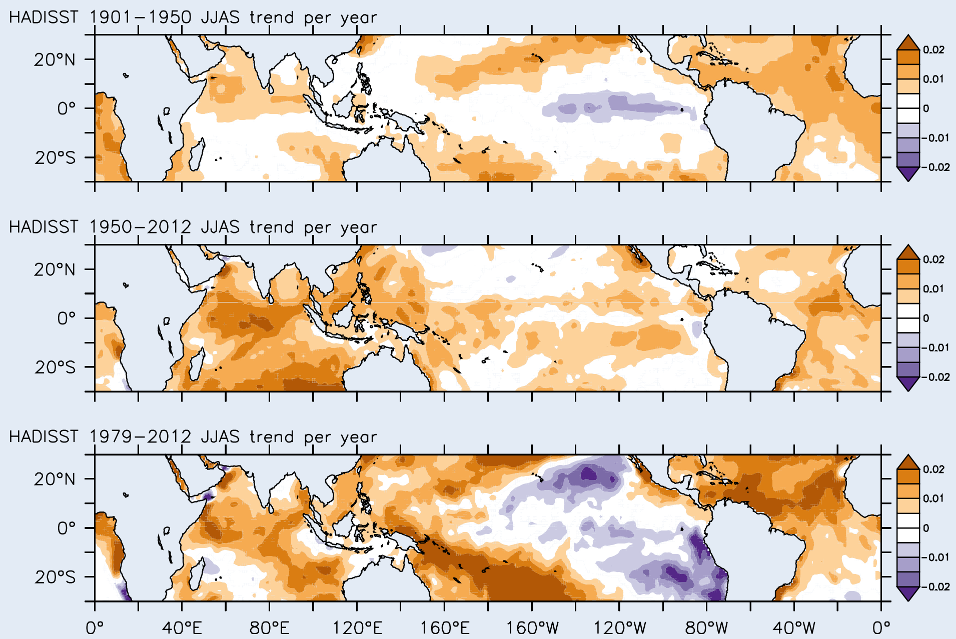
Church et al., *GRL*, 20111; Nuccitelli et al., *Phys.Lett.*, 2012;
IPCC, *AR5,* 2013

Heat gain in the ocean is also uneven
—Indian and Atlantic Oceans have warmed up

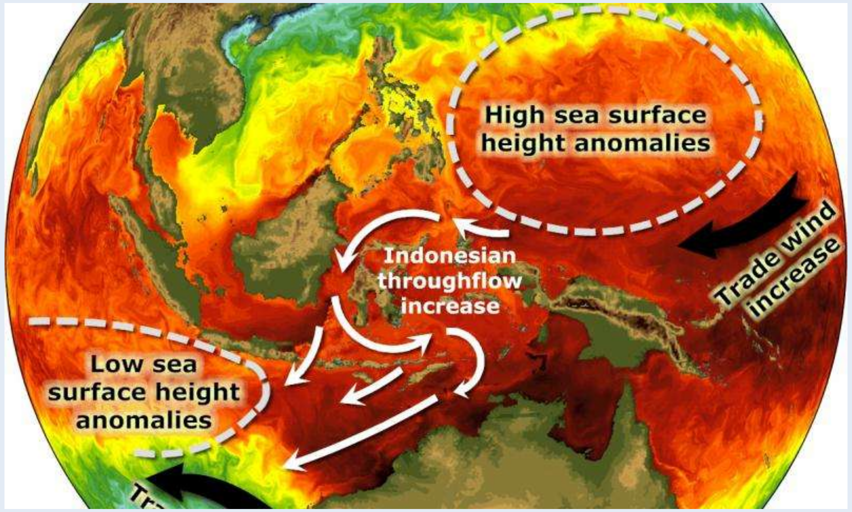


Roxy et al., *J.Climate,* 2014

Surface warming uneven through different periods —monotonous warming in the Indian and Atlantic Oceans



Subsurface warming in the Indian Ocean
Increased heat transport from Pacific Ocean to Indian Ocean

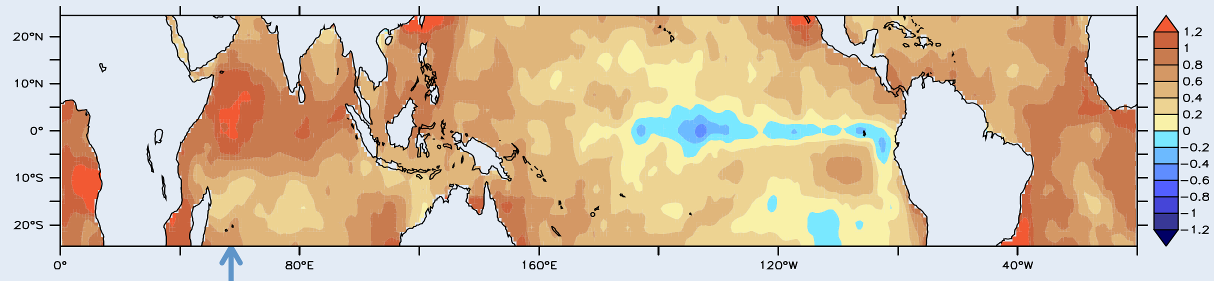


Indian Ocean heat content has increased abruptly, which accounts for more than 70% of the global ocean heat gain in the upper 700 m during the past decade.

Lee et al. *Nature Geosciences*, 2015

Indian Ocean during the last century
western Indian Ocean warmed up to 1.2degC, in 100 yrs

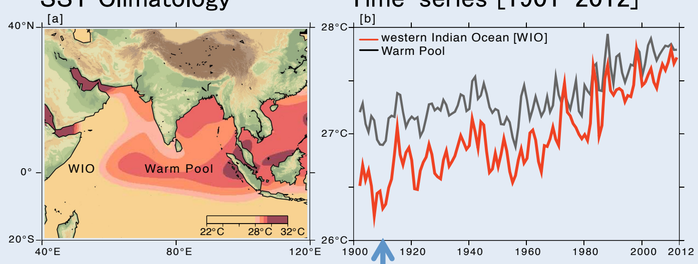
SST trend



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

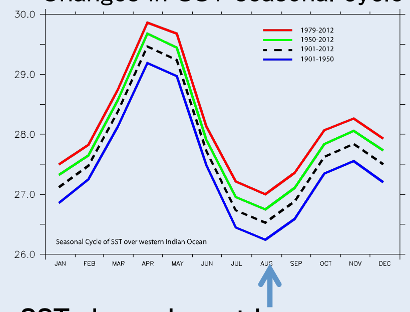
SST Climatology

Time-series [1901-2012]



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

Changes in SST seasonal cycle

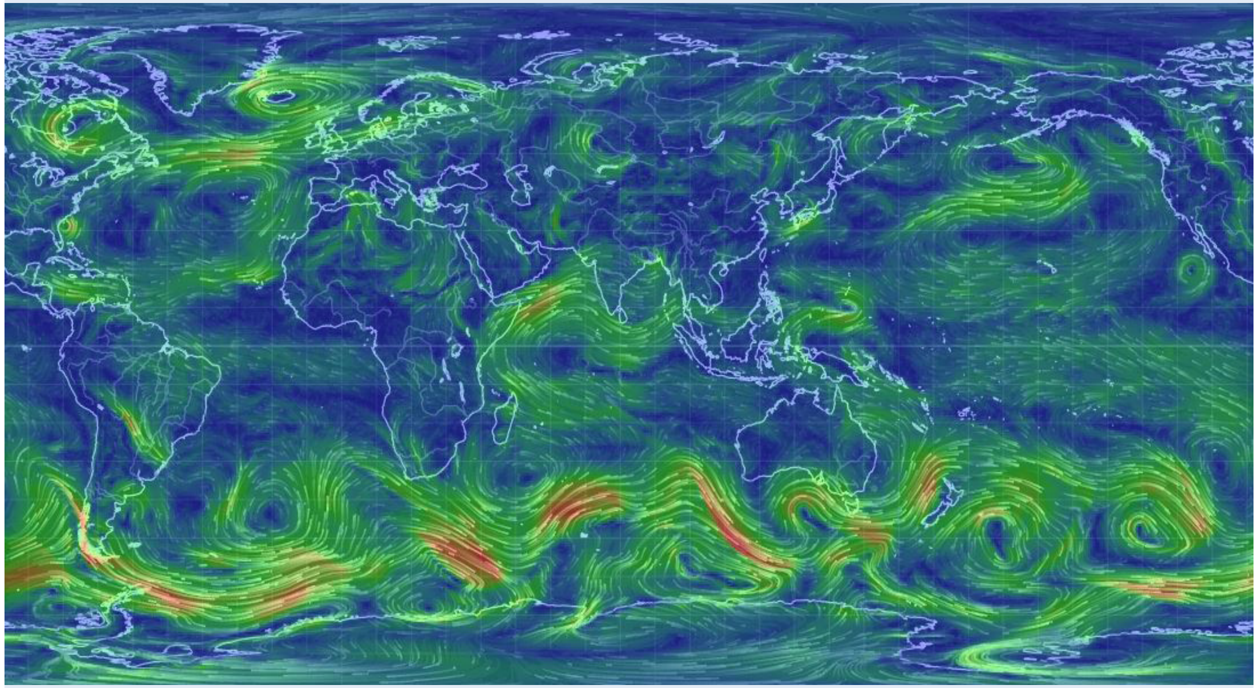


SST change largest in summer

Roxy et al. *J.Climate*, 2014

Pacific-Indian Ocean teleconnection during summer

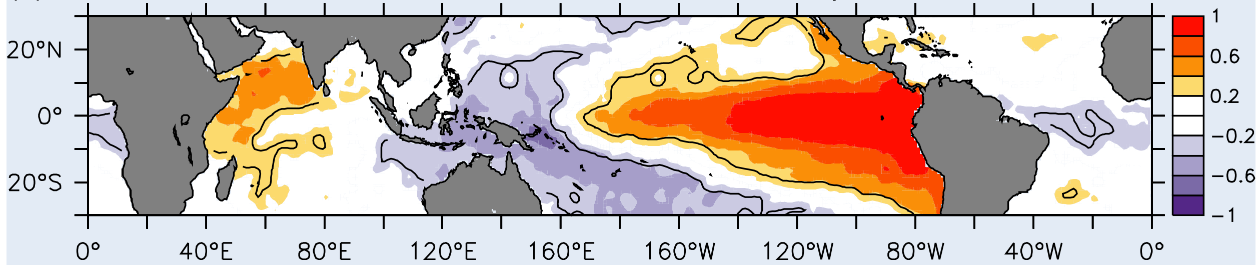
Walker Circulation

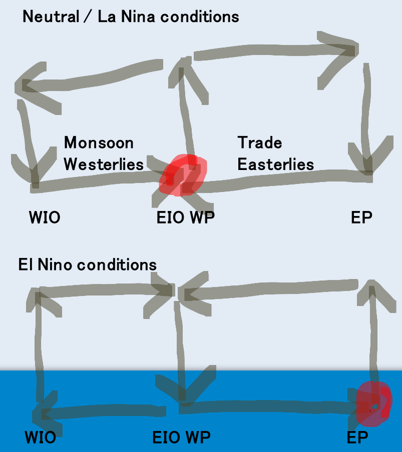


Pacific-Indian Ocean teleconnection during summer

Walker Circulation

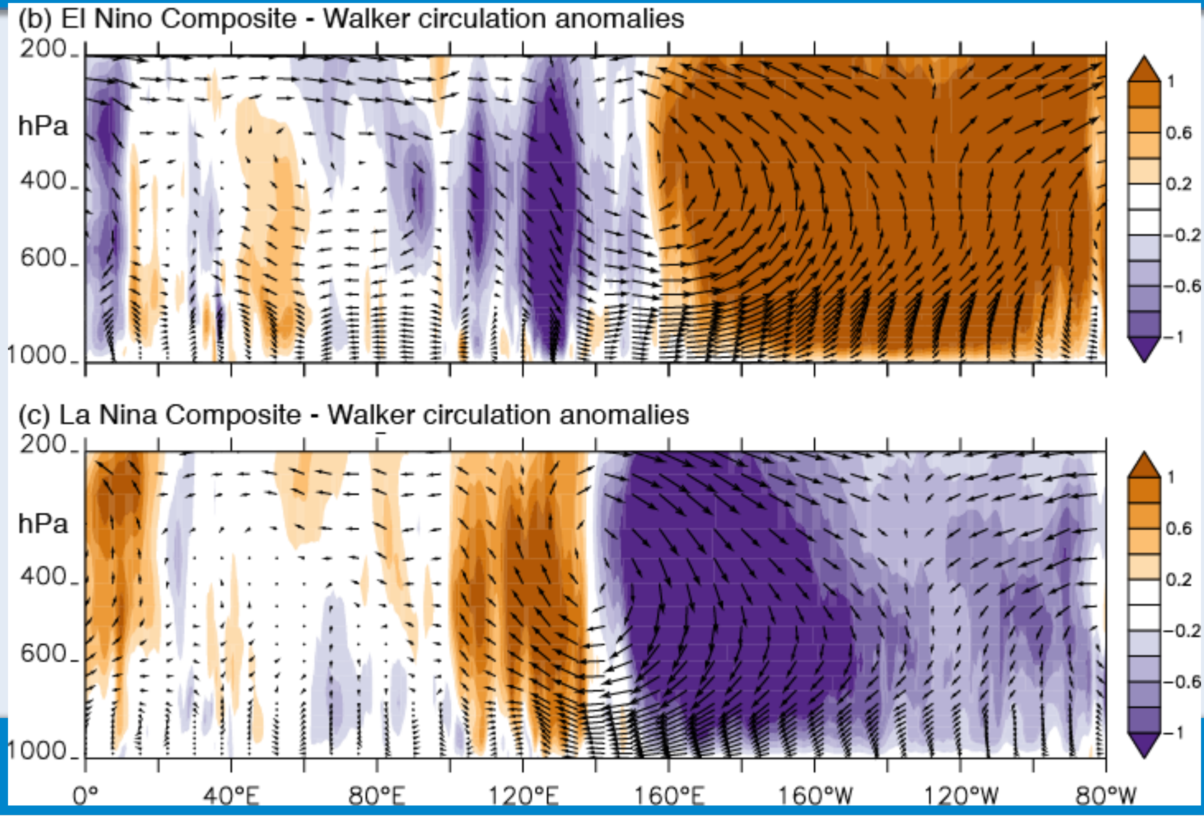
(a) Correlation: east Pacific SSTa vs Global SSTa, June-Sept mean





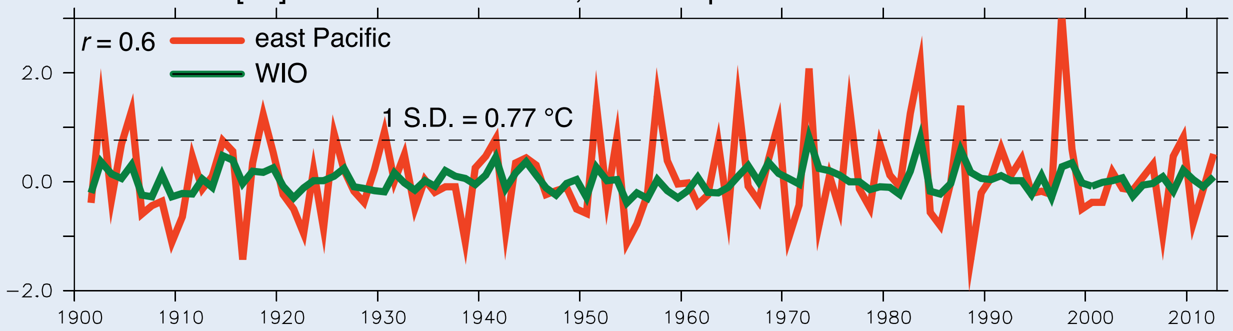
Asymmetry in ENSO forcing

Influence of El Niño > La Niña



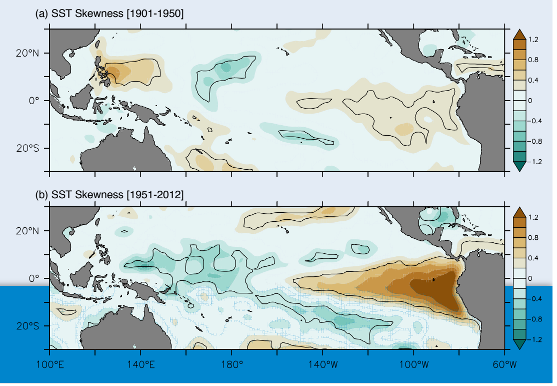
Skewness in El Niño forcing
Increase in Frequency and Magnitude of El Niños

SST anomalies [°C]: east Pacific vs WIO, June-Sept mean



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).

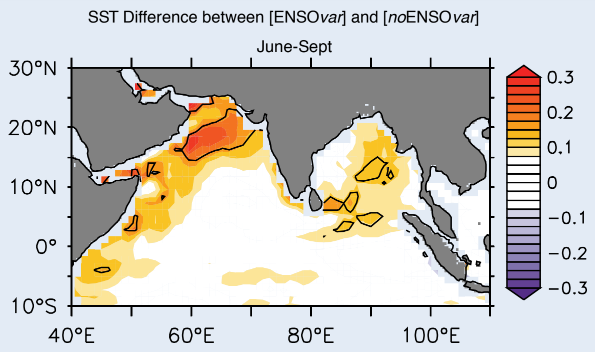
Positive skewness over east Pacific in recent decades >>



Roxy et al. *J.Climate*, 2014

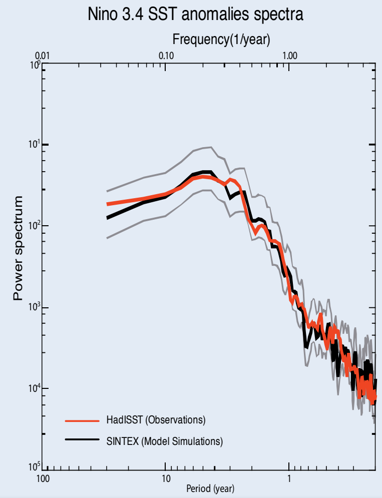
Indian Ocean warms without greenhouse gas forcing

Simulations (with-without) ENSO variability shows IO warming

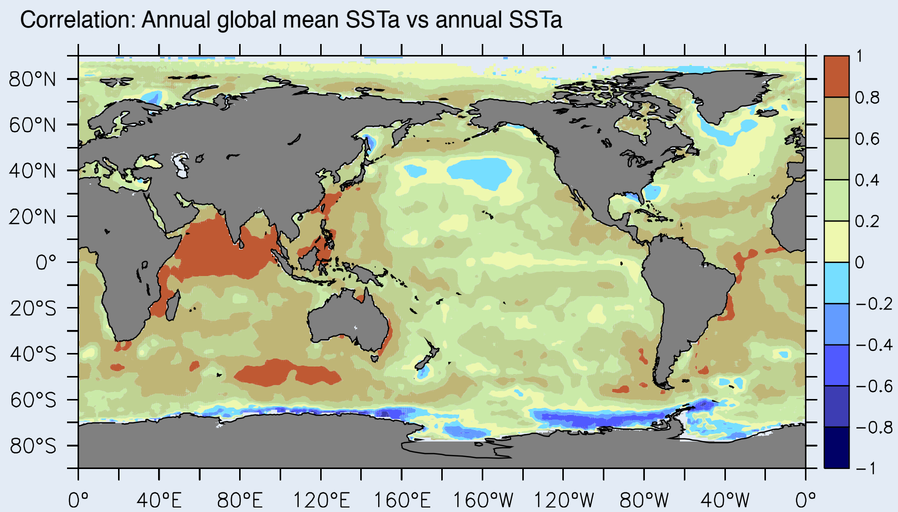


Magnitude of warming without greenhouse gas forcing is weak though

Model simulations using latest SINTEX coupled model with realistic ENSO variability



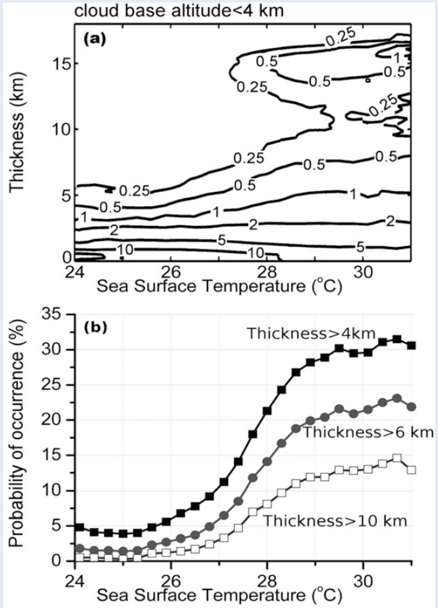
Indian Ocean warming "in phase" with global warming

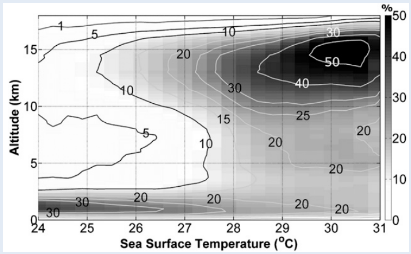


Roxy et al. *J.Climate*, 2014

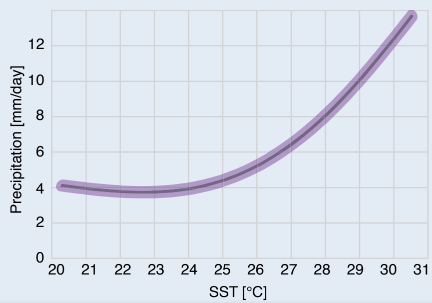
Impact of warming: Changes in Monsoon drivers
Increased ocean warming enhances convection?

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





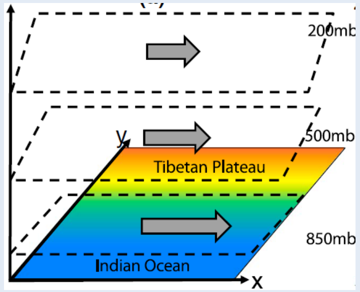
Increased SST enhances precipitation



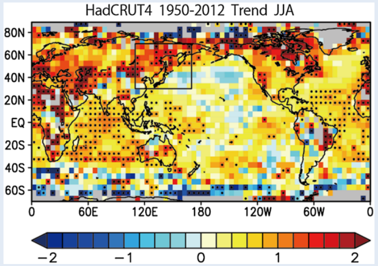
Gadgil et al.,*Nature*, 1984; Roxy,*Climate Dynamics*, 2013; Nair and Rajeev, *J.Climate*, 2013

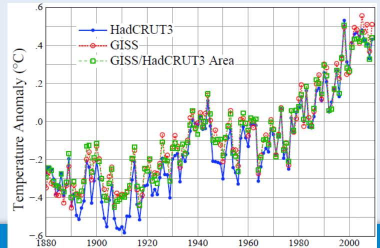
Impact of warming: Changes in Monsoon drivers
Increase in land-sea thermal gradient during past century?

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.

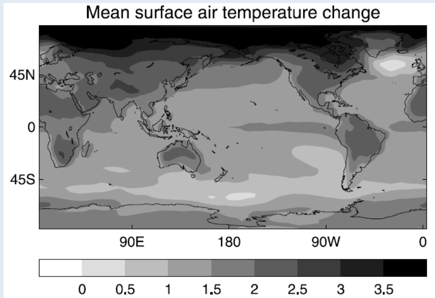


Observations





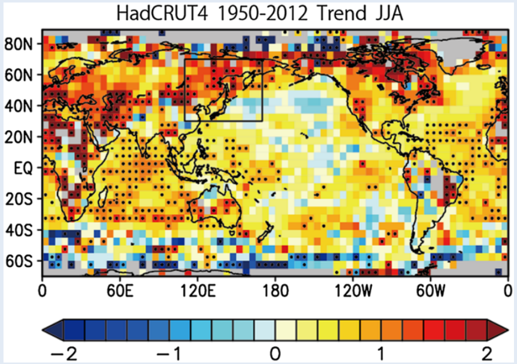
Climate Model response to CO_2 forcing (IPCC AR4 Ensemble)



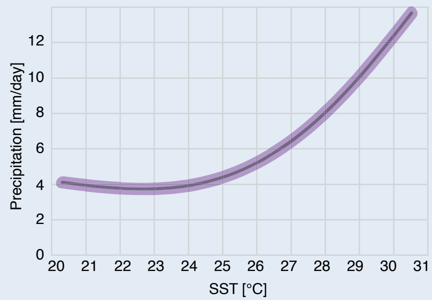
Sutton et al. *GRL*, 2007; Hansen et al. *Rev.Geophys*, 2010

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

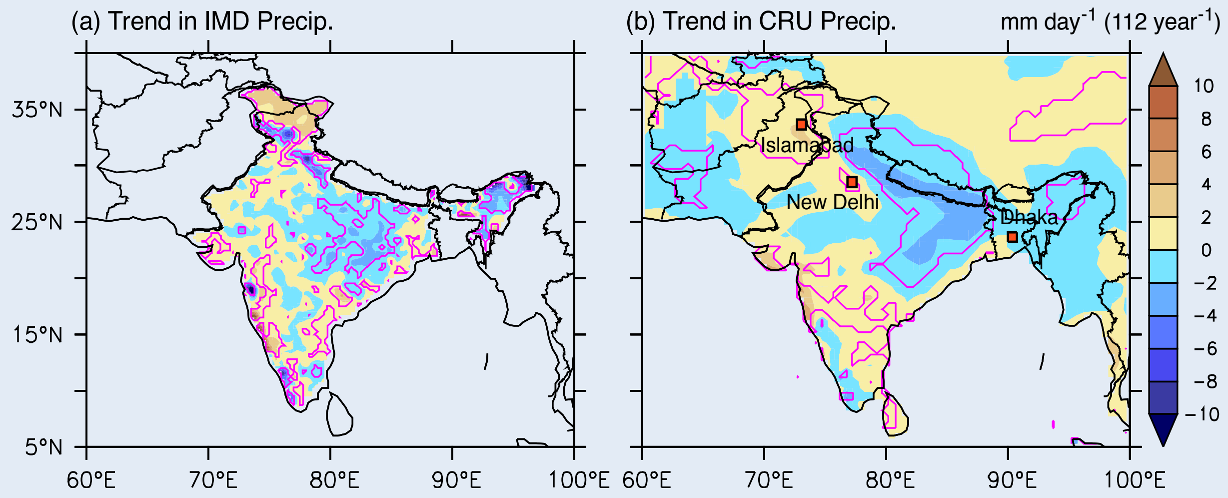
Increased land–sea thermal contrast



Increased ocean warming



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

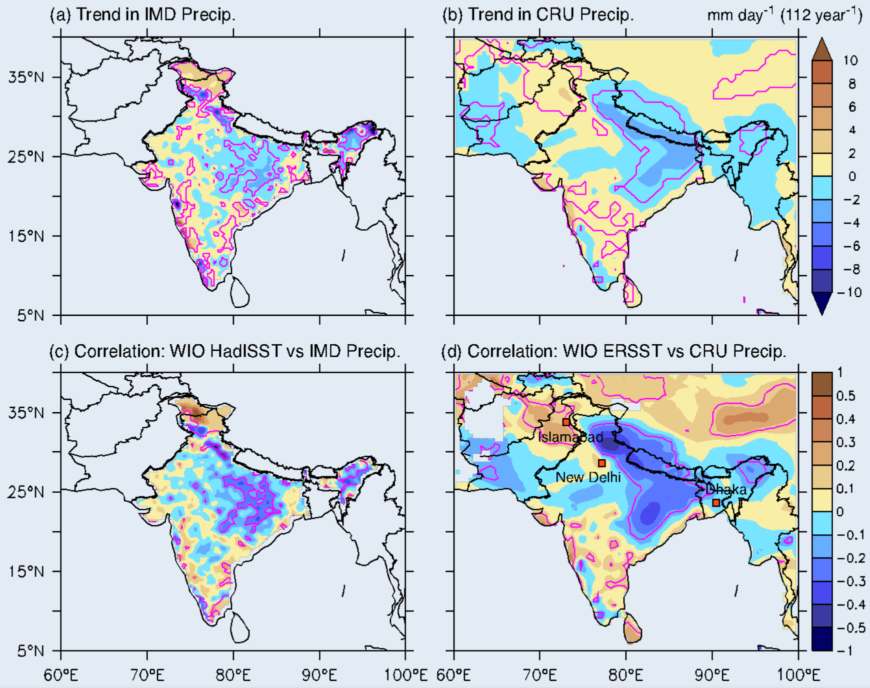


Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)

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.



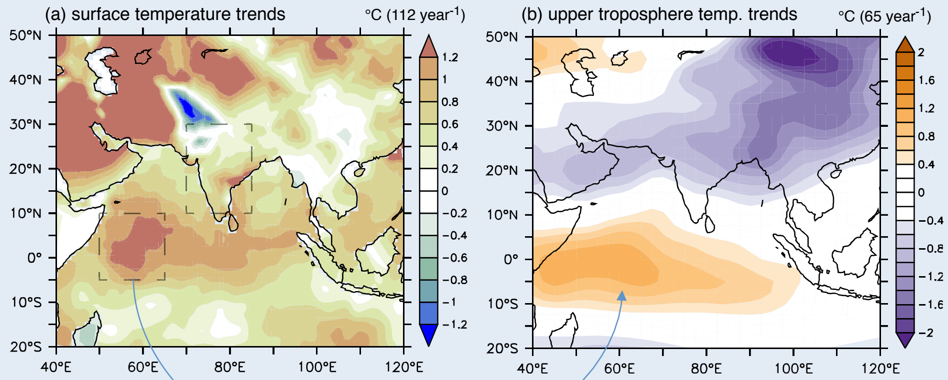
(a) & (b)
Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)

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

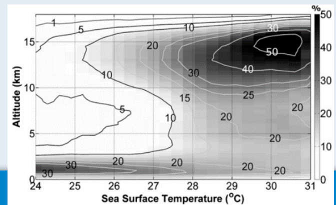
Land-sea thermal contrast over South Asian domain

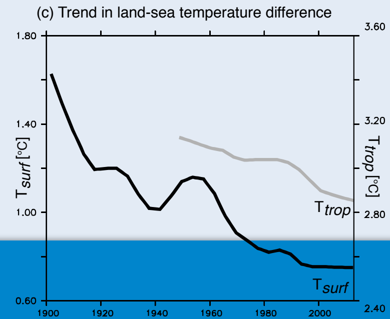
Indian Ocean–large warming, Subcontinent–suppressed warming

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

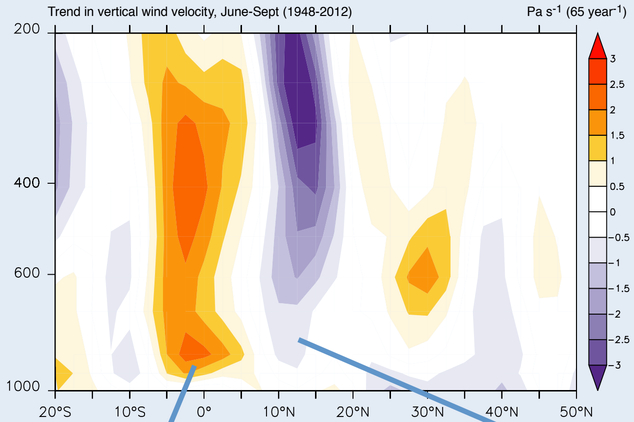


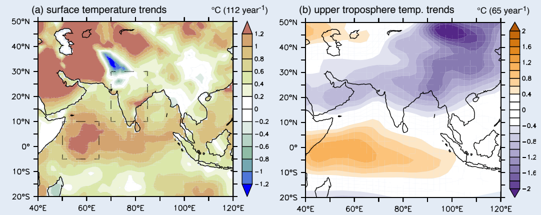


Roxy et al. *Nature Communications*, 2015

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

Observations: trend in vertical velocity (1948–2012)





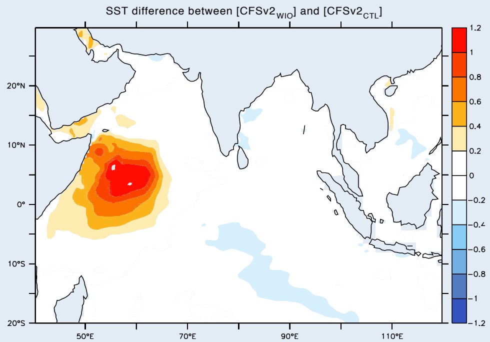
WIO warming extends the warm pool, and increases ocean convection

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

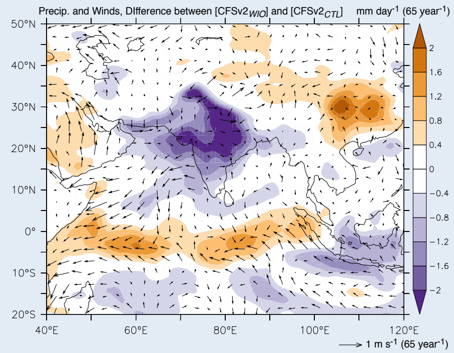
Compensated by subsidence of air over the subcontinent (10–20N), inhibiting convection over the landmass and drying the region.

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

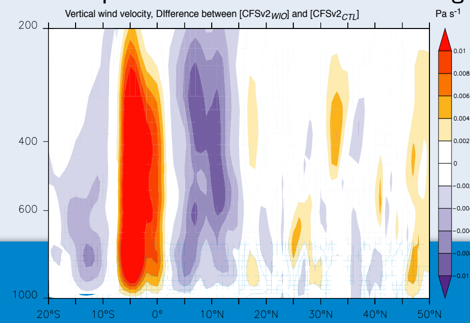
Model simulated warming of WIO



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

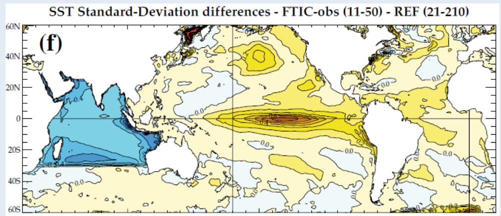
Indian Ocean warming may dampen the El Niño

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

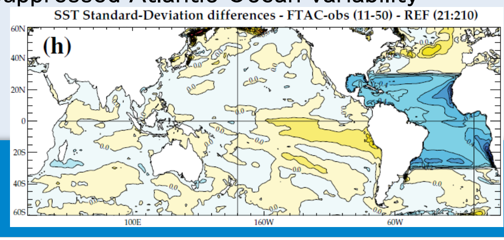
Name	REF	FTIC	FTIC-obs	FTAC	FTAC-obs
Correction area	None	Indian Ocean 30°E–120°E 25°S–30°N	Indian Ocean 30°E–120°E 25°S–30°N	Atlantic Ocean 100°W–20°E 25°S–25°N	Atlantic Ocean 100°W–20°E 25°S–25°N
Smoothing area	None	30°S–25°S	30°S–25°S	30°S–25°S 25°N–30°N	30°S–25°S 25°N–30°N
SST data	None	REF	AVHRR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

Suppressing the Indian Ocean SST variability increased the ENSO strength.

Suppressed Indian Ocean variability

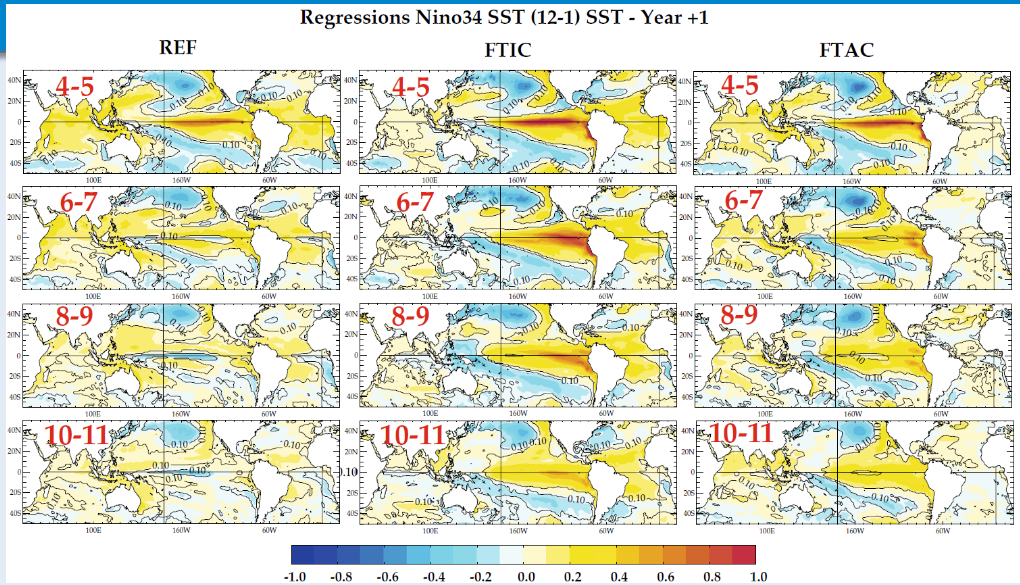


Suppressed Atlantic Ocean variability



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. increased Indian Ocean SST variability 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

Teleconnections between tropical Indian and Pacific Oceans —in relation to Indian Ocean warming

Indian Ocean warming:

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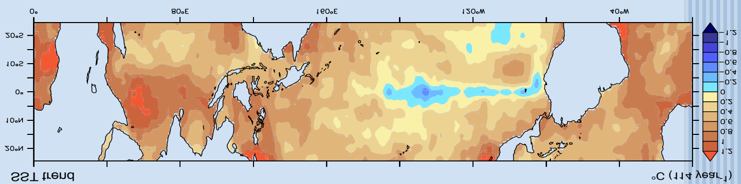
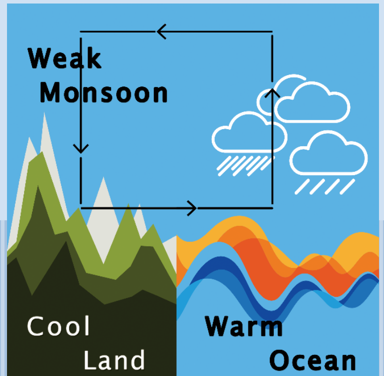
- Links to asymmetry/skewness in ENSO forcing





Potential Impacts:

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

Thank You !