Indian Ocean warming: possible causes, feedbacks and impact

C. Gnanaseelan

Indian Institute of Tropical Meteorology, Pune

Collaborators: S. Rahul, J.S. Deepa

ESM modelling workshop at IITM, 26 July 2016

OUTLINE

Possible mechanisms for Indian Ocean warming

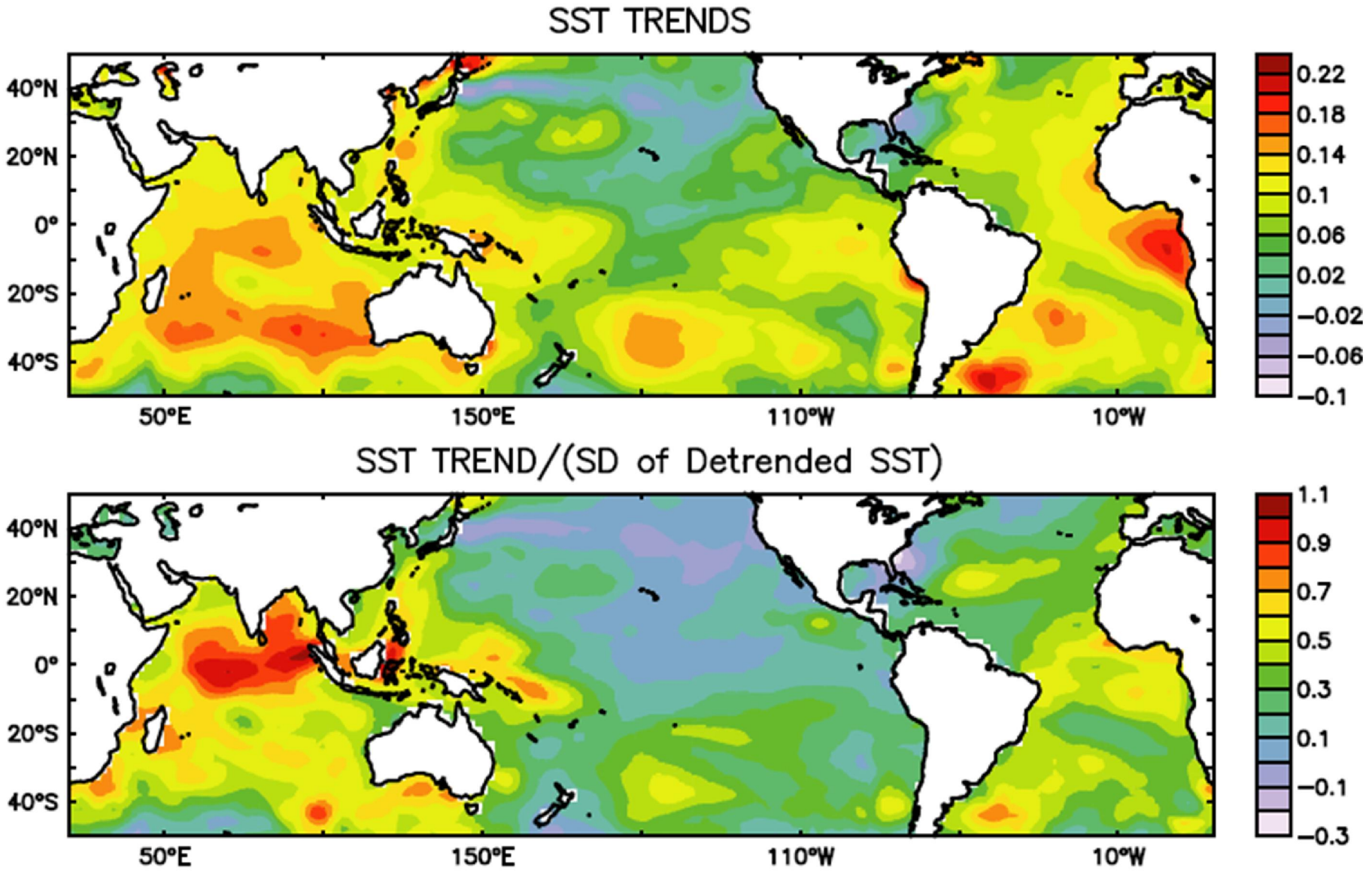
Role of surface circulation changes and its coupled feedback on Indian Ocean warming

Indian Ocean response to the recent global warming hiatus

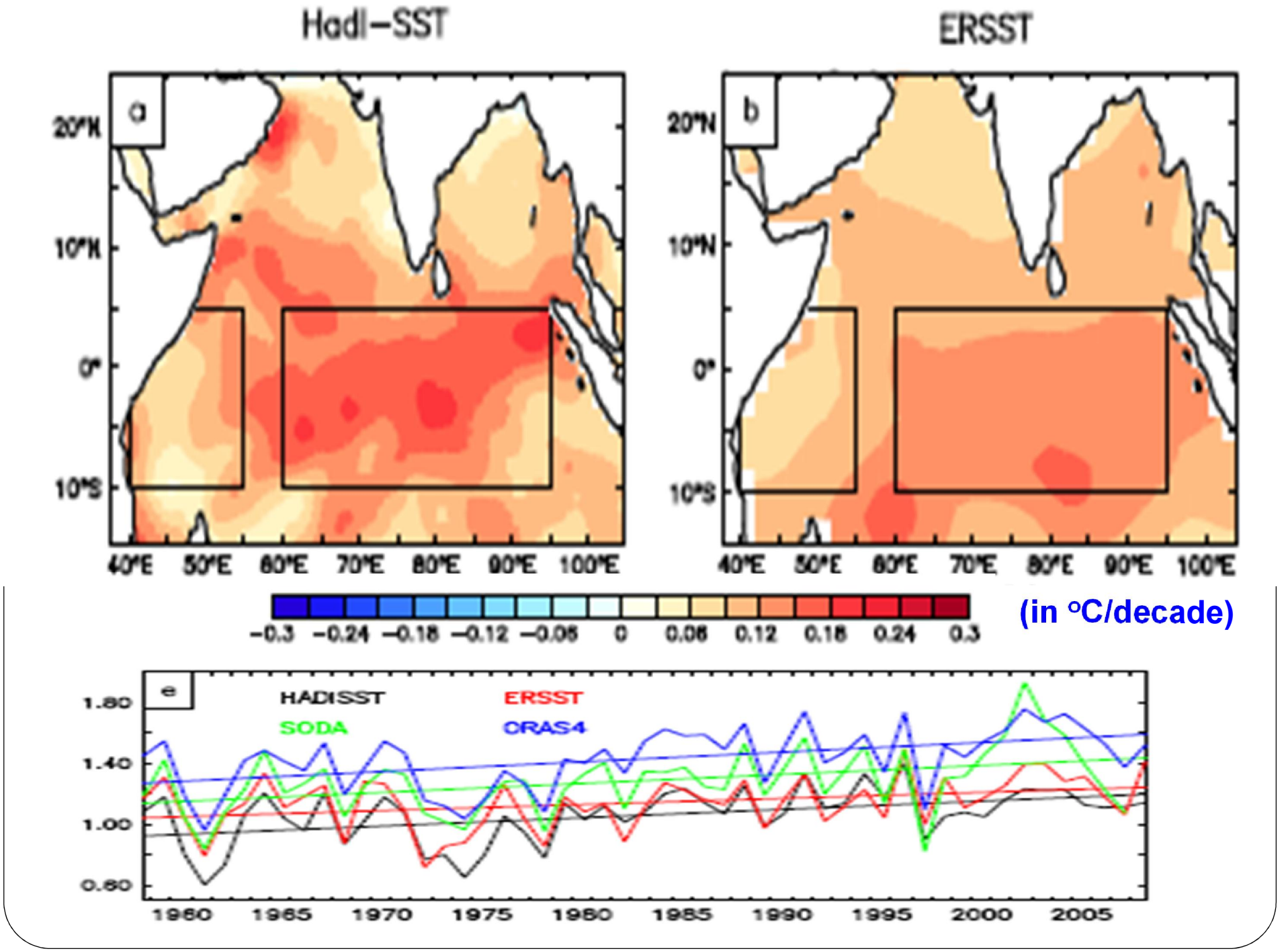
Role of Indonesian Throughflow on the Indian Ocean warming

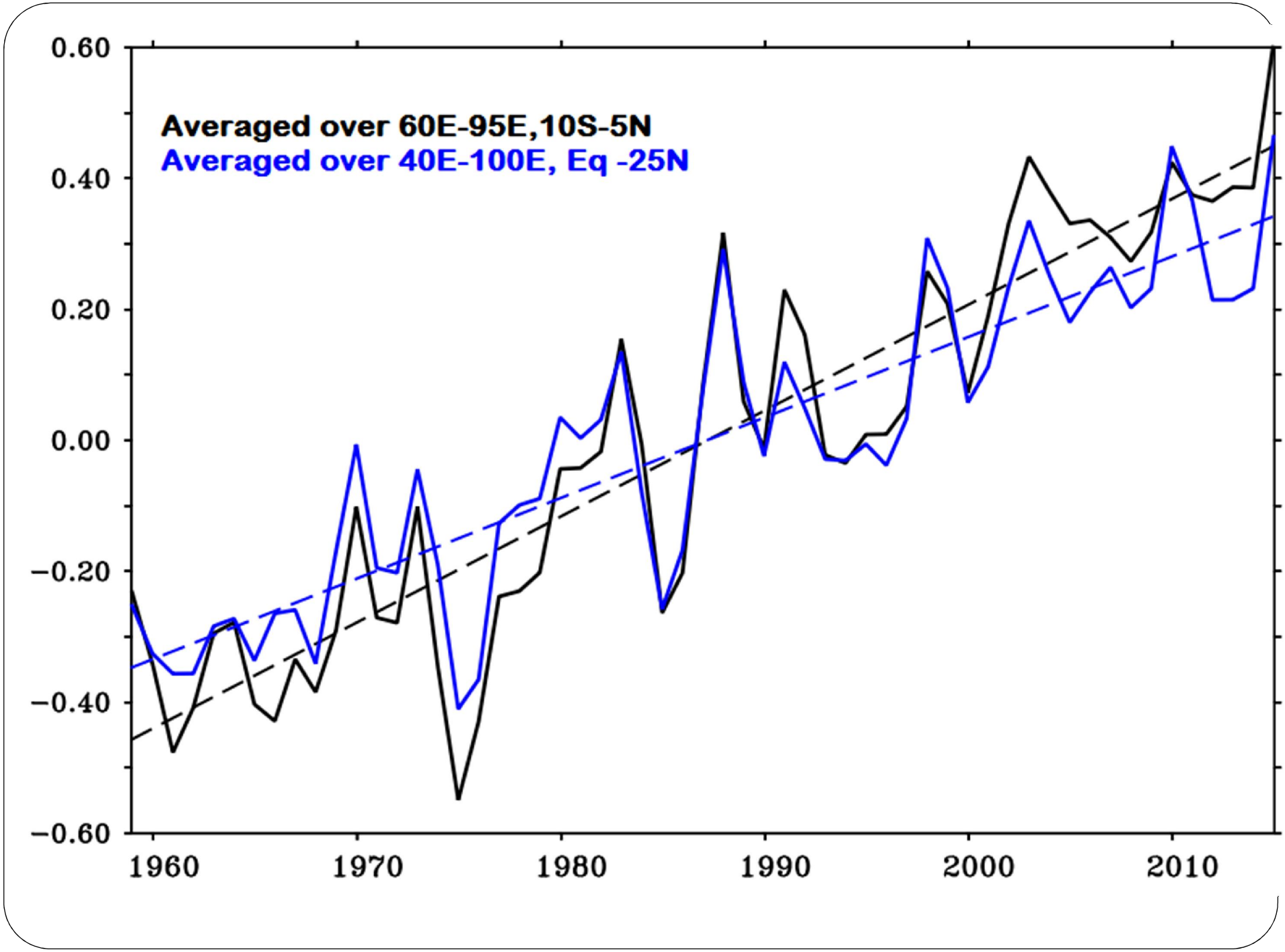
Meridional Overturning circulation on accelerating Indian Ocean warming

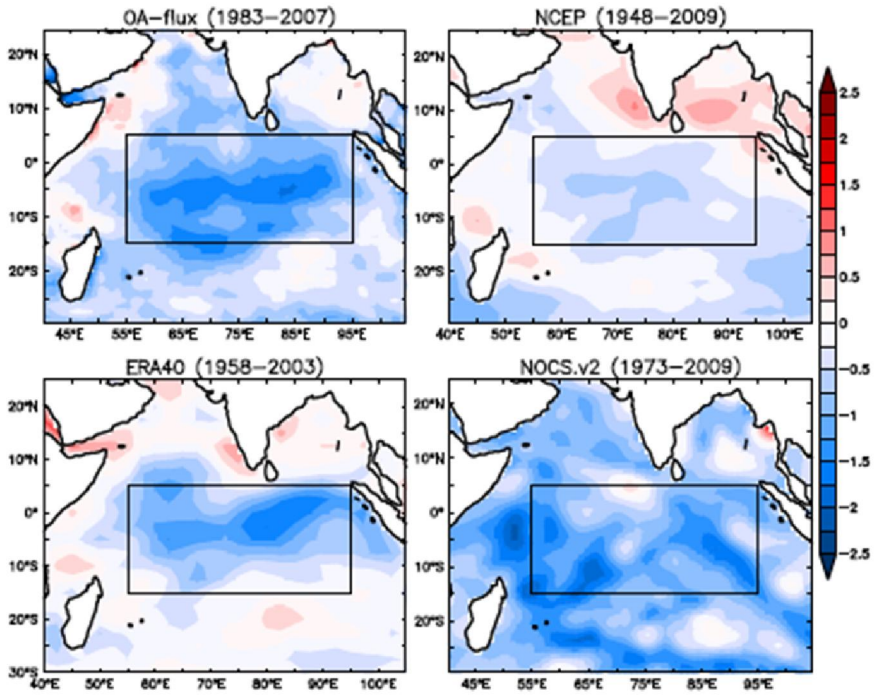
1958 to 2008



(in °C/decade)

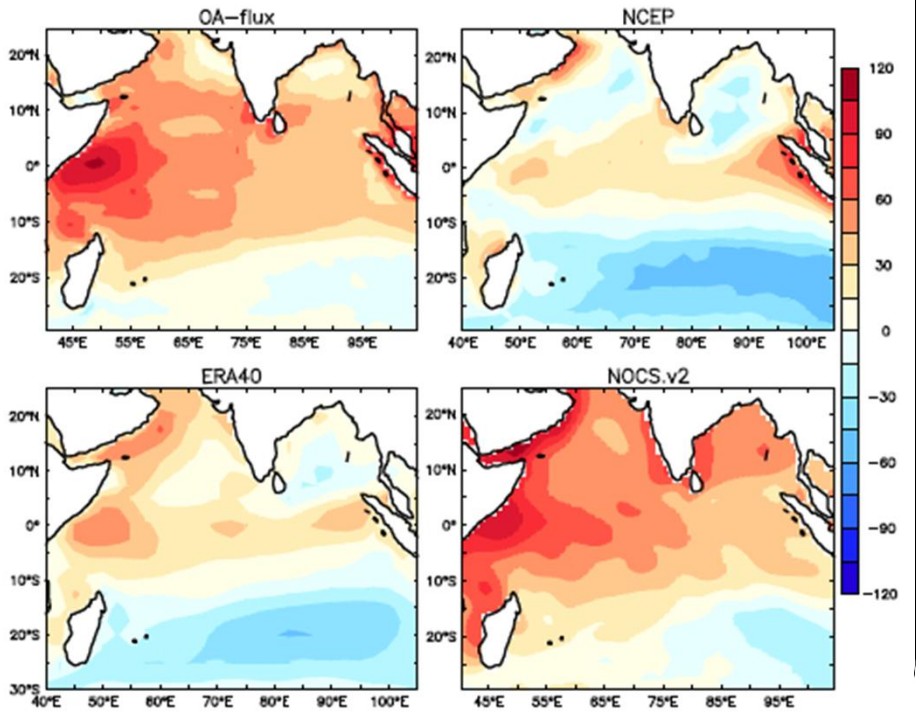

Hadl–SST
ERSST
a
b
20°N
10°N
0°
10°S
40°E
50°E
60°E
70°E
80°E
90°E
100°E
−0.3
−0.24
−0.18
−0.12
−0.06
0
0.06
0.12
0.18
0.24
0.3
(in °C/decade)
e
HADISST
ERSST
SODA
CRAS4
1.80
1.40
1.00
0.60
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005


Averaged over 60E-95E,10S-5N
Averaged over 40E-100E, Eq -25N
0.60
0.40
0.20
0.00
−0.20
−0.40
−0.60
1960
1970
1980
1990
2000
2010



Heat flux trends (W/m^2/year)

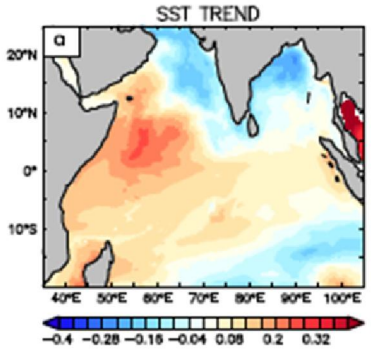
Large bias in heat flux products but they all agree in the negative heat flux trends



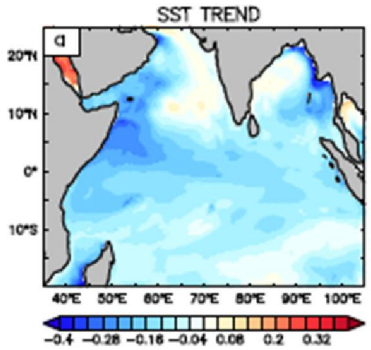
Net heat flux (W/m^2)

Rahul & Gnanaseelan, 2013, GSRL

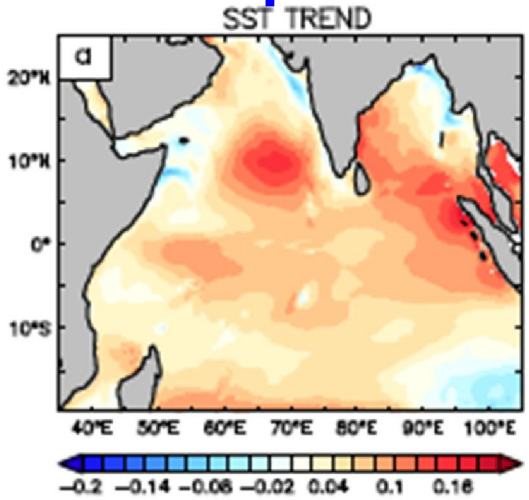
WIND-CLIM



NHF-CLIM

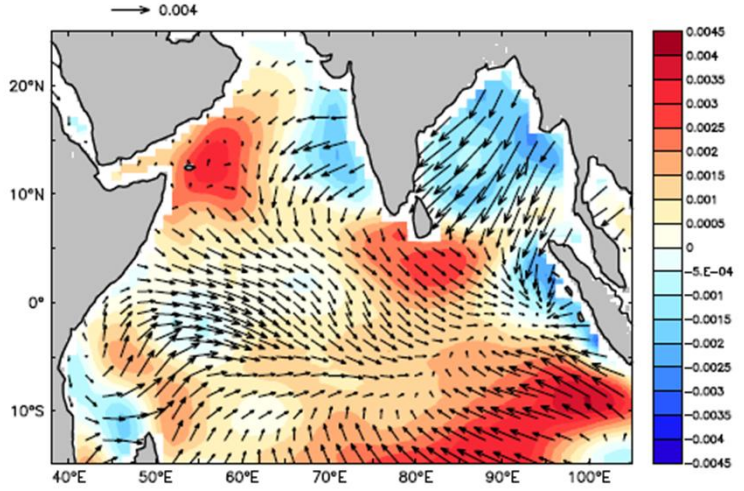


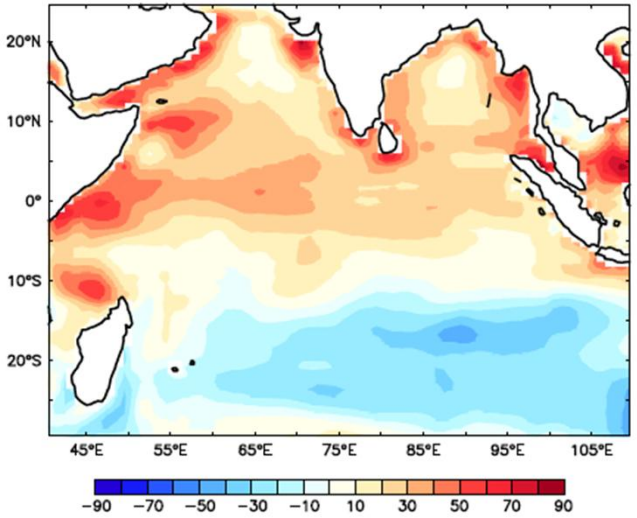
MOM5 experiments



Cooling in the western IO due to changing ocean dynamics is overcome by positive net heat flux

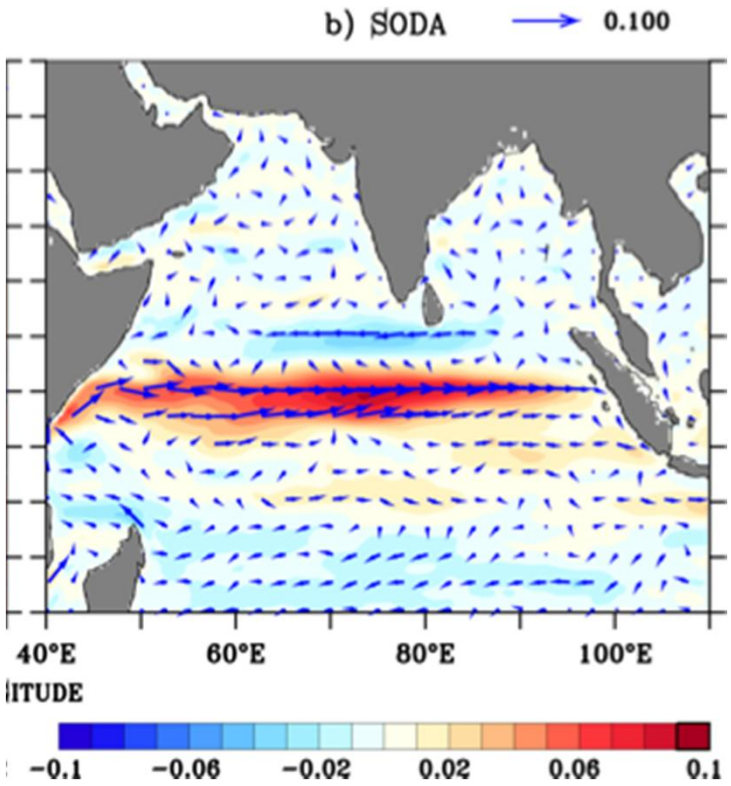
Trends in the model wind stress

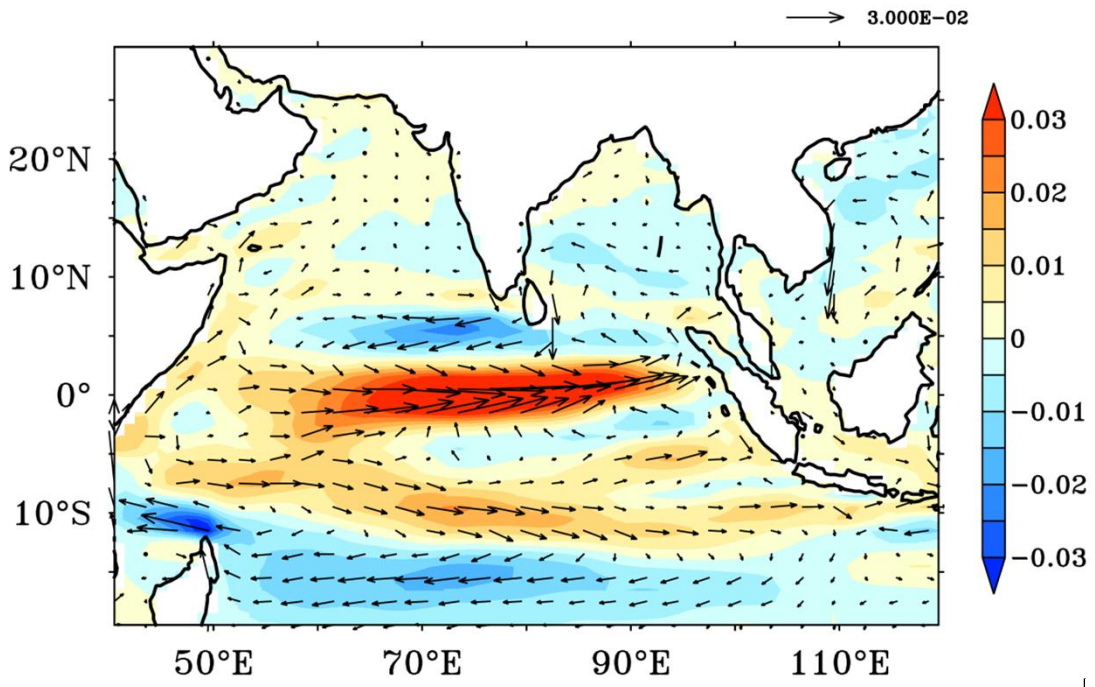




Annual mean net heat flux in model

TRENDS IN CURRENTS





per decade

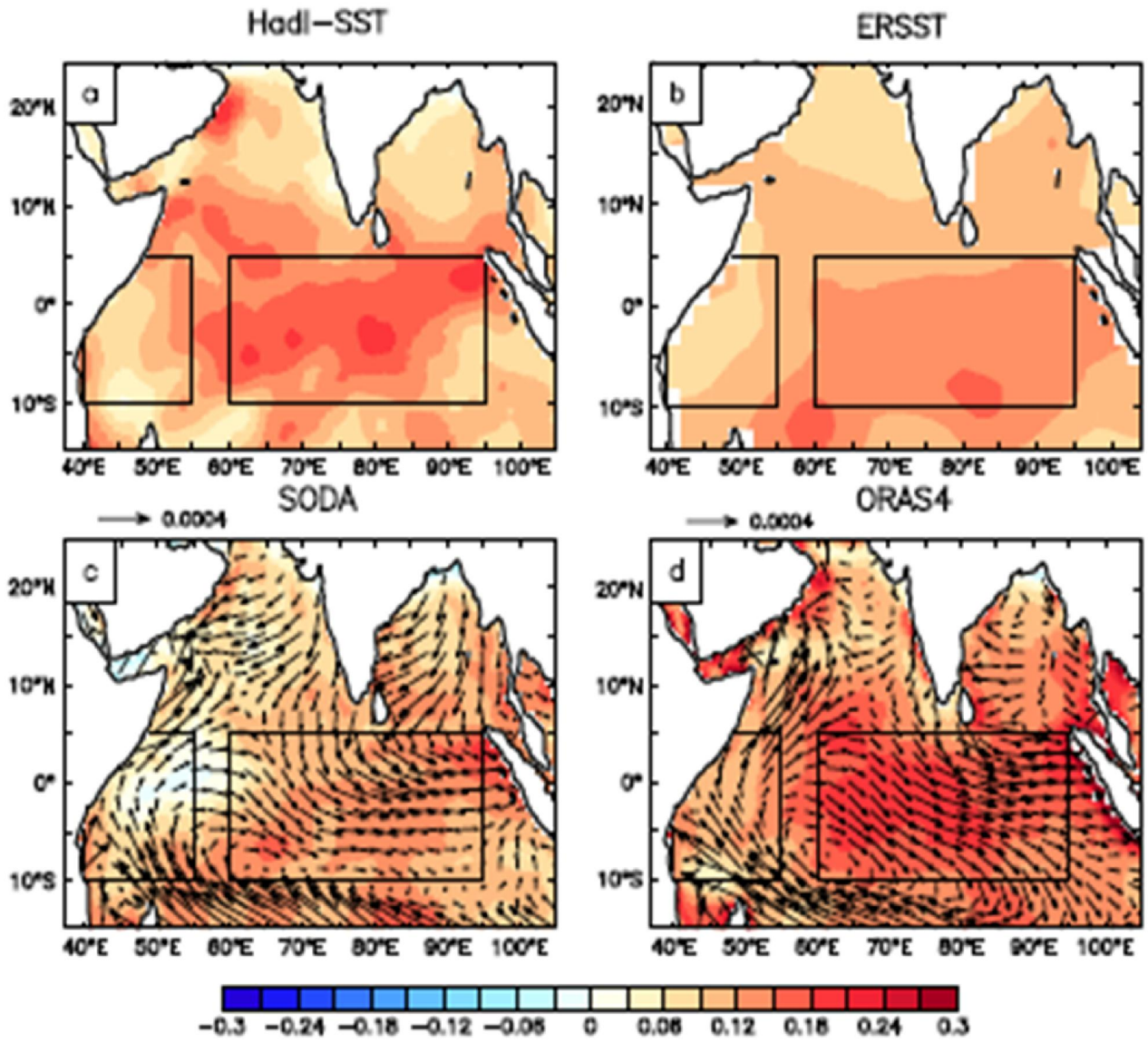
SODA
1958 to 2008

ORAS4
1958 to 2015

Gnanaseelan et al. (2016)

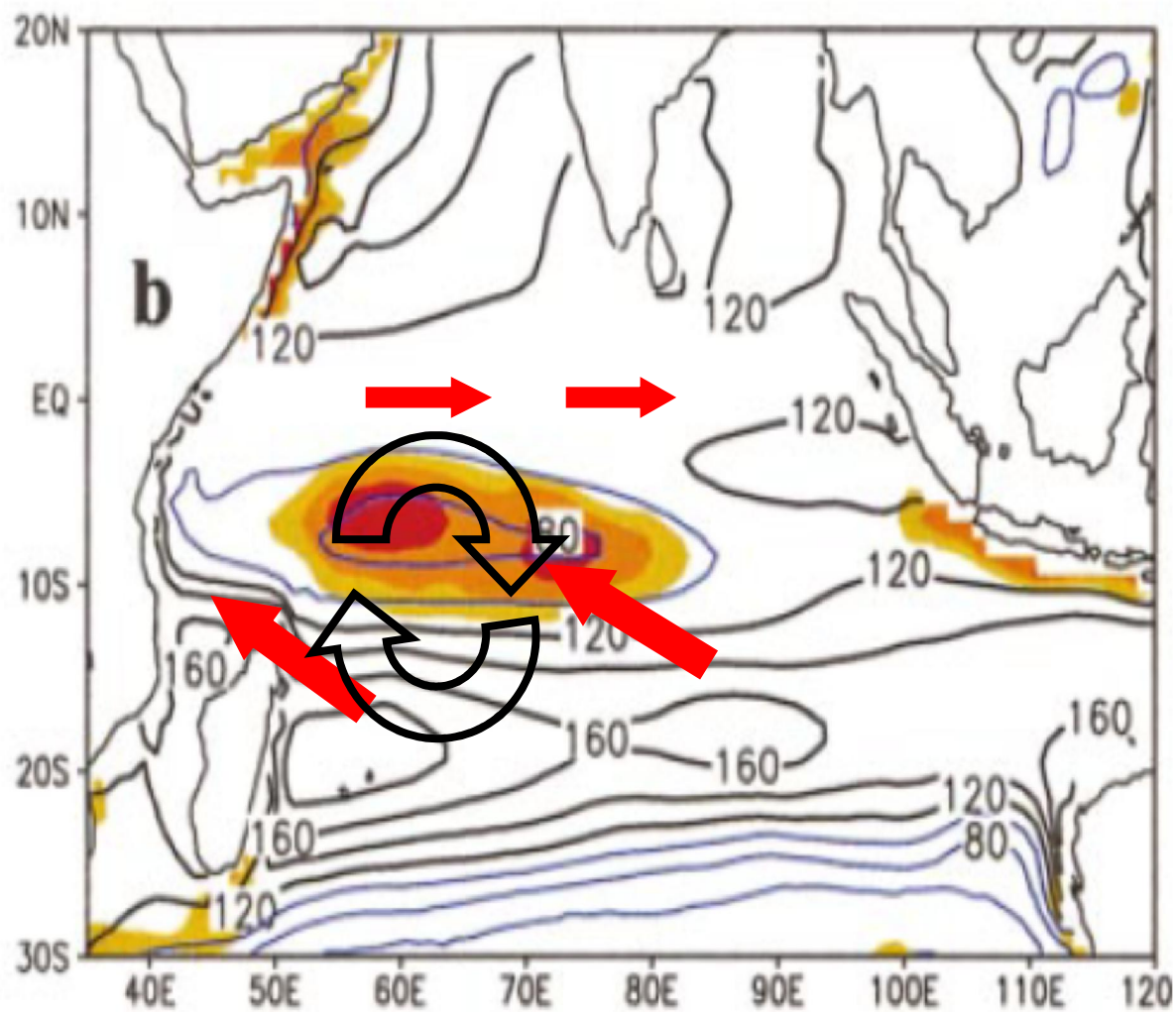
Courtesy: Rashmi

Trends in annual SST and winds



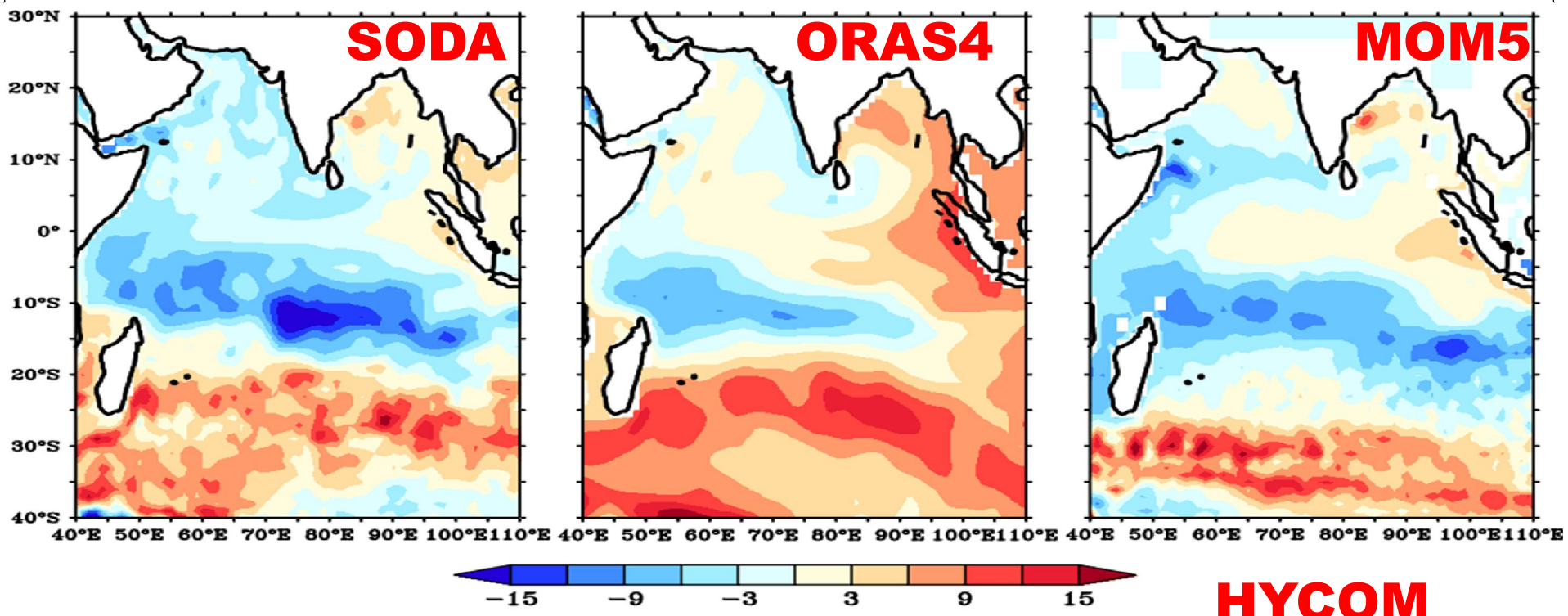
°C per decade

Rahul & Gnanaseelan, 2015, CD



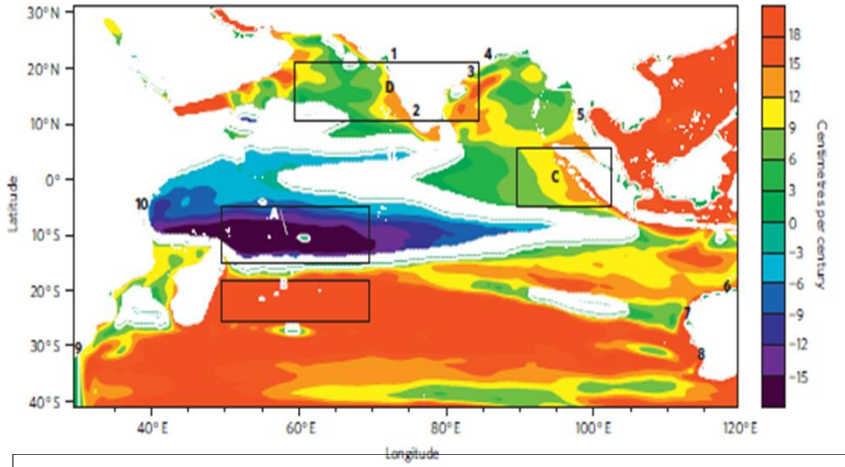
❑**Annual mean southeasterly trade in south IO and westerlies at equator induces a cyclonic curl in SWIO which manifests a unique open ocean upwelling zone in SWIO (5^{o} to 15^{o}S and 50^{o} to 80^{o}E) and characterized by Shallow thermocline (Known as thermocline ridge in Indian ocean).**

Ocean response (in thermocline depth or SSHA)



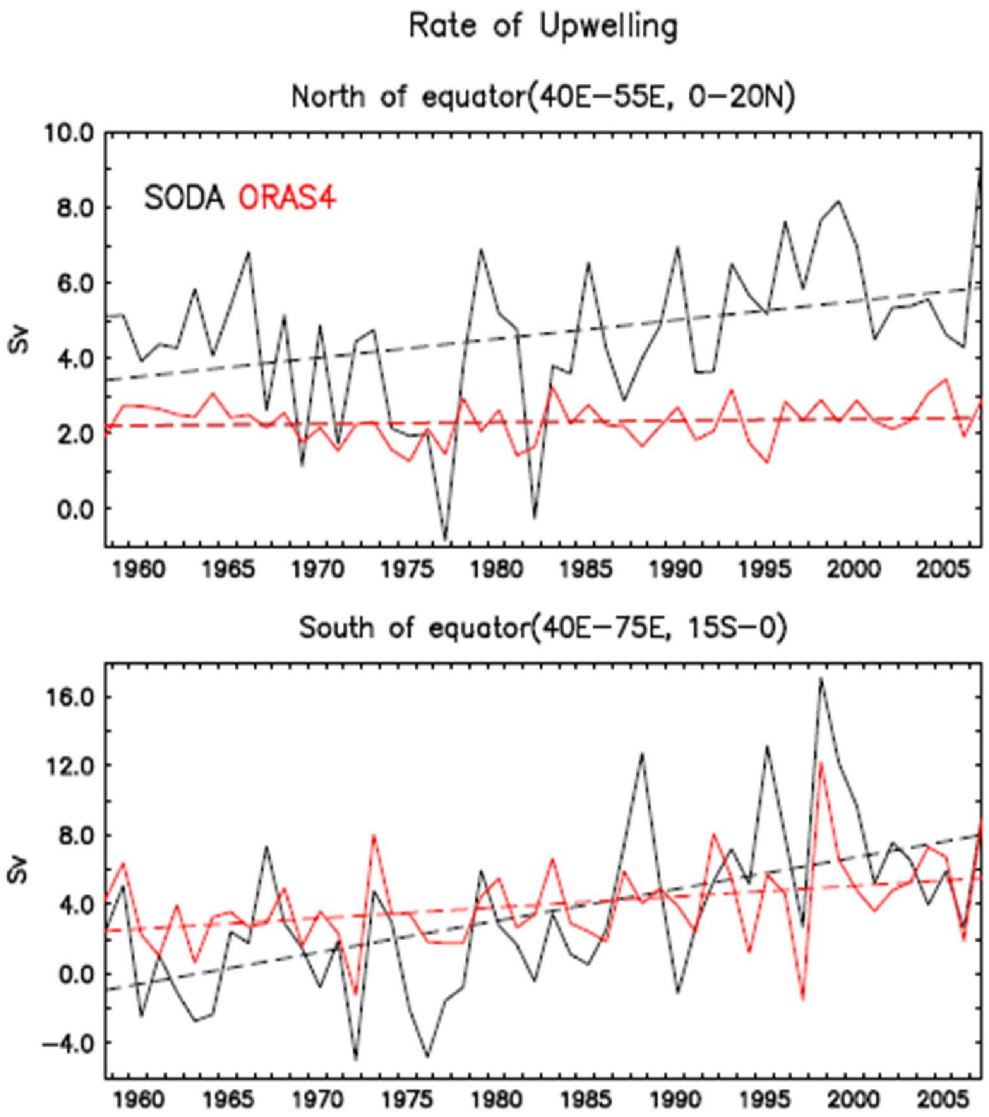
SSHA trend for Indian Ocean based on SODA,ORA, and MOM5 (1959-2008)

HYCOM



HYCOM SSHA trend for 1961-2008 (Han et.al,2010)

Rate of upwelling



Upwelling in the north

- Upwelling at 110m depth, well below the tropical mixed layer
- Computed in upwelling regions south and north of equator
- Increasing upwelling strength is well evident in SODA.

Upwelling in the south

Helmholtz decomposition of ocean currents

$$V = V_r + V_p$$

$$V_r = \hat{k} \times \nabla \psi \qquad V_p = \nabla \phi$$

Poissons Equation

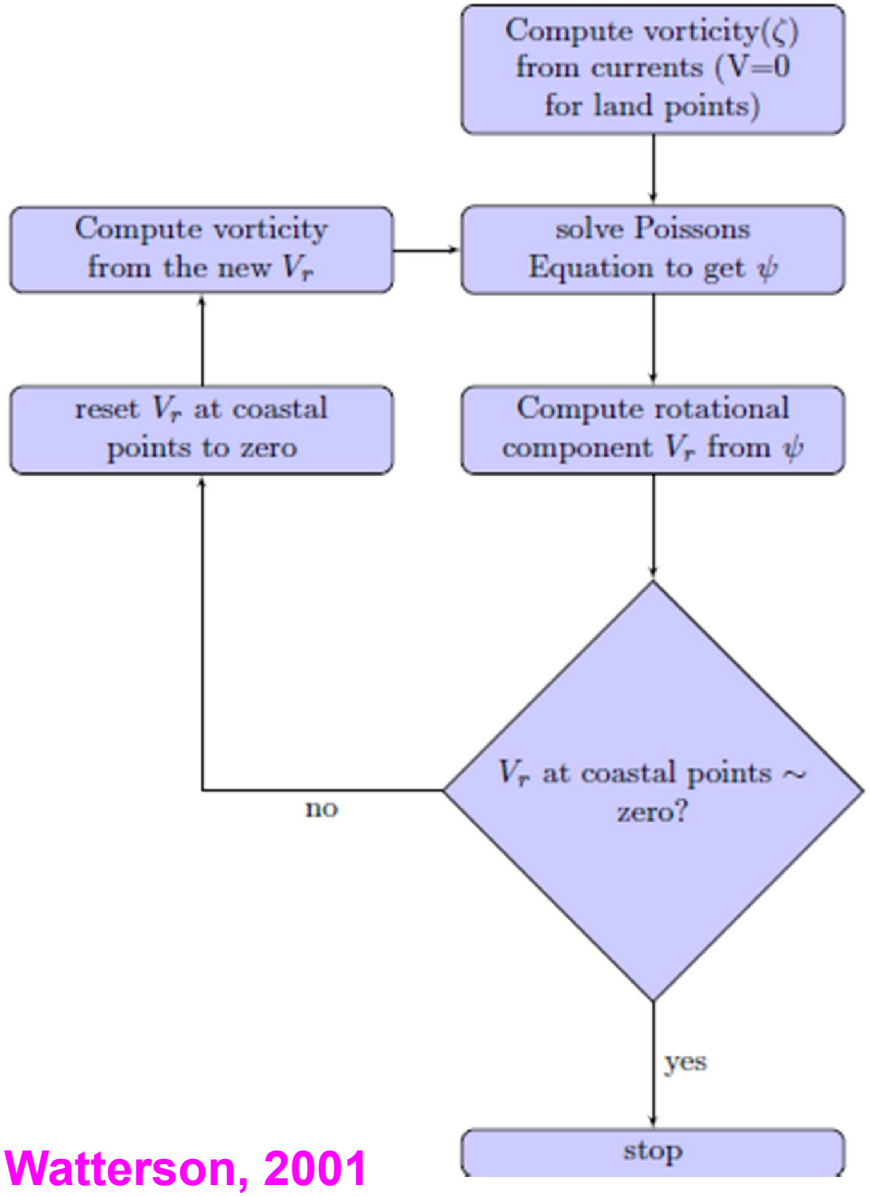
$$\nabla^2 \psi = \zeta \quad where \quad \zeta = \hat{k} \cdot \nabla \times V$$

$$\nabla^2 \phi = D \quad where \quad D = \nabla \cdot V$$

Overturning streamfunction

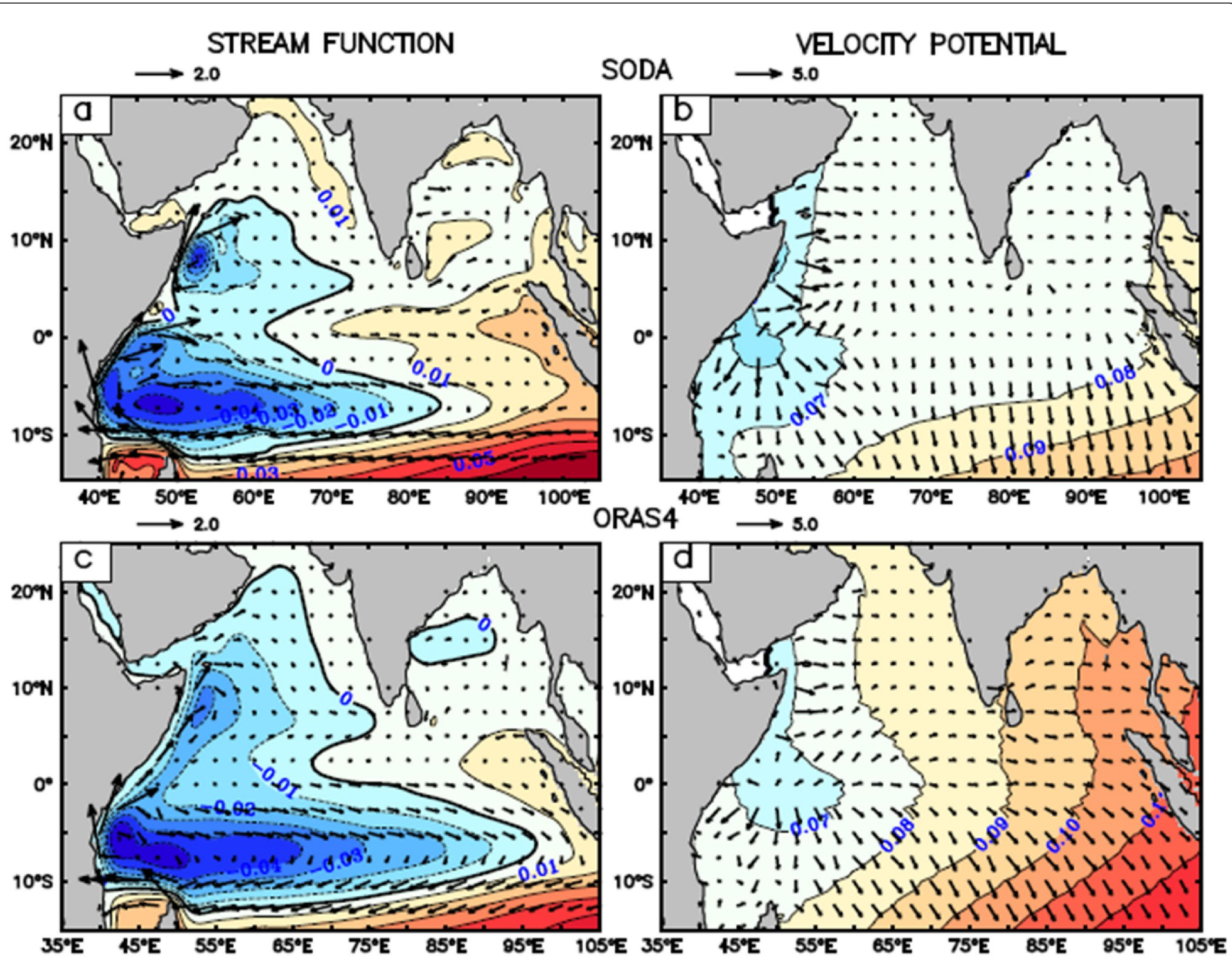
$$\phi_m(z) = \int_H^z v_p(z) dz$$

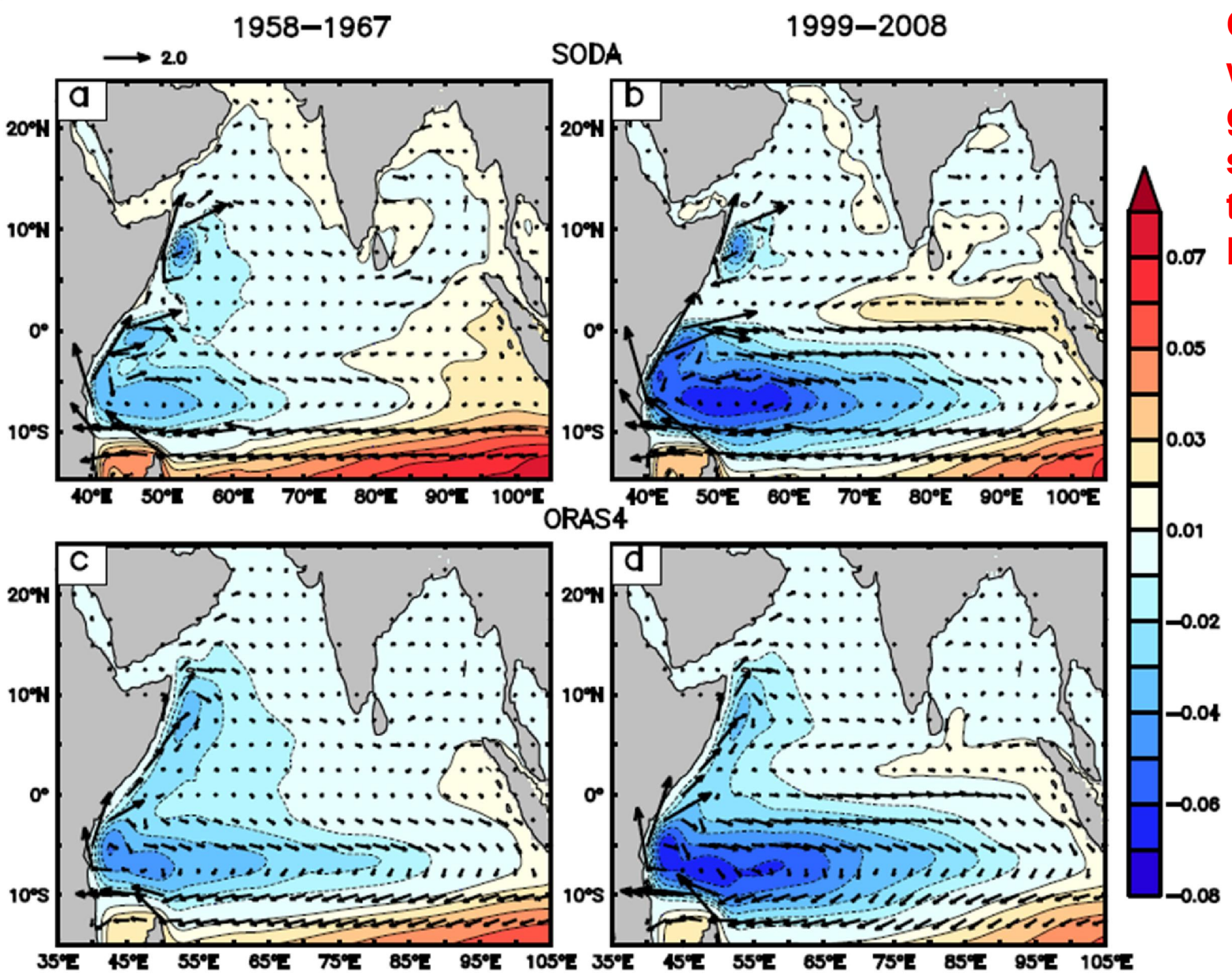
H is depth of ocean $\phi_m(H) = 0$



Courtesy: Rahul

Watterson, 2001


STREAM FUNCTION
VELOCITY POTENTIAL
SODA
ORAS4
2.0
5.0
a
b
c
d
20°N
10°N
0°
10°S
40°E
50°E
60°E
70°E
80°E
90°E
100°E
35°E
45°E
55°E
65°E
75°E
85°E
95°E
105°E

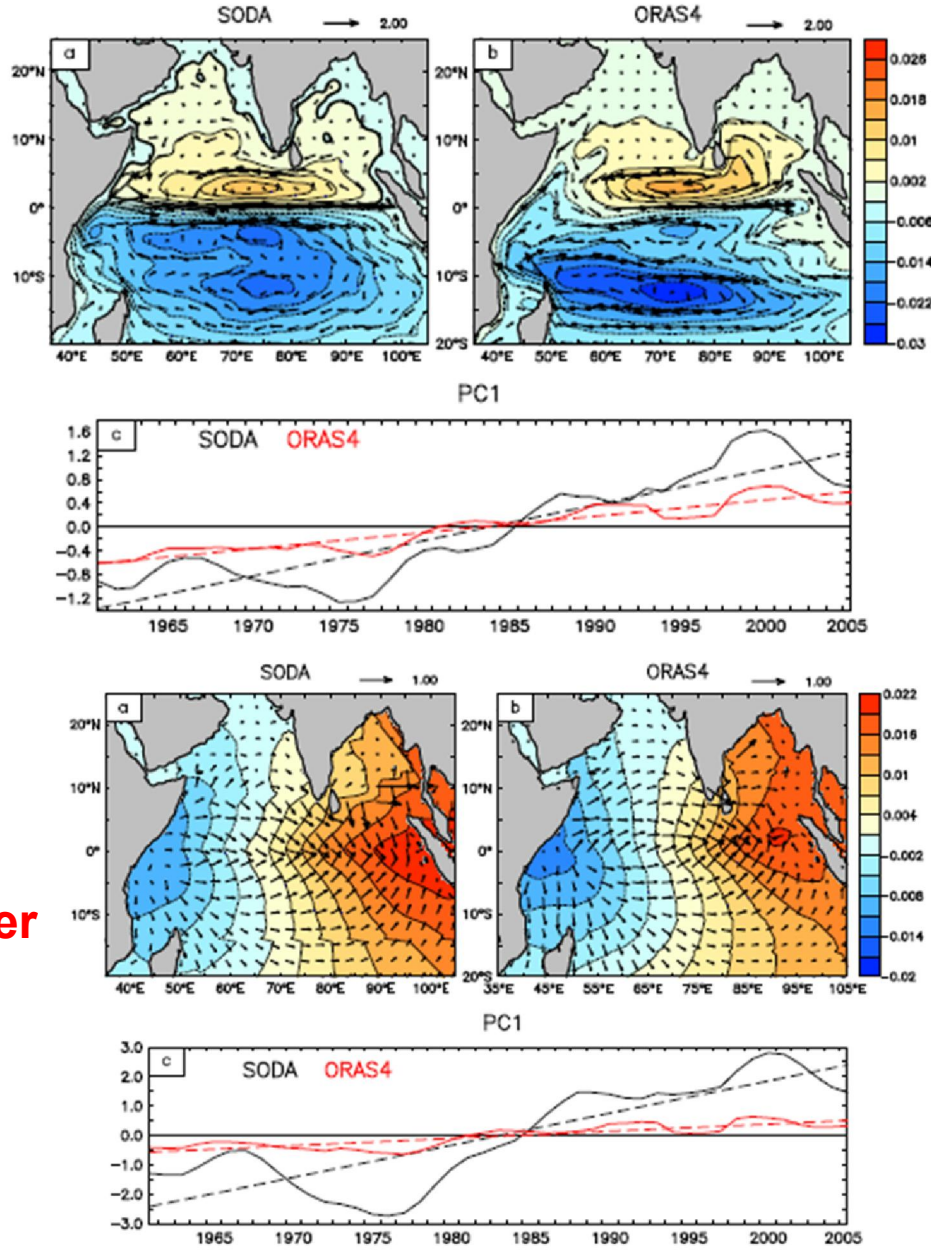


Concides with the global mean surface temperature hiatus

Rahul & Gnanaseelan, 2016, Clim Dyn

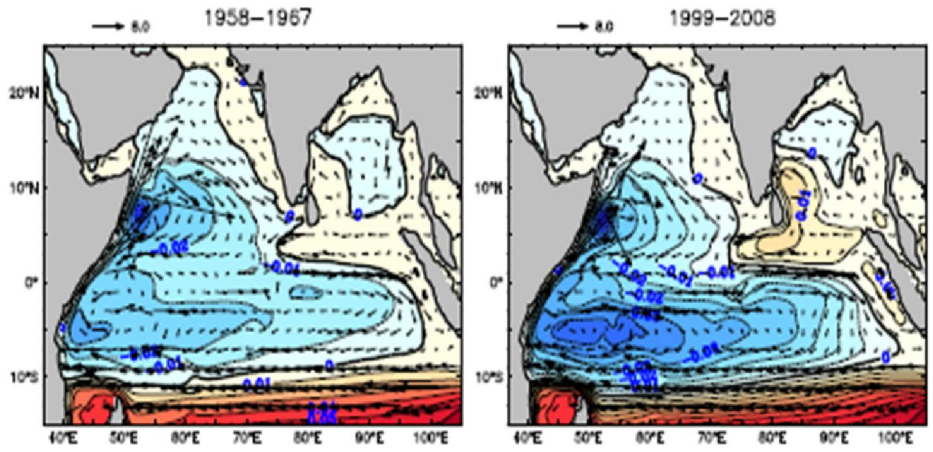
Model captures these epochal changes ….

First EOF of stream function (after applying a 7 year running mean)



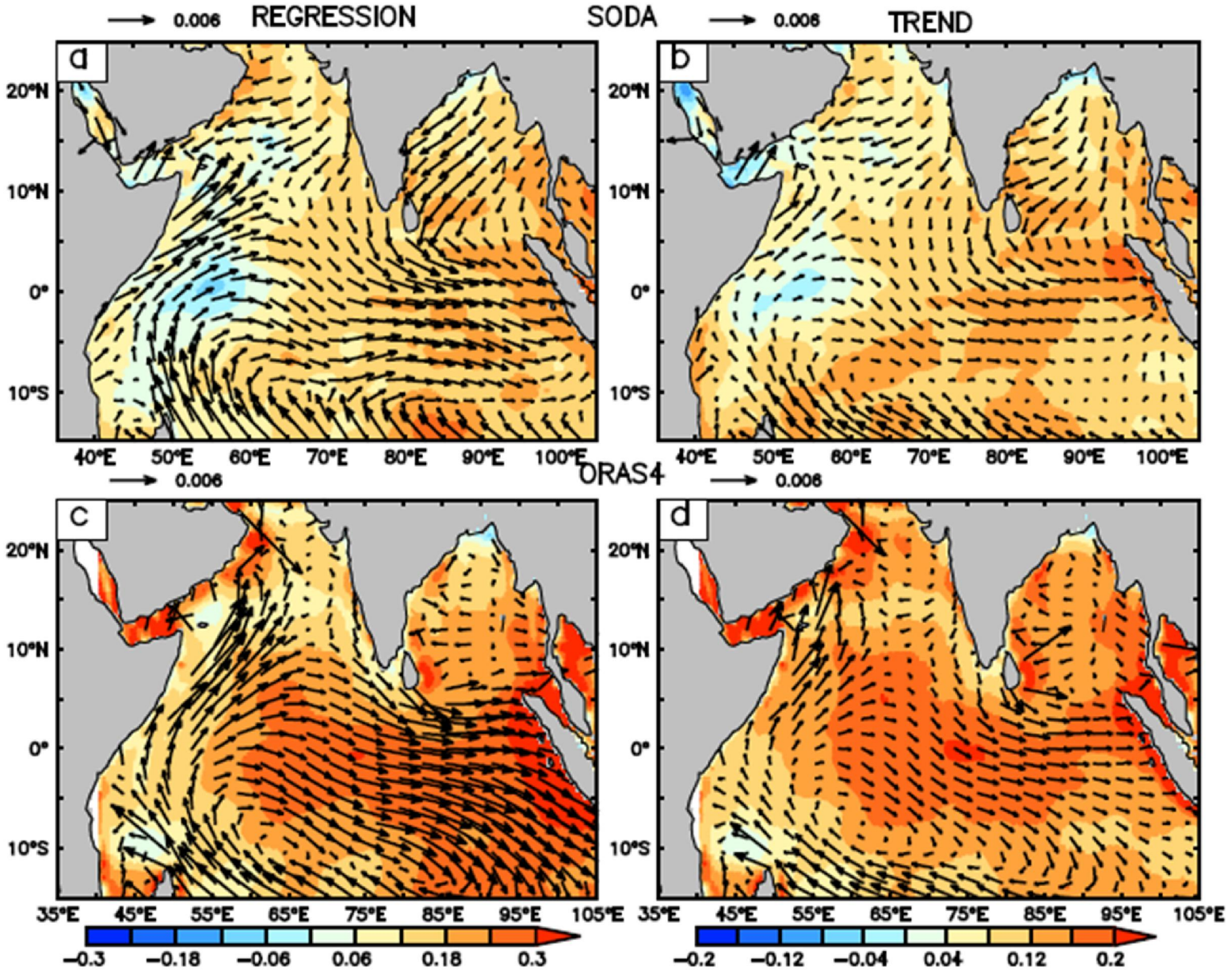
Surface circulation pattern

MOM5



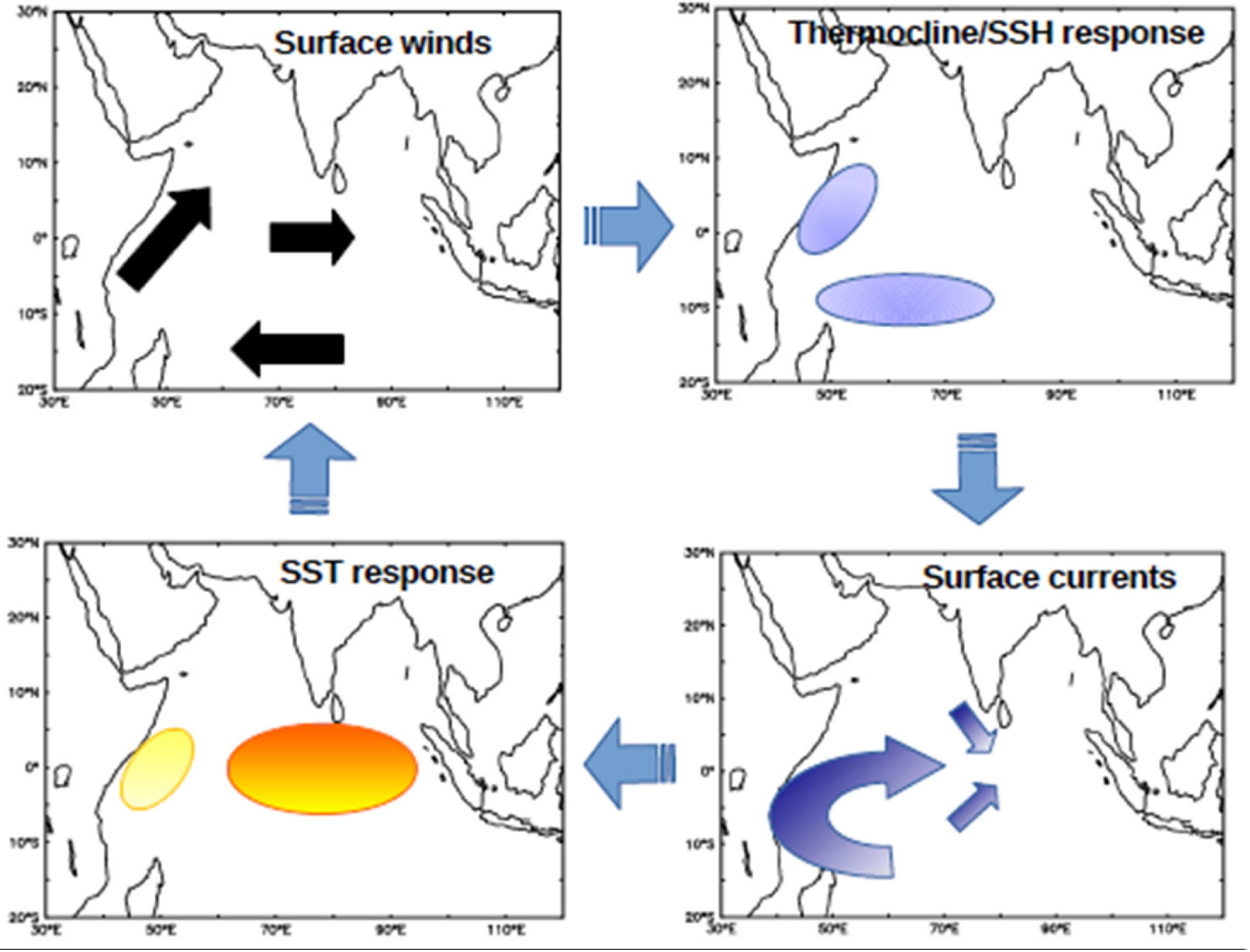
First EOF of velocity potential (after applying a 7 year running mean)

Rahul & Gnanaseelan, 2016, Clim Dyn



SST and winds regressed with the first PC of stream Function, and their trends are shown in the right panels

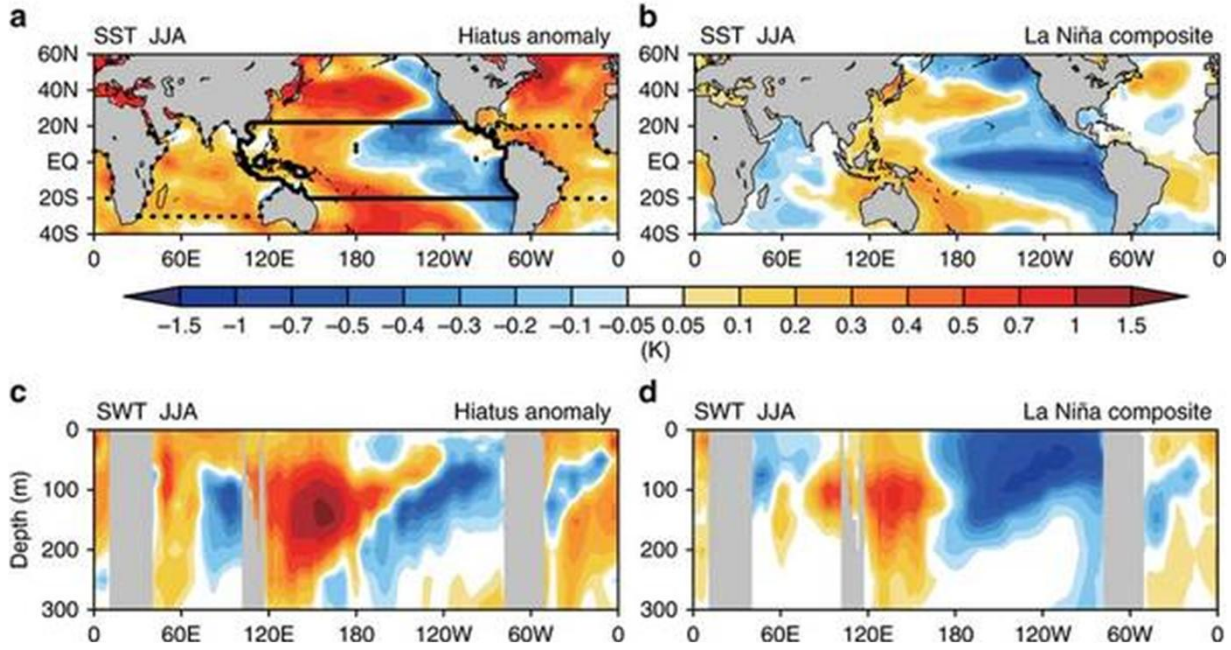
Coupled feedback mechanism



Hiatus anomaly

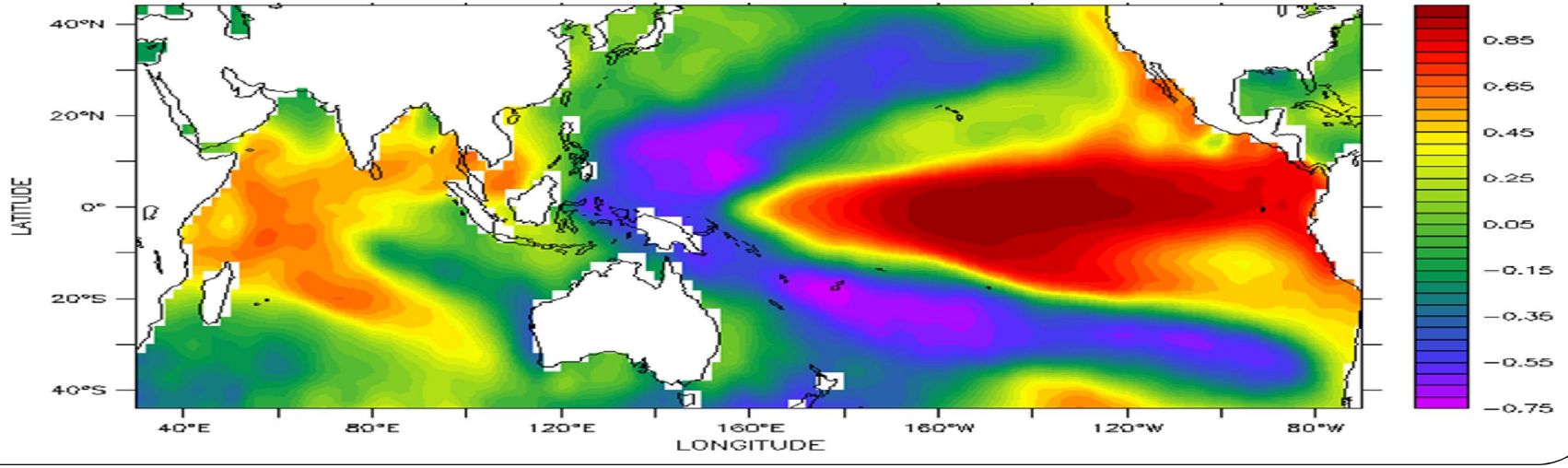
La Nina anomaly comp

Ueda et al. 2015, nature comm.

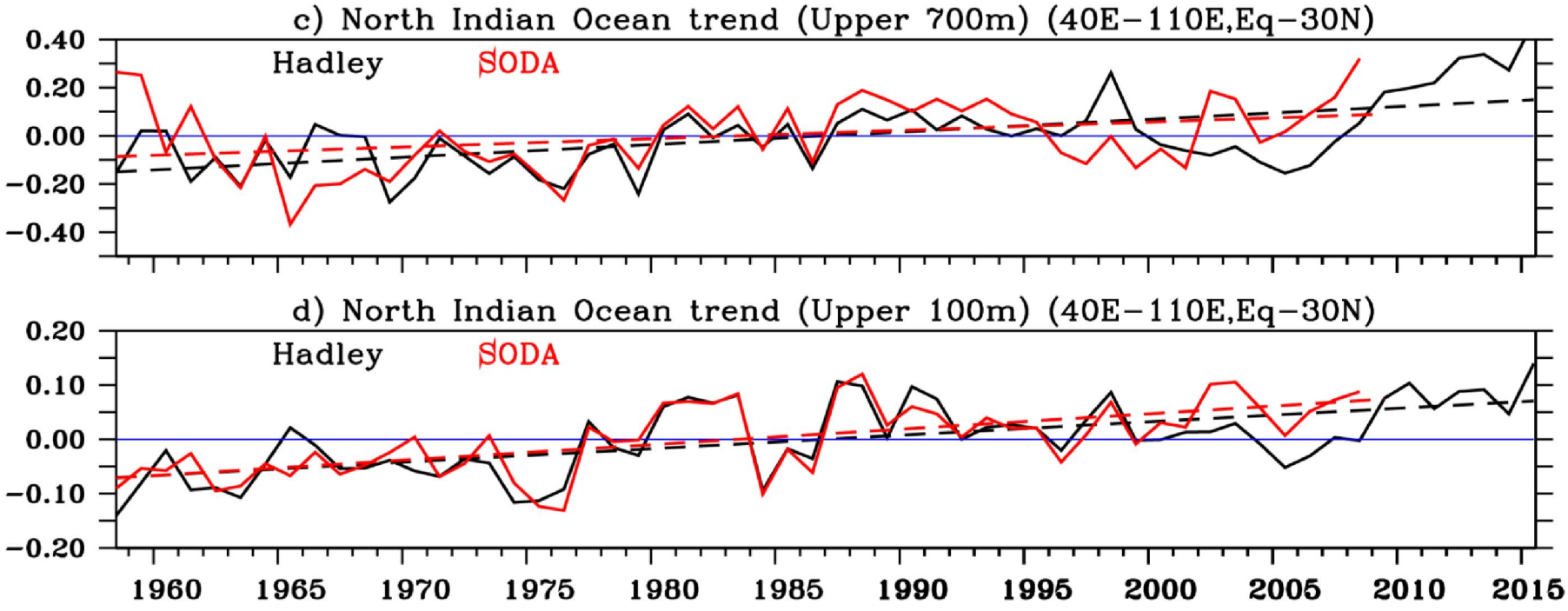


1999 to 2014

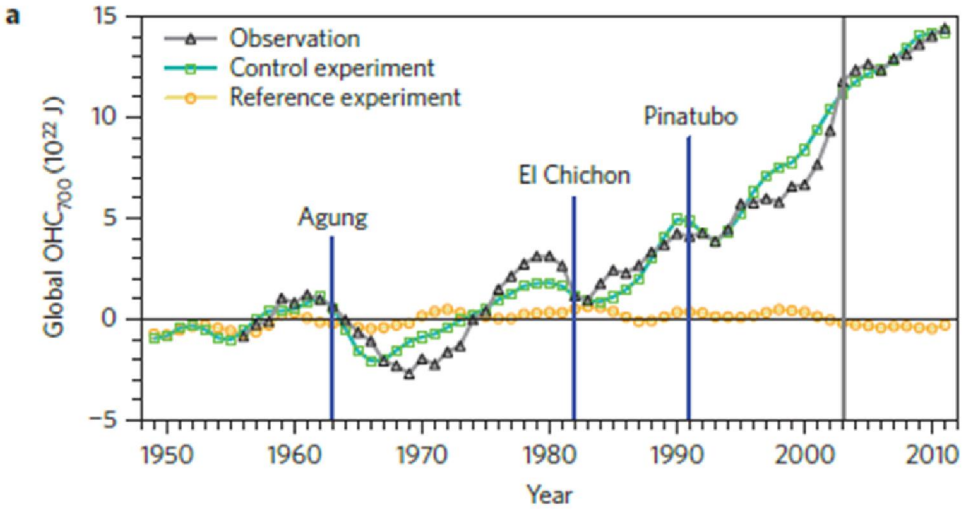
Correlation between Nino3.4 index with Indo-Pacific SSTA



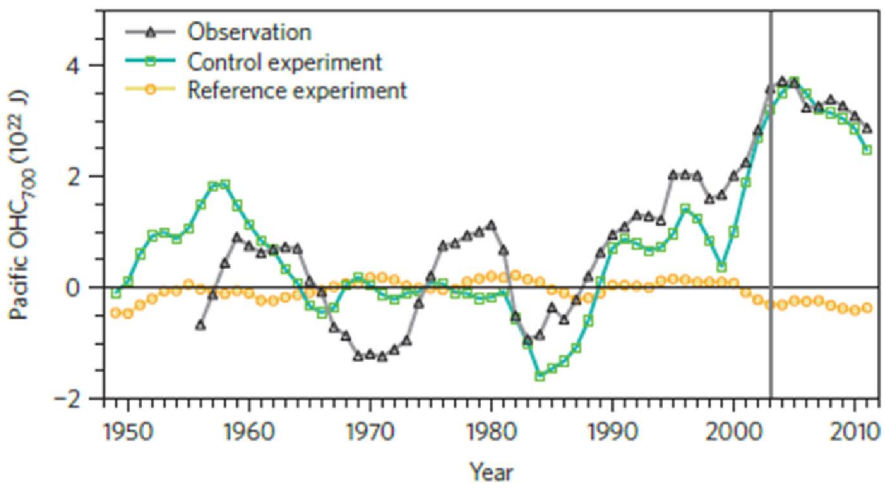
North Indian Ocean warming



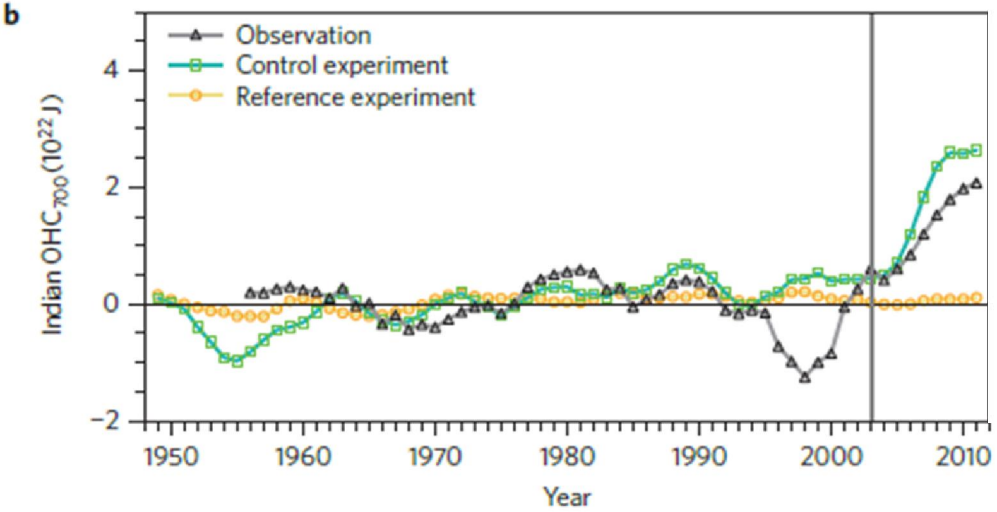
Global ocean heat content (700m)



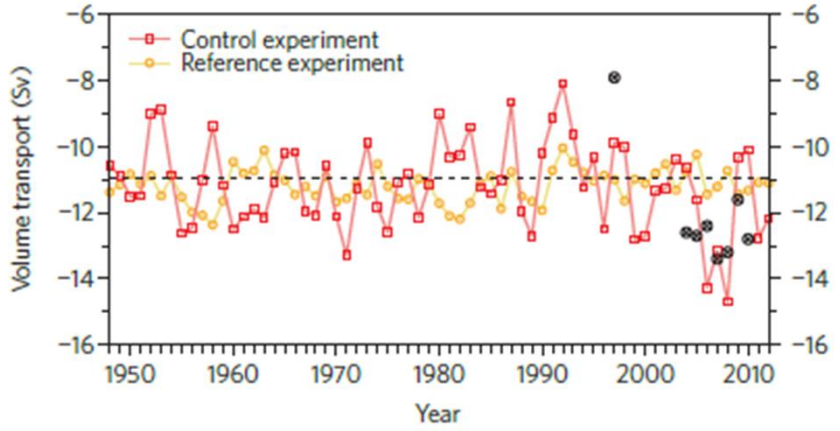
Pacific Ocean heat content



Indian Ocean heat content

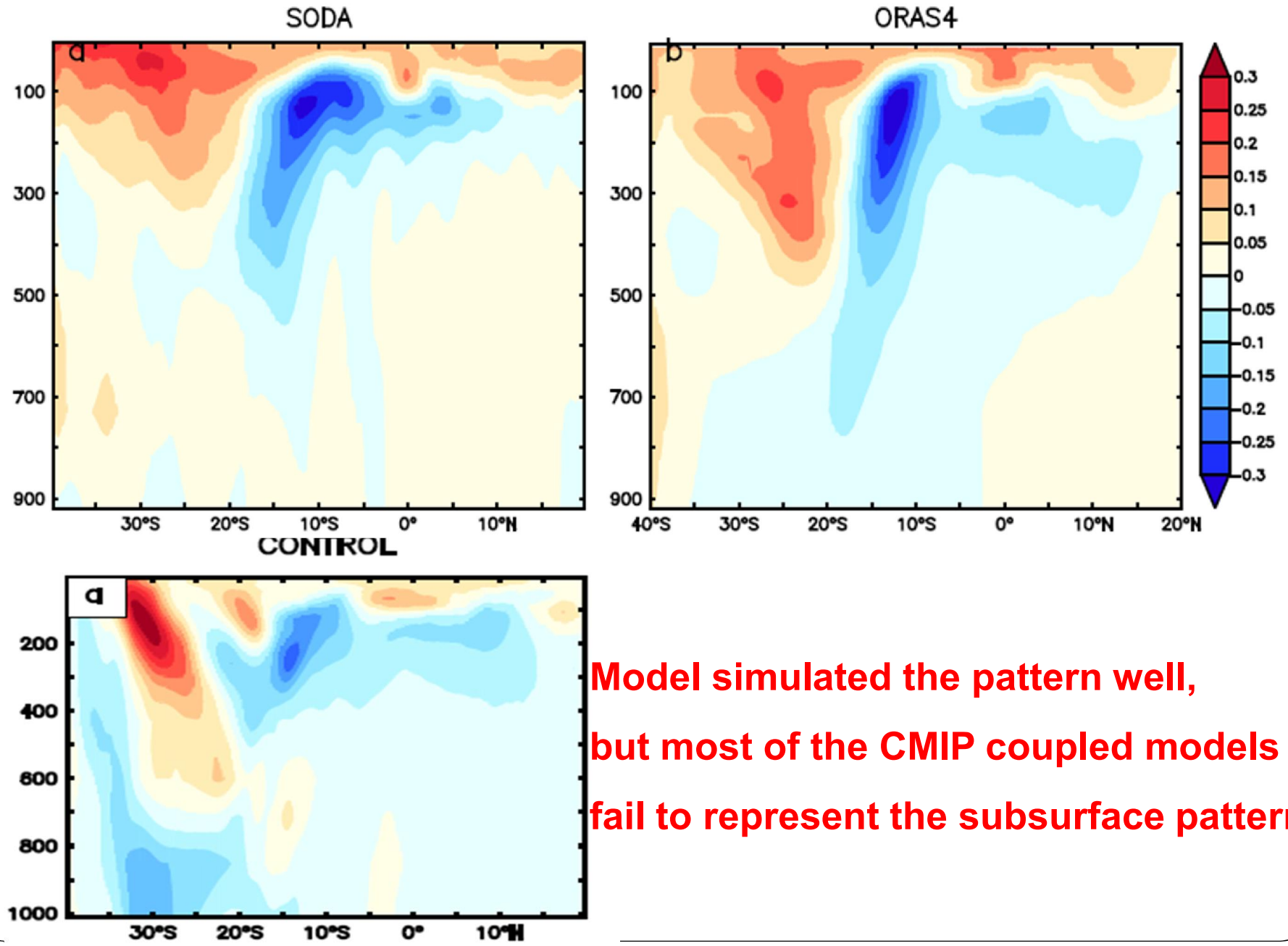


ITF transport



Lee et al. 2015, nature geos.

Vertical structure of temperature trends



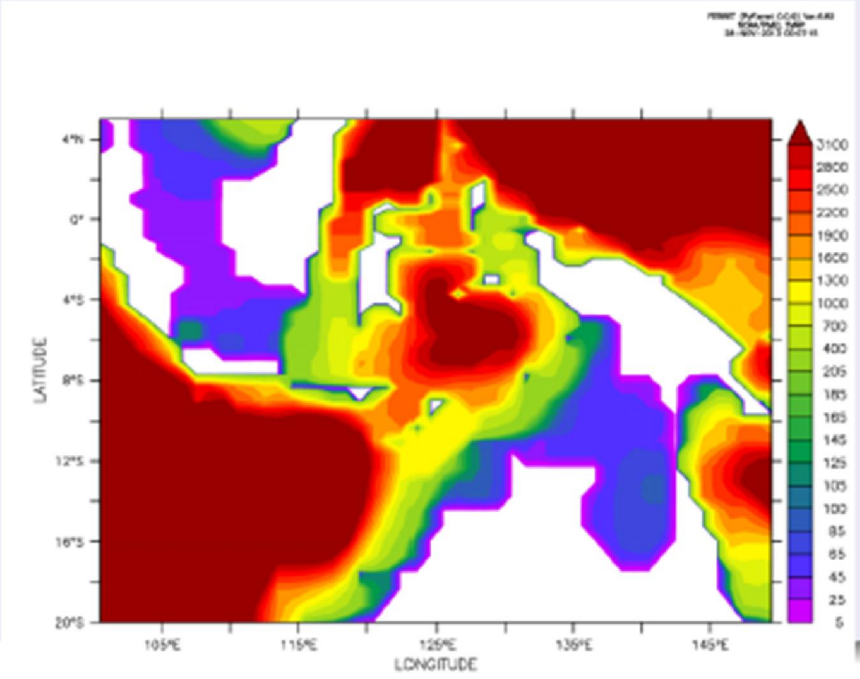
Model simulated the pattern well,

but most of the CMIP coupled models

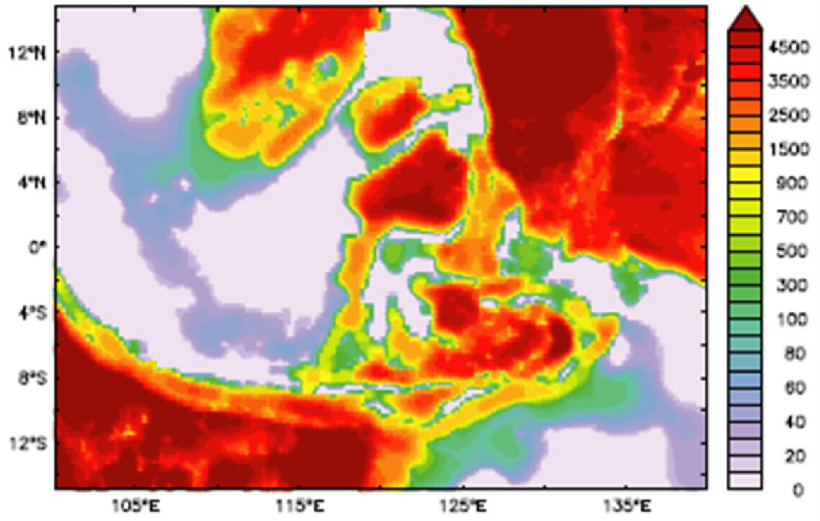
fail to represent the subsurface pattern

Indonesian Through Flow can modulate Indian Ocean temperature

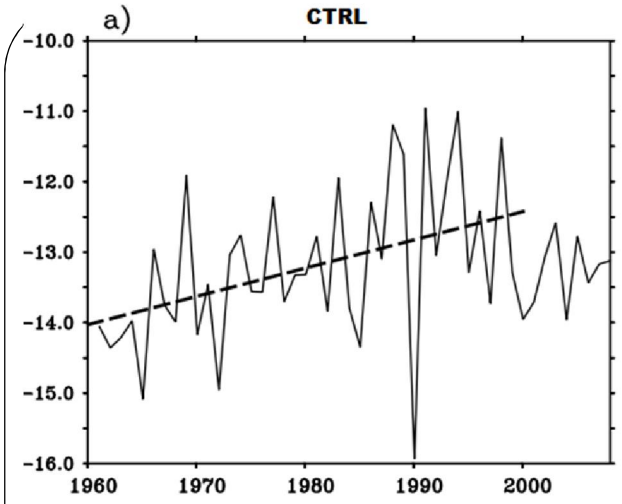
Global Domain

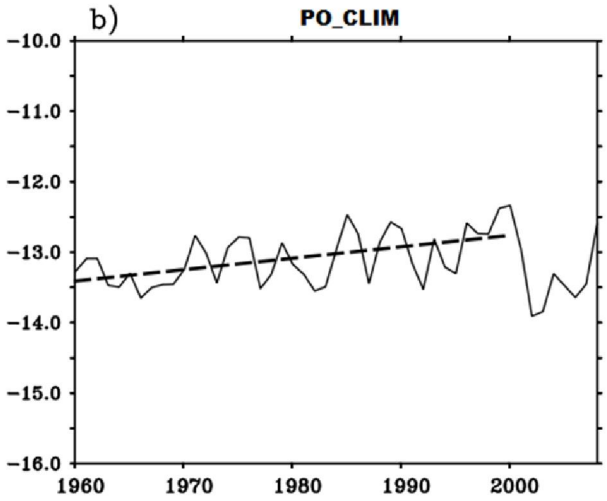


Indo-Pacific Domain

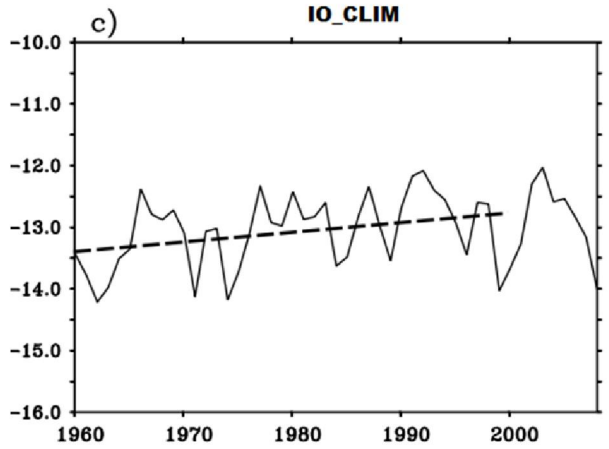


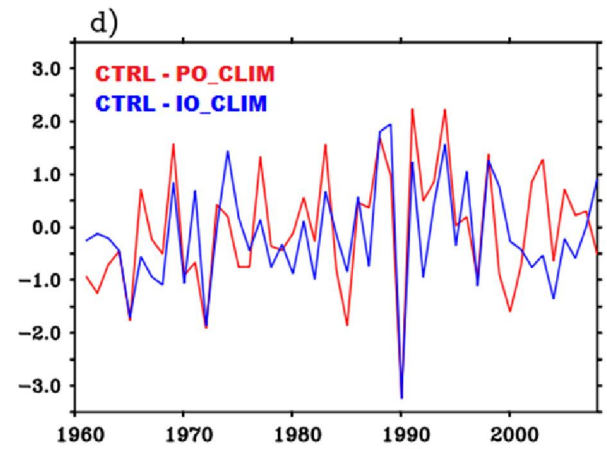
ITF in MOM5

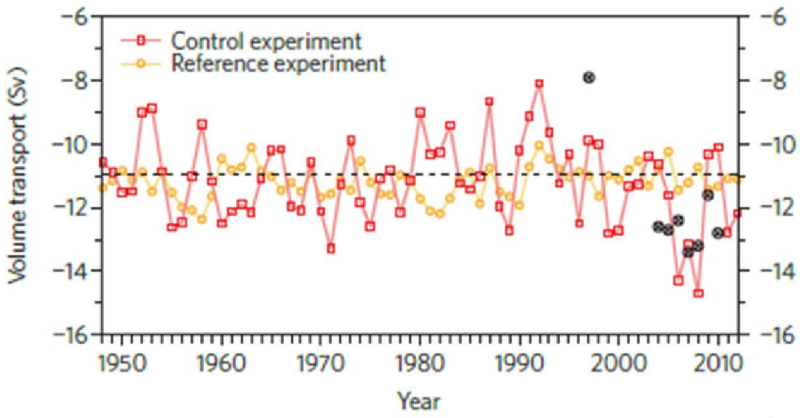




Deepa et al. 2016

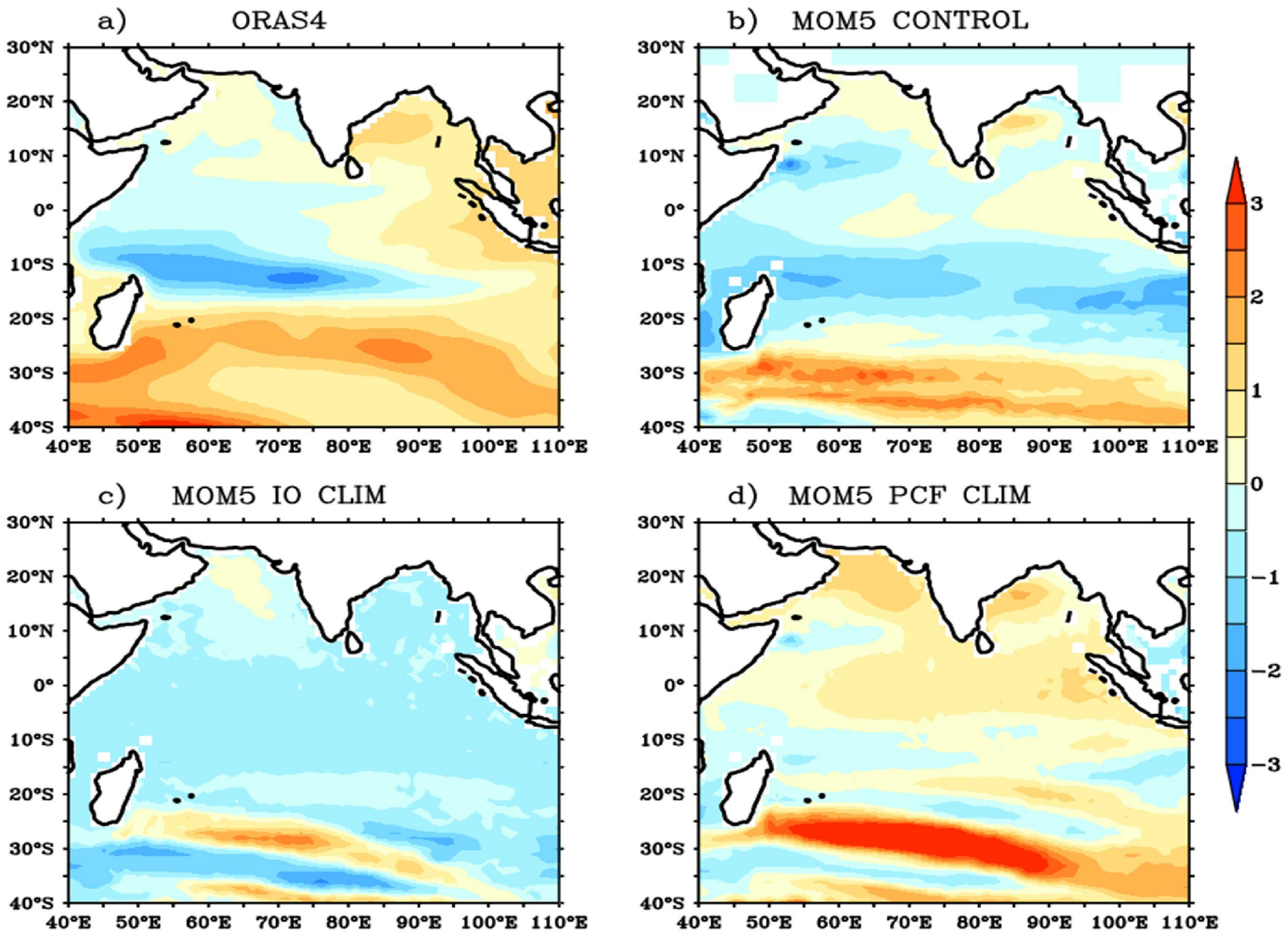




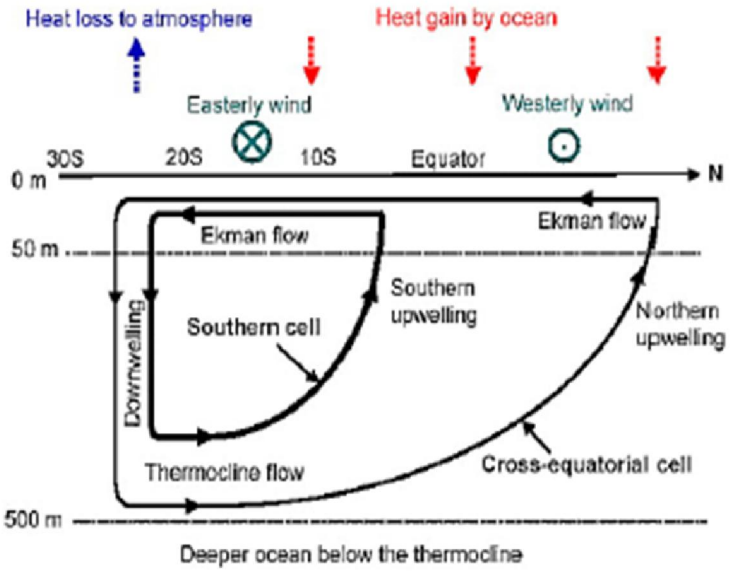


Lee et al. 2015

Sea level anomaly trend(mm/year) 1959-2008



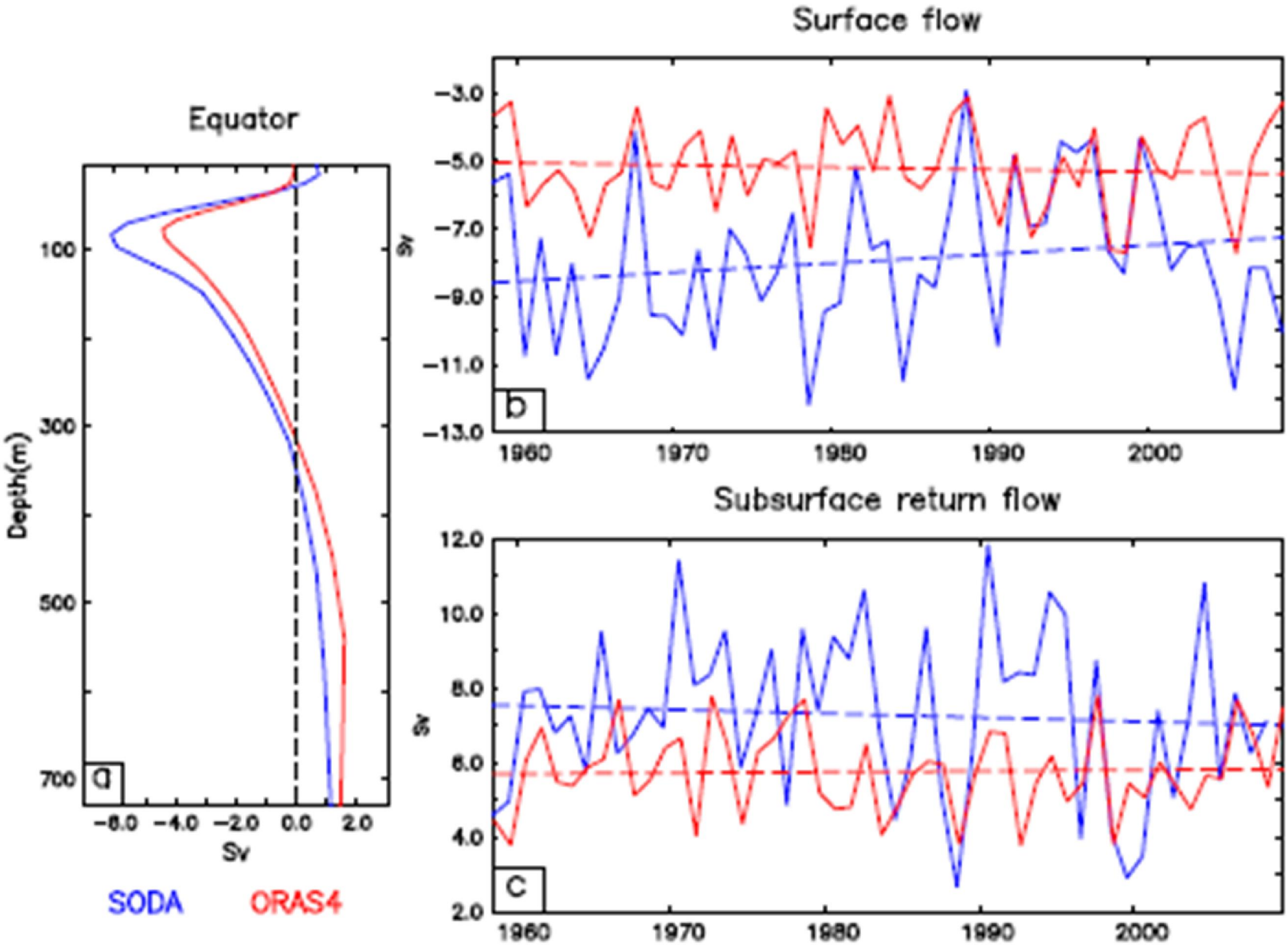
Indian Ocean Meridional Overturning structure



- Meridional Overturning circulation redistributes the heat received in tropics to mid latitudes and maintains the net heat balance of oceans.
- If MOC is weakening, it can support surface warming, as heat redistribution from tropical ocean will be reduced.

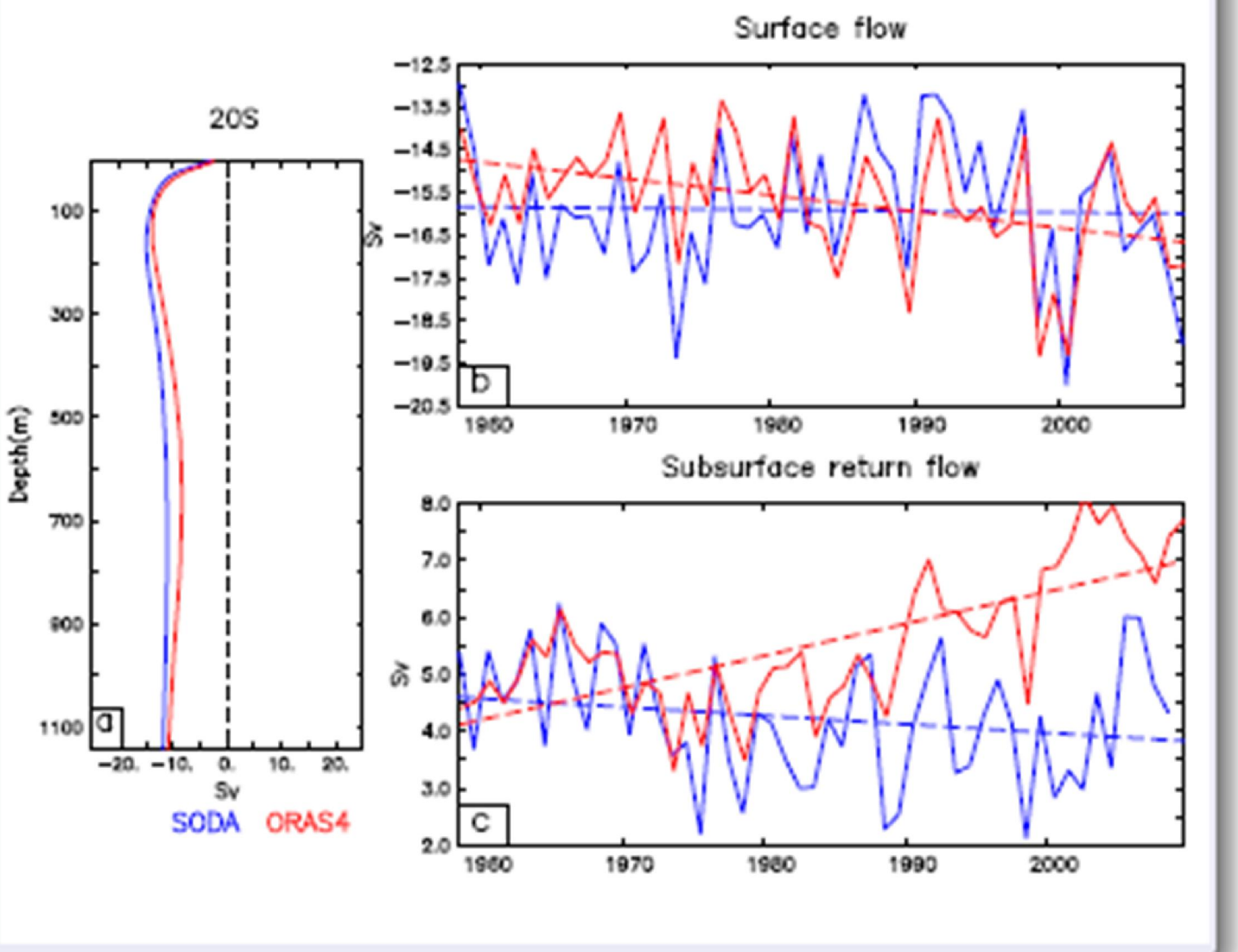
- Shallow cell South of equator (SEC) and a deeper Cross Equatorial Cell (CEC) in TIO.
- Subducted water in the south is transported mainly by the South equatorial currents and is brought to surface by net upwelling over north
- SEC- Upwelling from deep ocean due to Ekman divergence near 10°S while CEC upwelling is maily in sunmmer months over Arabian Sea.

Meridional Volume transport across the Equator



Meridional Volume transport across 20°S

35°E -110°E



SUMMARY

Indian Ocean warming trends can not be explained by net heat flux

Recent Indian Ocean warming pattern is not associated with the atmospheric teleconnections, and ocean dynamics plays an important role

Changing surface circulation patterns explains the recent IO warming trends to a large extent

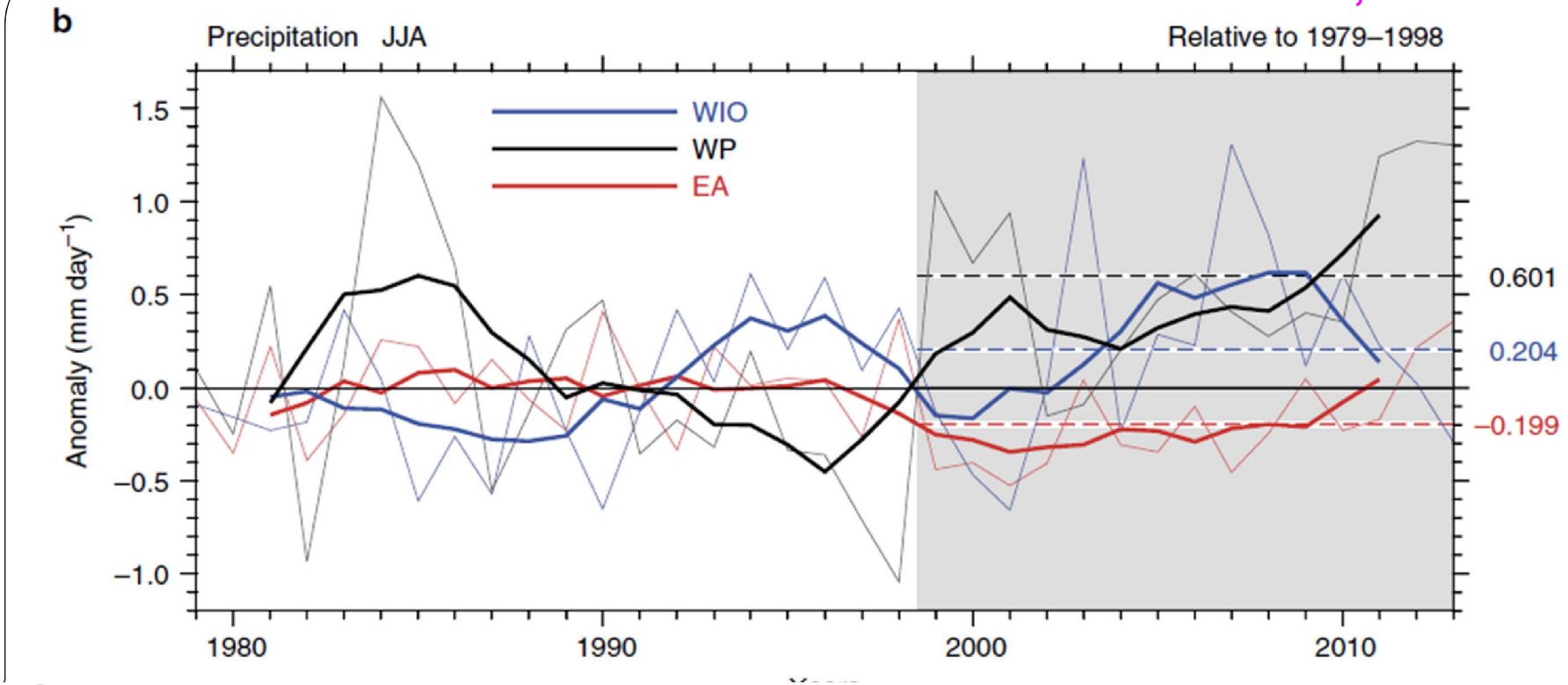
Cooling in the western IO due to changing ocean dynamics is overcome by positive net heat flux

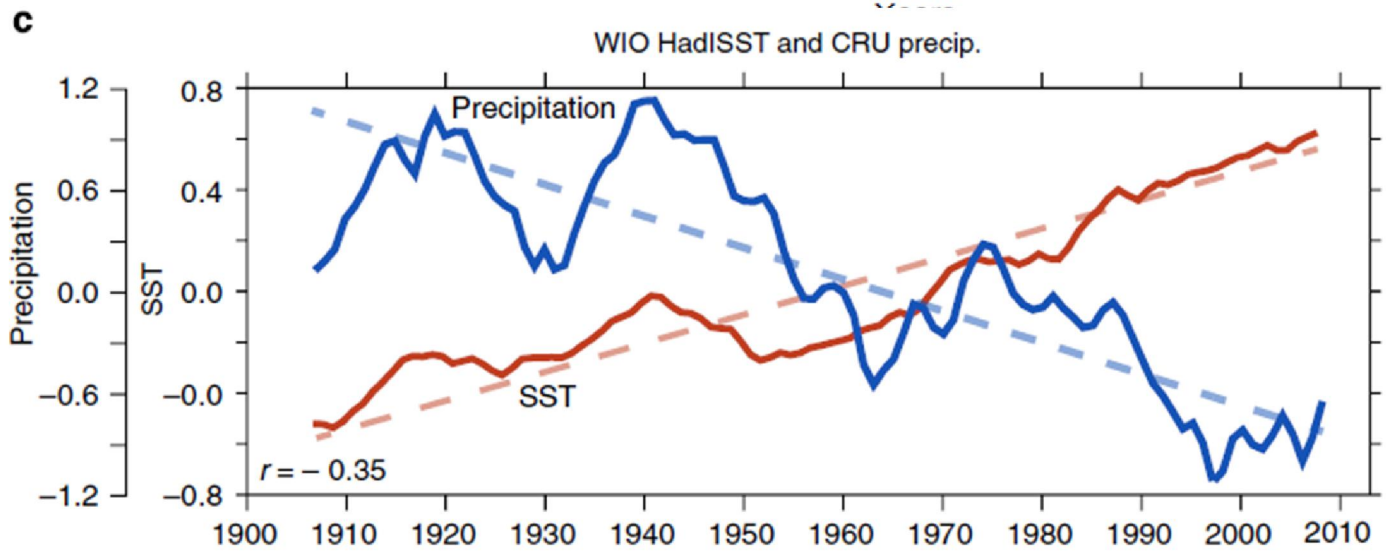
Recent increase in ITF explains subsurface warming trends in the southern TIO

The equatorial Indian Ocean forcing affects ITF and then to the subsurface warming in the south


Thank You
We need a good model to understand the Indian Ocean warming

Ueda et al. 2015, nature comm





Roxy et al. 2015, nature comm

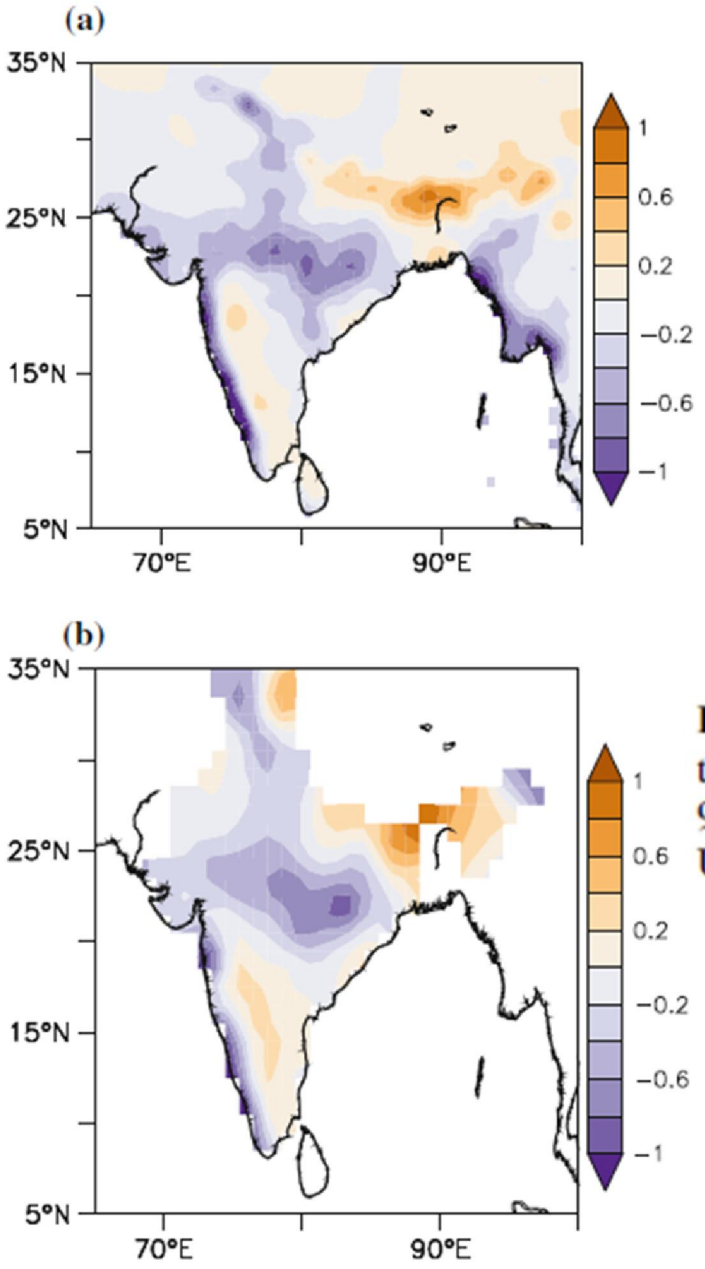


Fig. 4 Anomaly patterns generated by regressing the rainfall upon the first PC of the 850 hPa zonal wind profile averaged from 70°E to 90°E from ERA **a** APHRODITE rainfall **b** IMD gridded rainfall. Units of regression pattern are (mm day^{-1}) (ms^{-1})$^{-1}$

Swapna et al. 2014