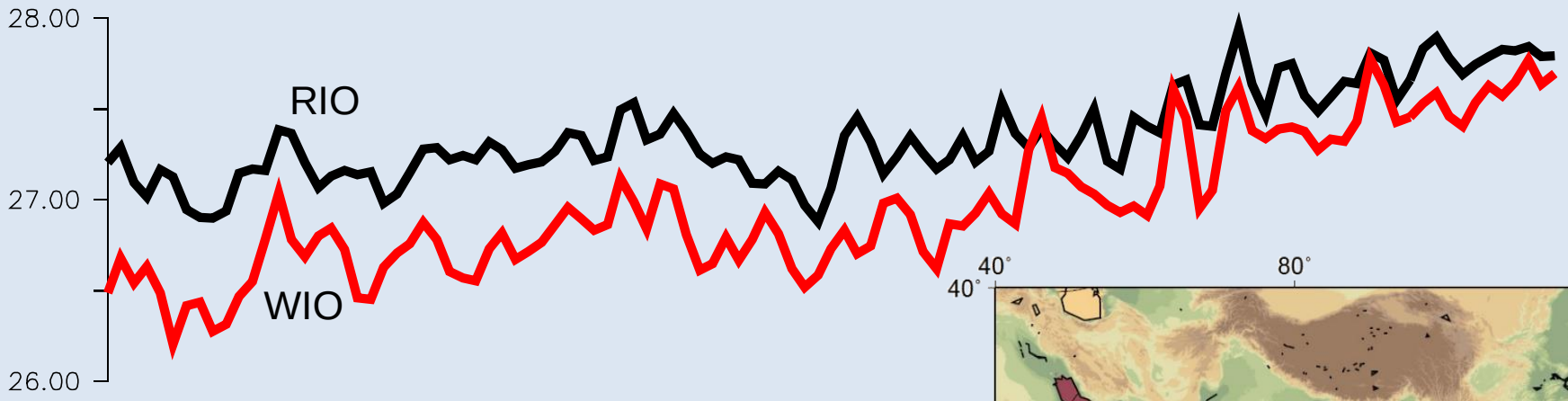
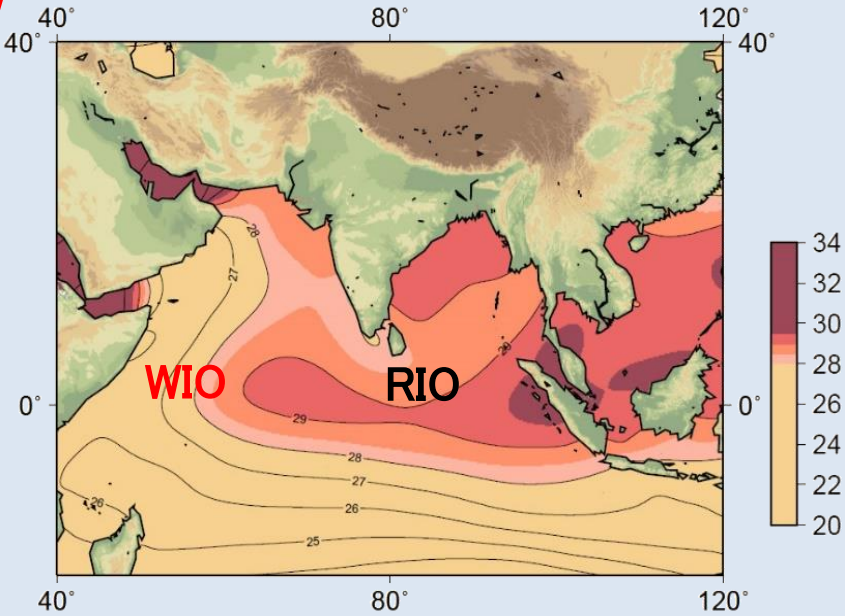
Long-term warming trend over the Indian Ocean





1. **Western Indian Ocean experienced strong, monotonous warming during the last century**
2. **Links to asymmetry and skewness in ENSO forcing**
3. **Strong influence on monsoon trends**

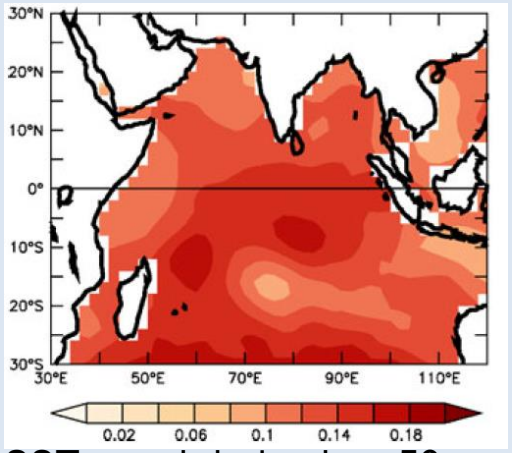
Data:

SST: HadISST, ERSST, HadMAT (marine-nighttime)
Precip: IMD, CRU
Other parameters: ERA-Interim, NCEP Reanalysis
Coupled Models: NCEP-CFSv2, SINTEX-F2, CMIP5

Roxy M. K., K. Ritika, P. Terray and S. Masson
Indian Institute of Tropical Meteorology, Pune

Indian Ocean warming - background

Basin-wide / Warm-pool warming in recent years



SST trend during last 50 yrs

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

Suggested cause: Apart from greenhouse warming,
Weakening winds causing warming trends
Warm SST weakening the winds which in turn warm SST again

Warm-pool enlargement in recent years

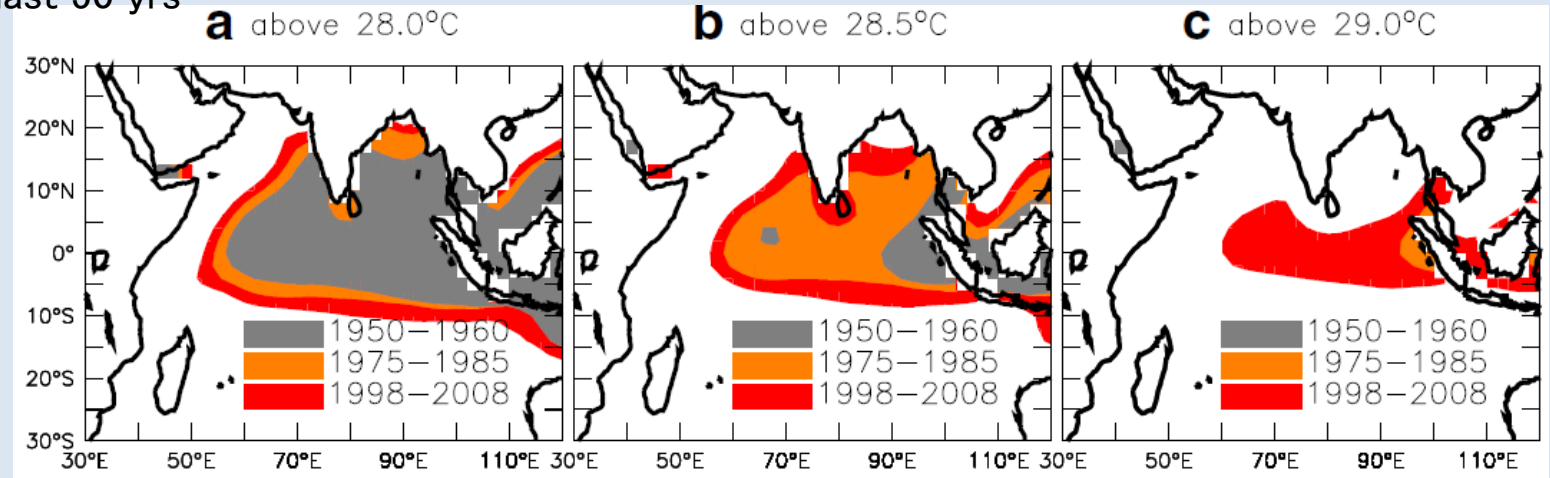
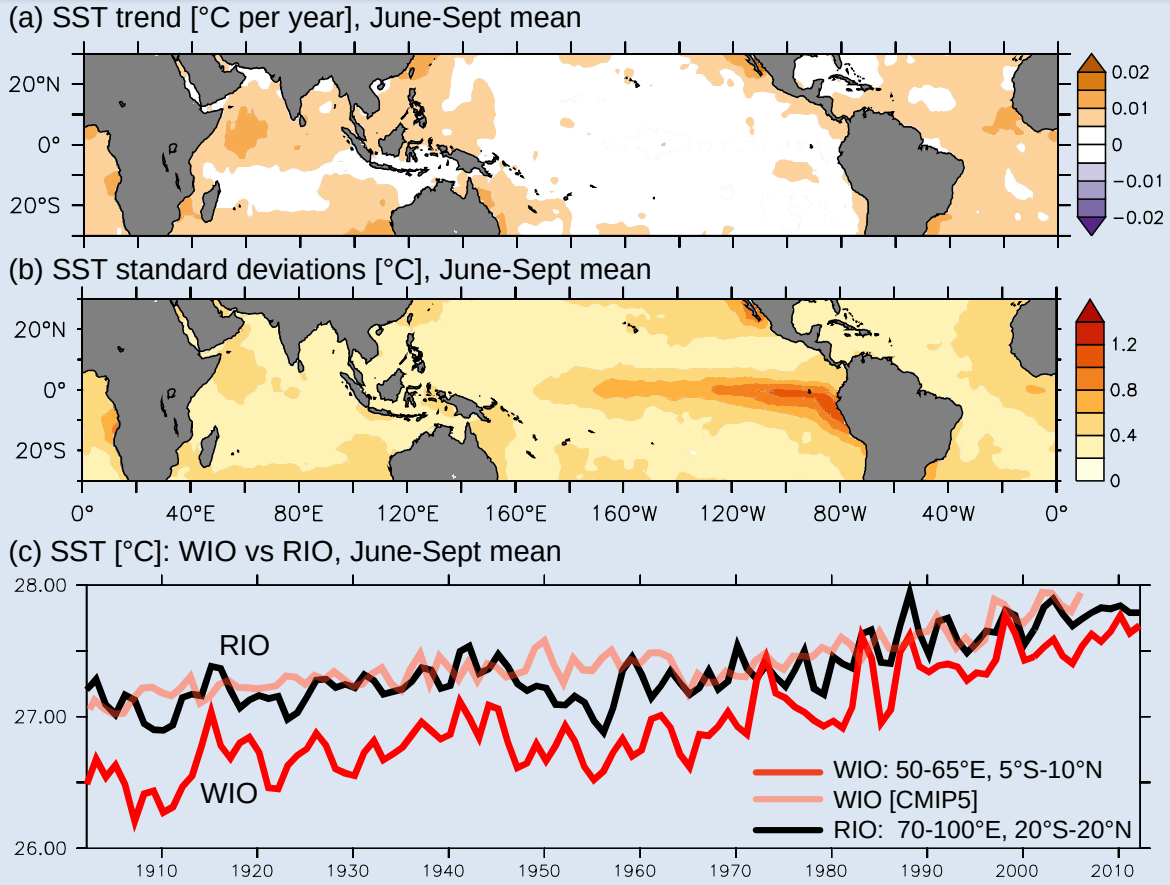


Fig. 2 Warm pool area during 1950–1960, 1975–1985, 1998–2008 with SST **a** above 28.0°C, **b** above 28.5°C and **c** above 29.0°C

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

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

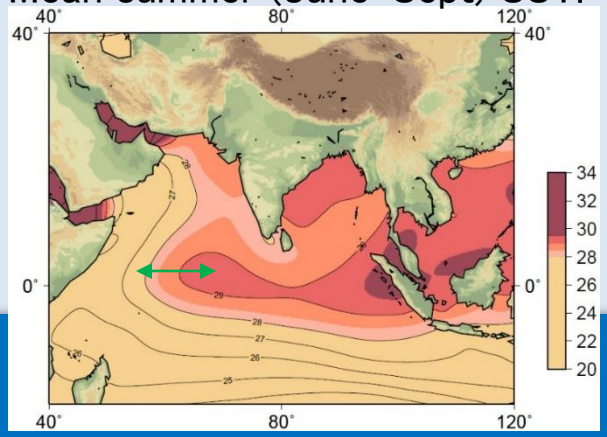


a) Basin-wide warming over the Indian Ocean with enhanced, **significant warming over western Indian Ocean.**

b) The **western region has largest interannual variability** over Indian Ocean. Warming here might influence monsoon dynamics!

c) In early 1900s, the western Indian Ocean was much cooler than the warm-pool. The monotonous **warming over west nullifies zonal SST gradient** – may influence monsoon dynamics.

Mean summer (June-Sept) SST:

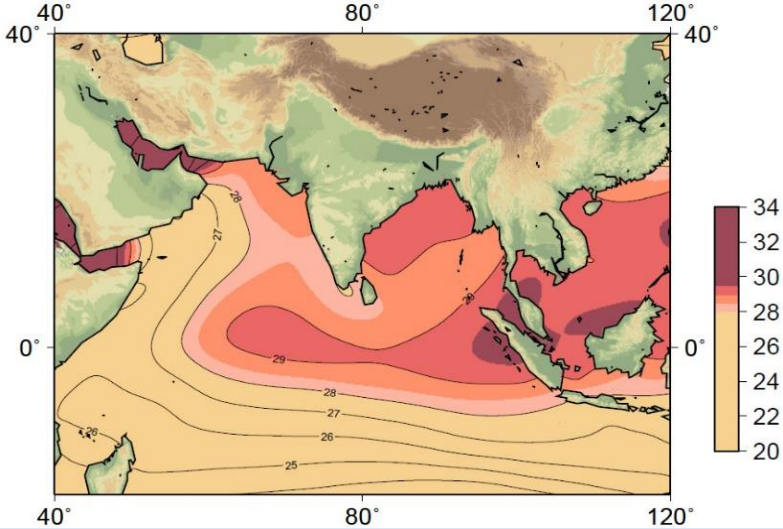


The historical simulations with CMIP5 models do not reproduce the WIO warming (light pink color), which means that apart from direct radiative forcing due to greenhouse warming, other unaccounted mechanisms might be responsible (eg: ENSO variability)

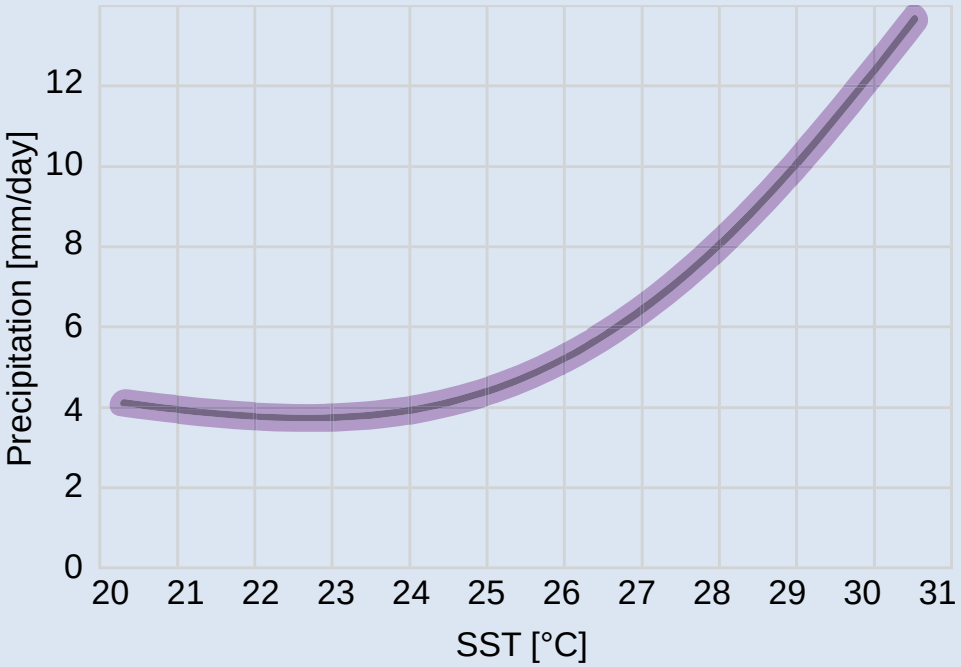
Roxy et al. *J.Climate*, 2014, *Under Review*

SST > 28degC = enhanced convection

Mean summer (June–Sept) SST:



Significant increase in precipitation with respect to higher SSTs.

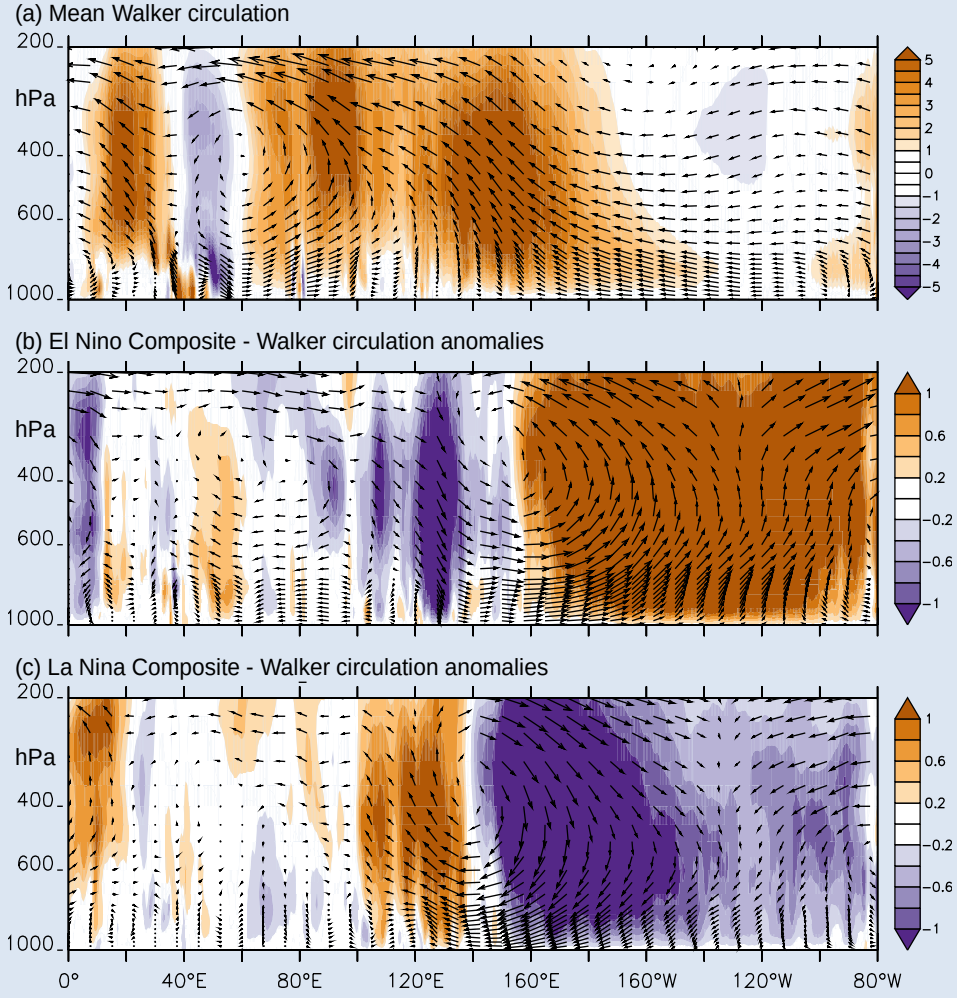


SST–precipitation relationship when the lag is considered

Gadgil et al., *Nature*, 1984; Roxy, *Climate Dynamics*, 2013

Asymmetry in ENSO forcing

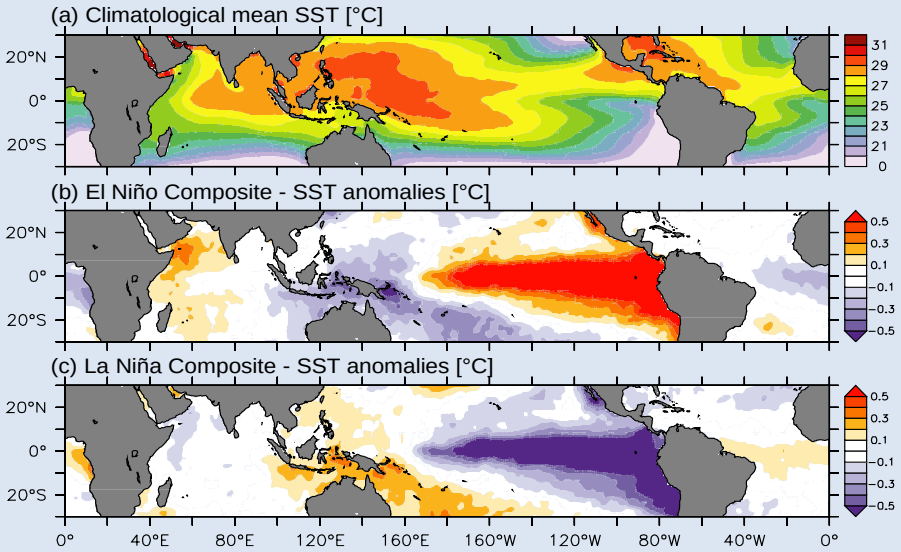
Influence of El Niño > La Niña



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

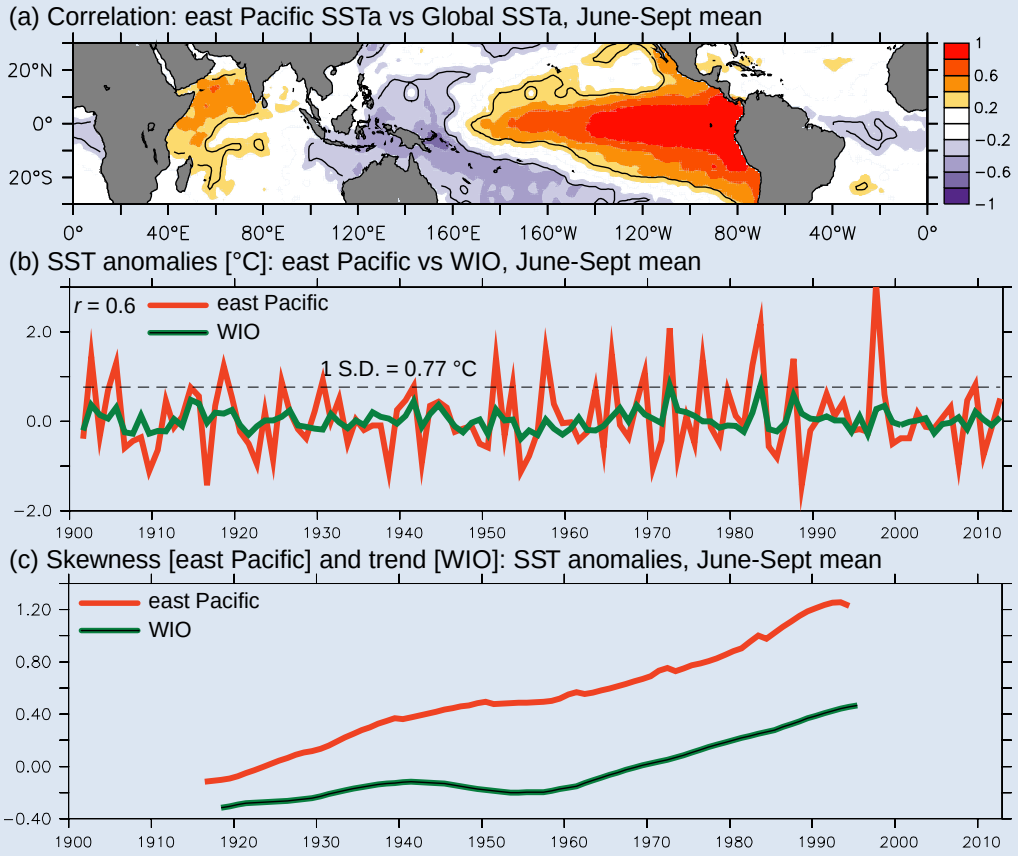
but...

La Niña events does not result in significant anomalies over the Indian Ocean

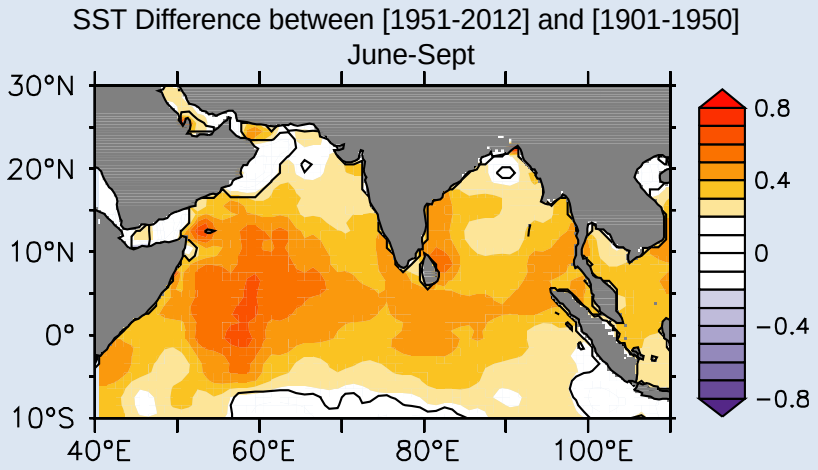


Skewness in El Niño forcing

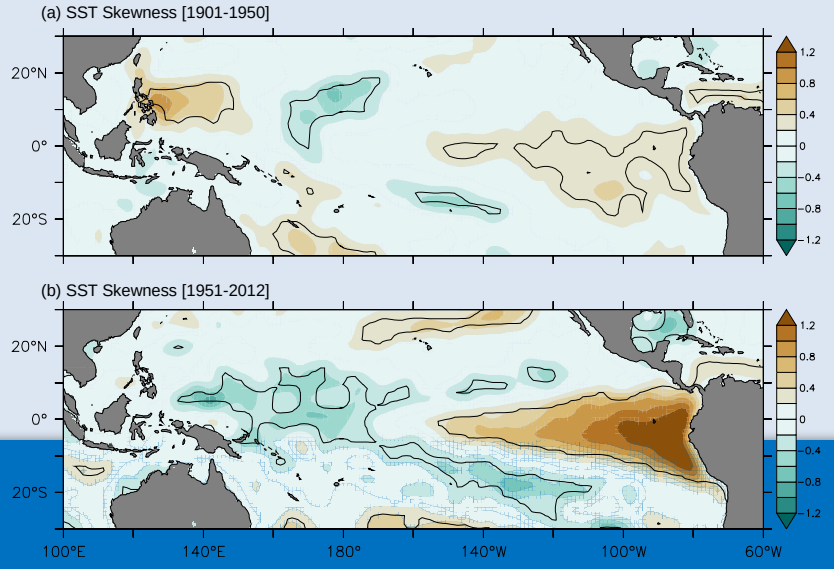
Increase in Frequency and Magnitude of El Niños



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).

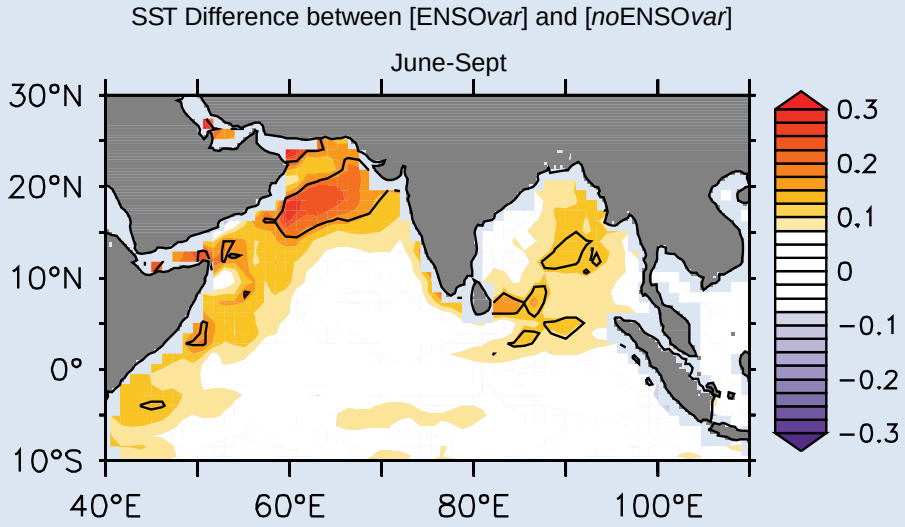


Indian Ocean warming (above) associated with positive skewness over east Pacific (below)



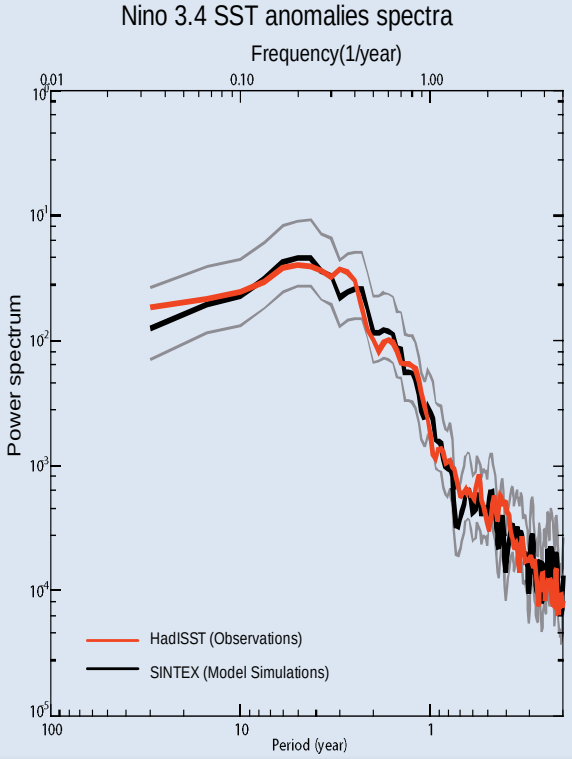
Indian Ocean warms without greenhouse gas forcing

Simulations (with–without) ENSO variability shows IO warming



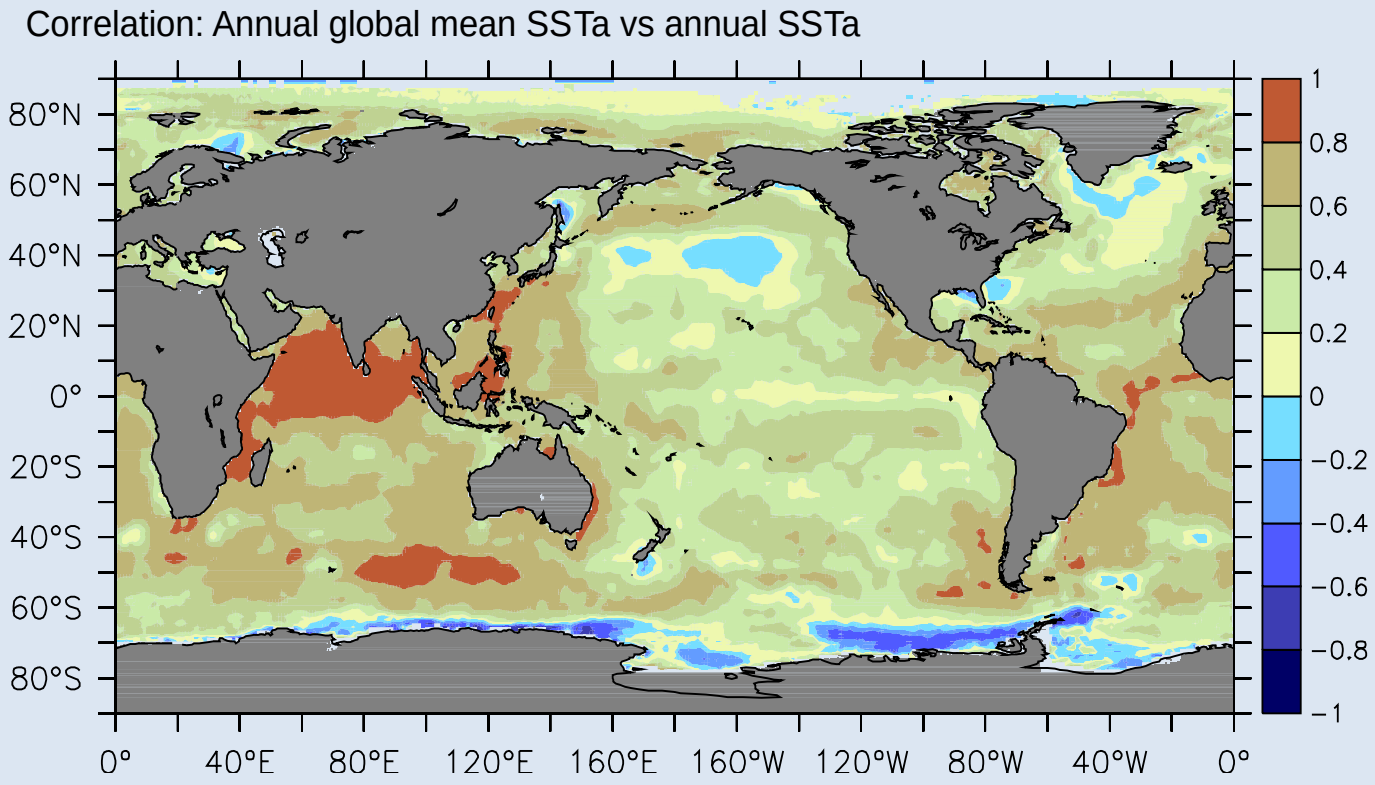
Magnitude of warming without greenhouse gas forcing is weak though

Model simulations using latest SINTEX coupled model with realistic ENSO variability



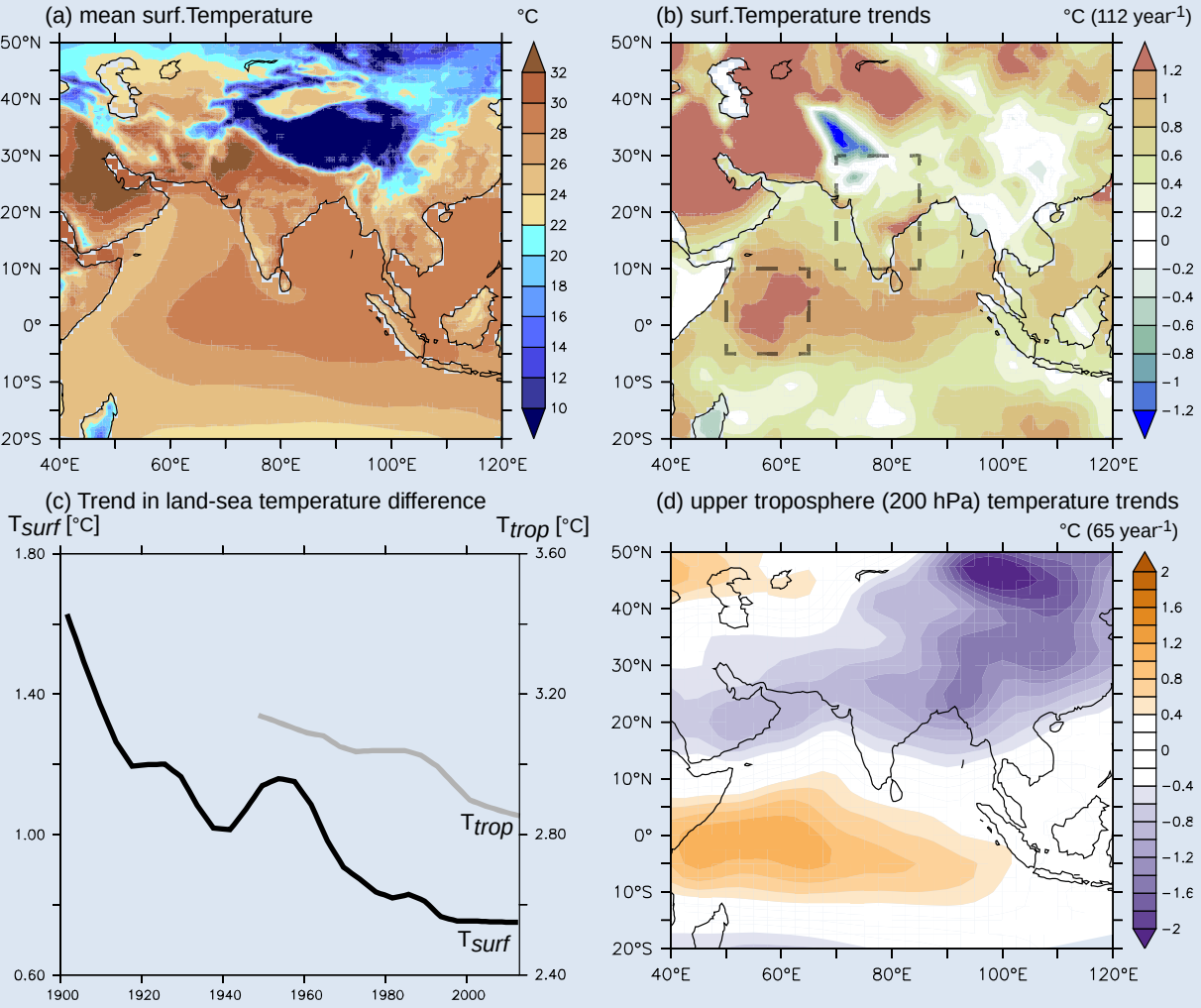
Largest contributor to global warming?

Indian Ocean warming in phase with global warming



Land-sea contrast decrease in the past century

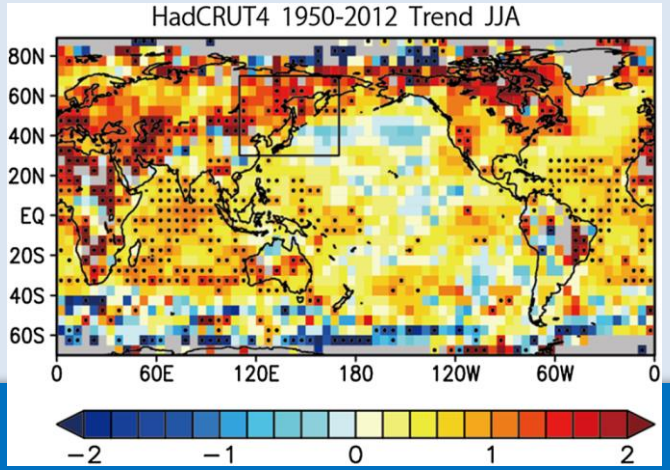
Contradicts model/observations for Northern Hemisphere



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.

The decrease in land–sea contrast reflects in tropospheric temperature gradients also.

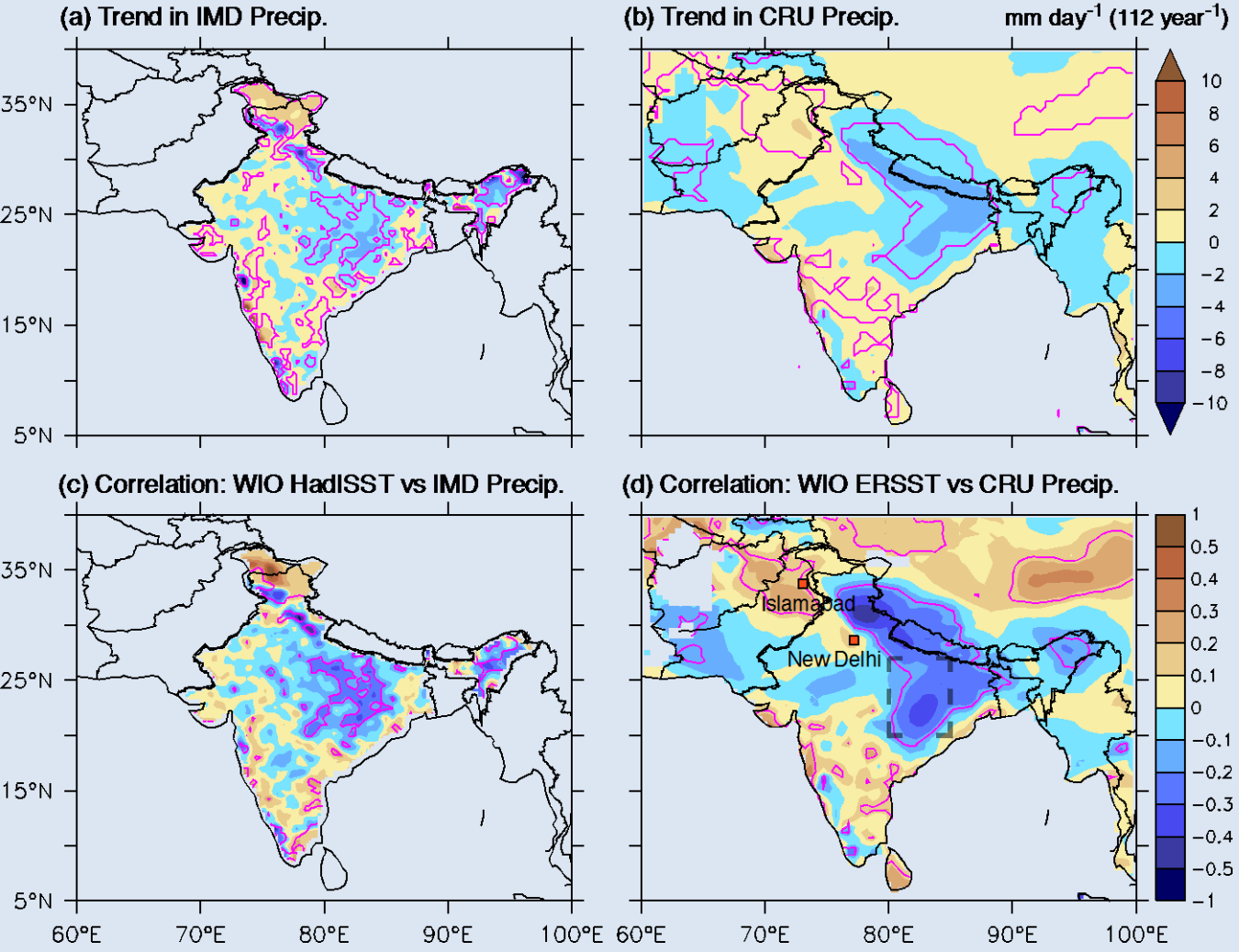
Observations suggest an increase in land–sea contrast over Northern Hemisphere during recent decades



Roxy et al. *Nature Geoscience*, 2014, *Under Review*

Warm Indian Ocean, Weak south Asian Monsoon

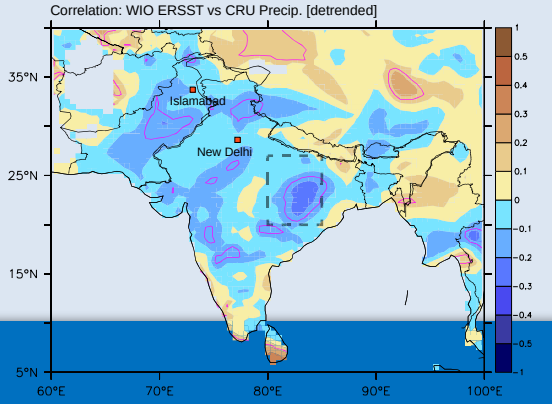
Indian Ocean warming well correlated with weak Precip.



(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!

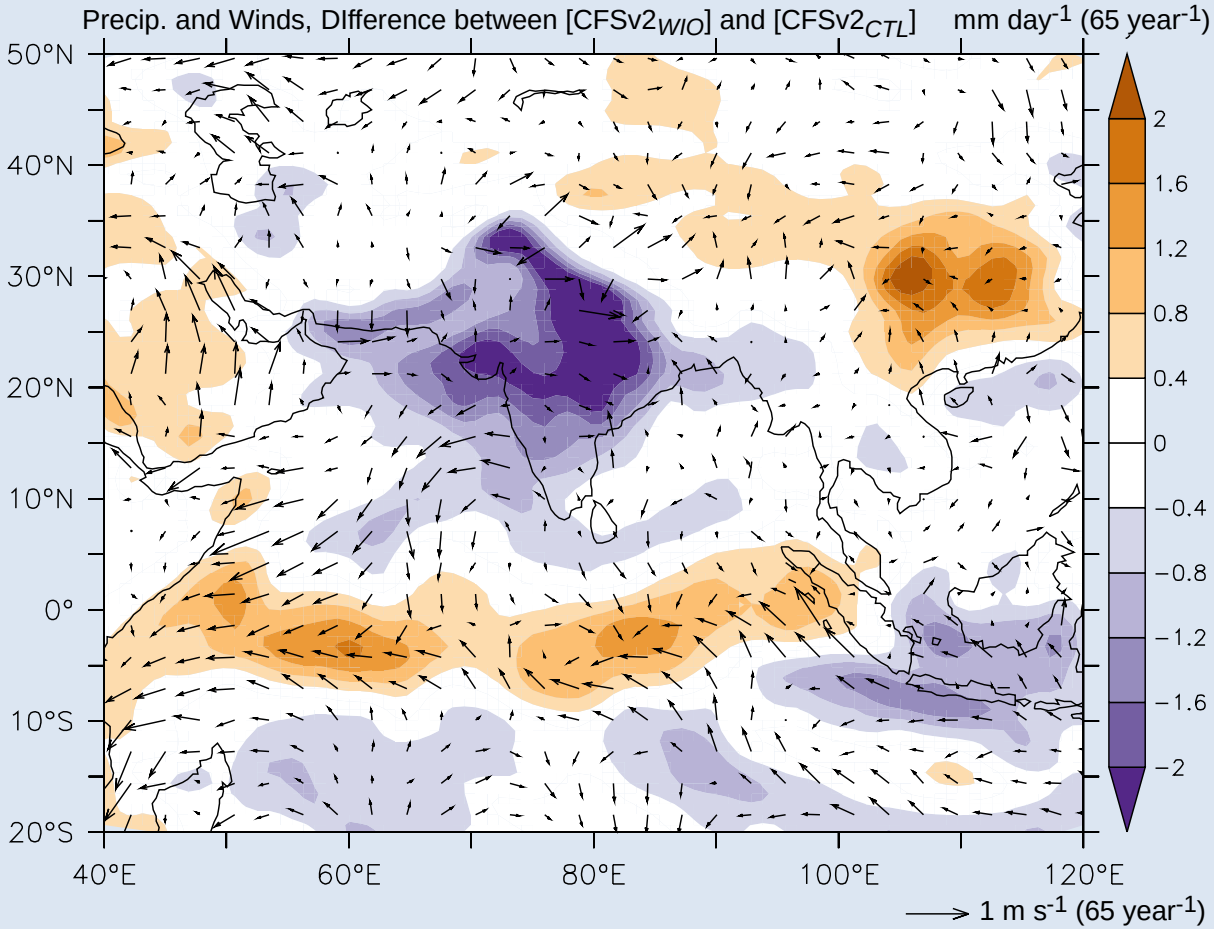
Correlation of detrended anomalies:



Roxy et al. *Nature Geoscience*, 2014, *Under Review*

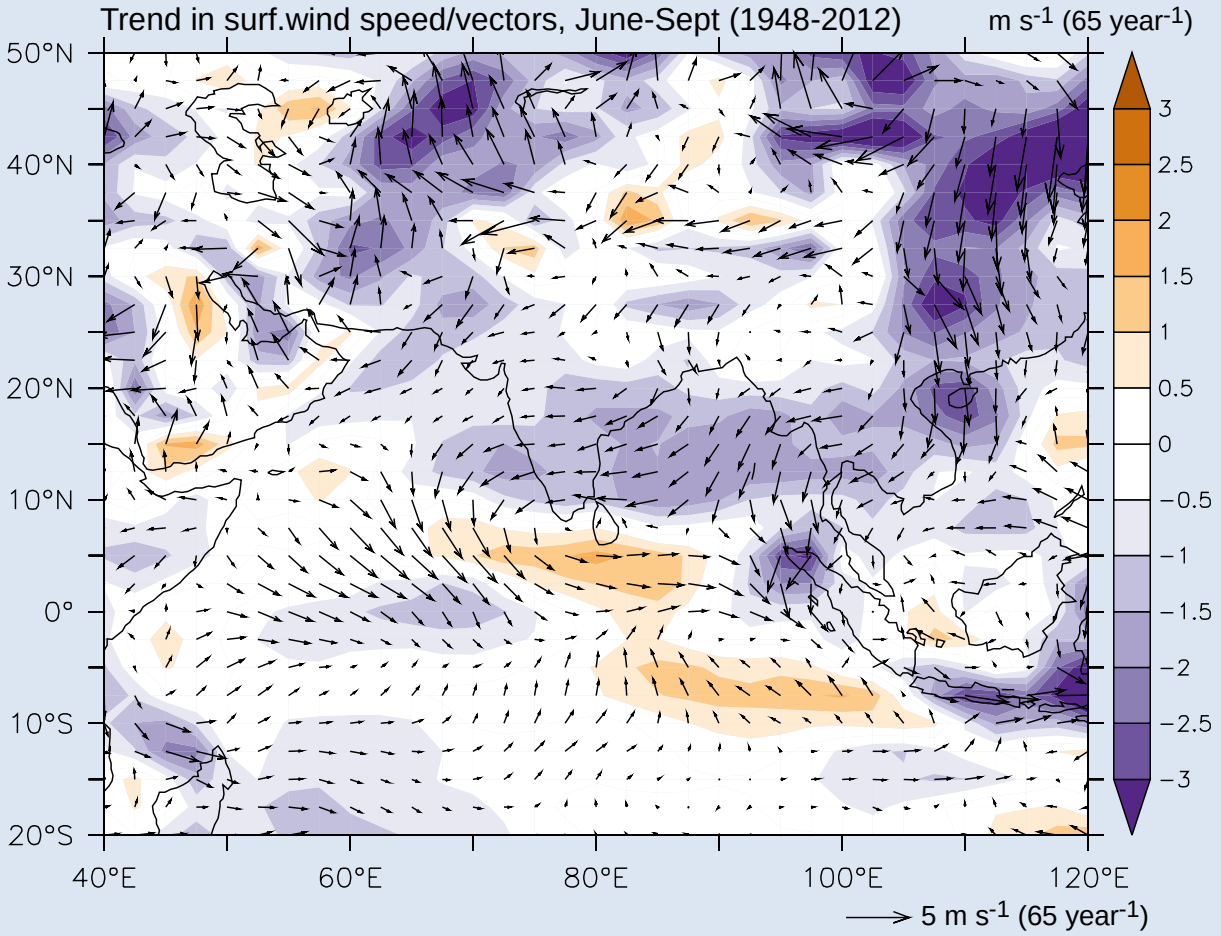
Weakened Monsoon precip/winds due to warming

Model simulations with Indian Ocean warming



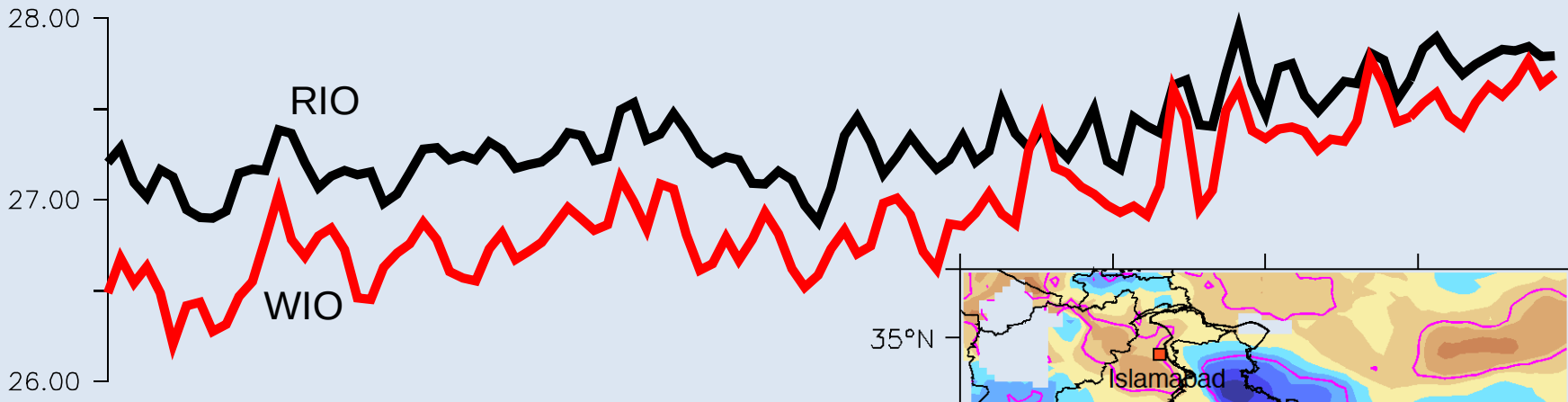
Decreasing rainfall over the south Asian subcontinent:
horse-shoe pattern in model simulations with increased IO warming

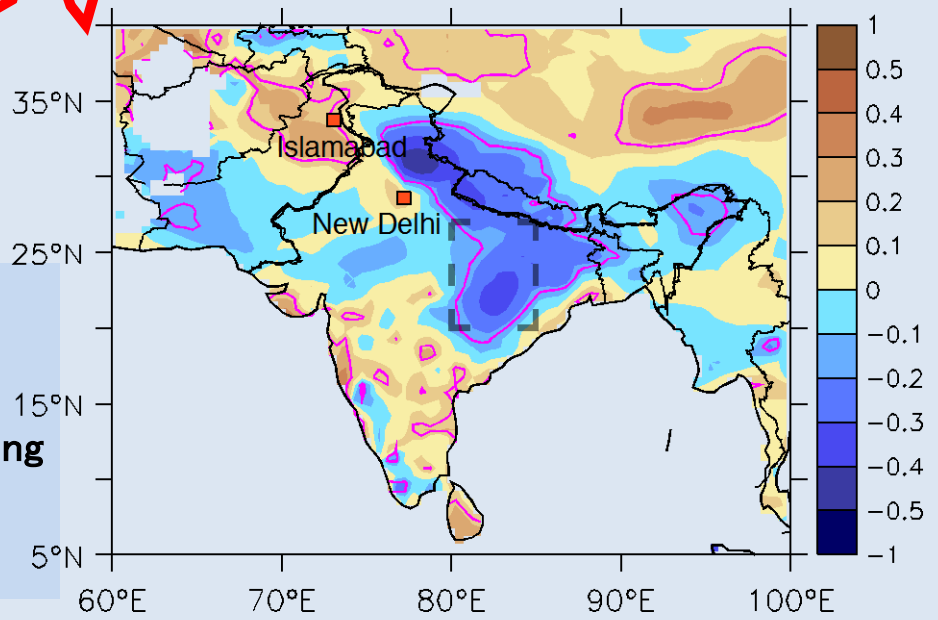
Observations show similar weakening of winds
north–easterly anomalies indicate weak south–westerlies



NCEP reanalysis winds during last 65 years suggest similar weakening of the mean south–westerly monsoon flow.

Long-term warming trend over the Indian Ocean





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