Patterns of Indian Ocean sea level change in a warming climate

Weiqing Han
Department of Atmospheric and Oceanic Science,
University of Colorado at Boulder

In collaboration with:
G.A. Meehl, B. Rajagopalan, J.T. Fasullo, A. Hu, J. Lin, W. Large, J.-W. Wang, X. Quan, L.L. Trenary, A. Wallcraft, T. Shinoda, S. Yeager

Nature Geoscience, 2010
OSTST Meeting, Oct. 18, 2010, Lisbon

1. Background

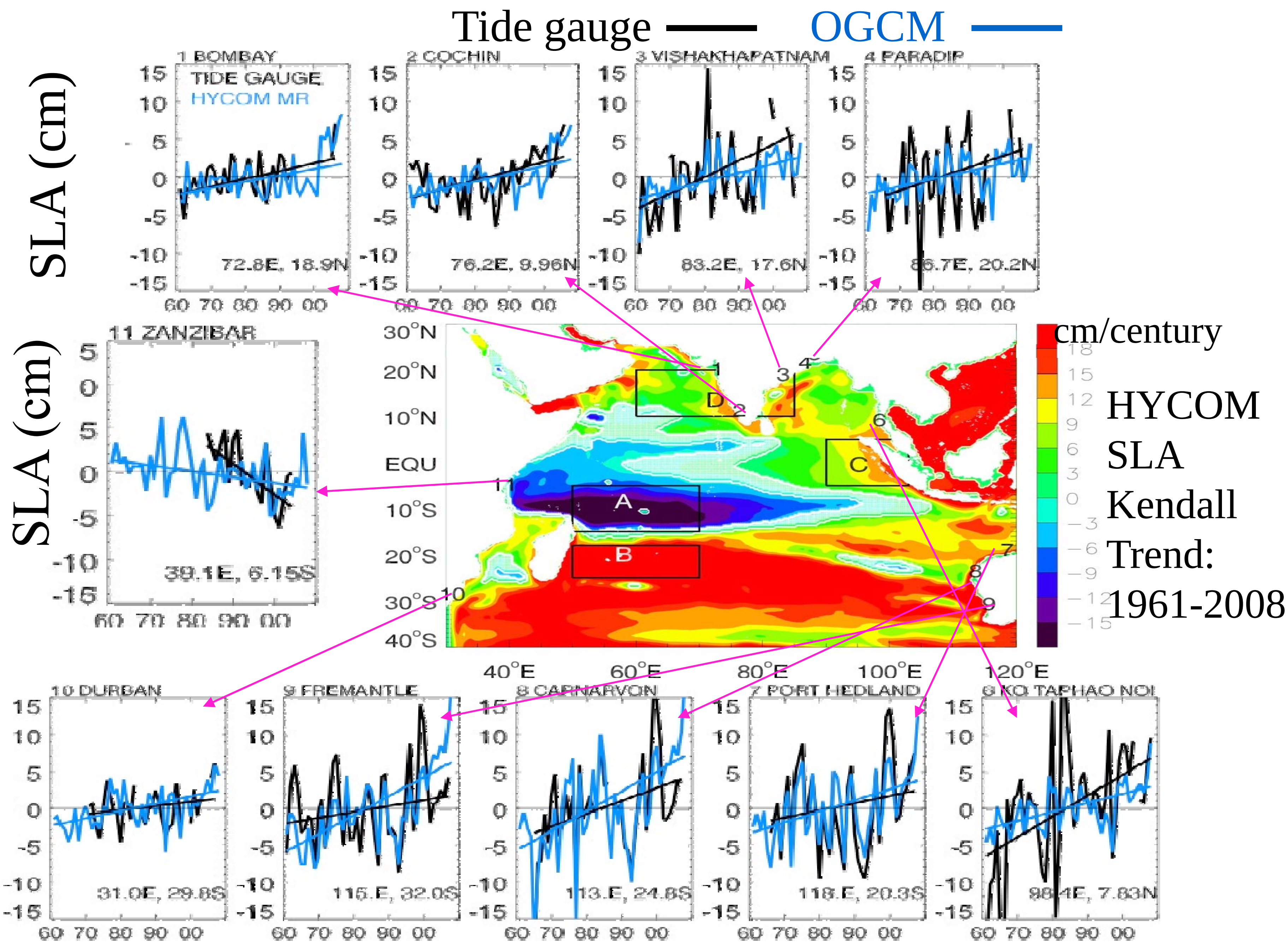
IPCC AR4

- Global mean

~18cm/century from 1961-2003;

~30cm/century from 1993-2003

- Geographically non-uniform: sea level rise in some regions accompanies a fall somewhere else



Tide gauge
OGCM
SLA (cm)
1 BOMBAY
TIDE GAUGE
HYCOM MR
72.8E, 18.9N
2 COCHIN
76.2E, 9.96N
3 VISHAKHAPATNAM
83.2E, 17.6N
4 PARADIP
86.7E, 20.2N
11 ZANZIBAR
39.1E, 6.15S
cm/century
HYCOM
SLA
Kendall
Trend:
1961-2008
A
B
C
D
10 DURBAN
31.0E, 29.8S
9 FREMANTLE
115.E, 32.0S
8 CARNARVON
113.E, 24.8S
7 PORT HEDLAND
118.E, 20.3S
6 KO TAPHAO NOI
98.4E, 7.83N

Goal:

Detect the regional variations of sea level change in the IO since the 1960s; and investigate its causes.

Challenge: Lack of "direct sea level observations" before satellite altimetry;

Approach: utilize available independent ocean-atmos. observations, combined with multi-model experiments – seek physical consistency

Significance:

Sea level rise – due to both natural variability and anthropogenic warming - affects the lives of millions of people who live near coasts and on islands; regional estimates of future sea level rise are essential for effective risk assessment (Milne et al. 2009)

2. Approach: Combined - observations and model experiments

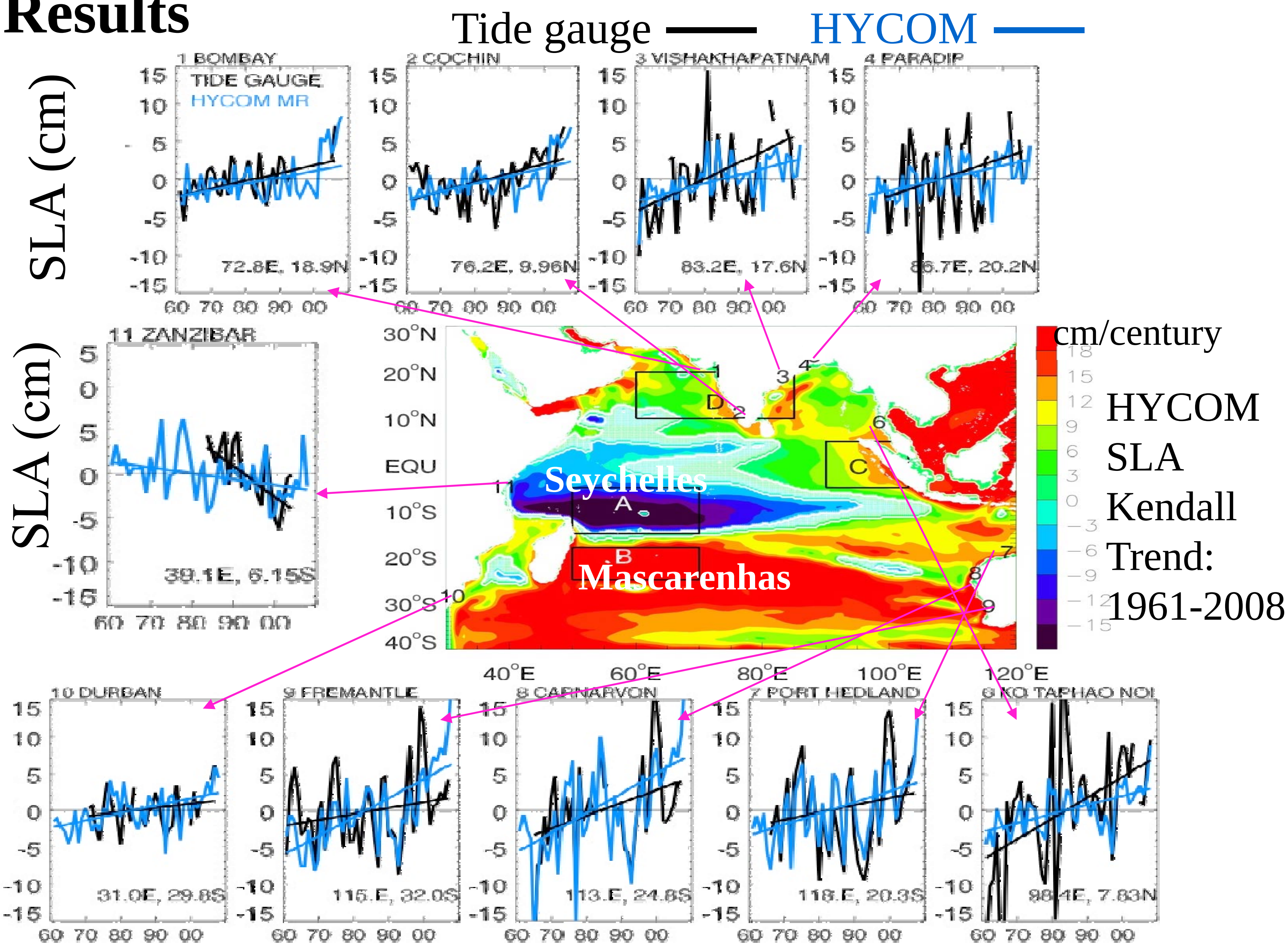
- **Observed Data:** Tide gauge (land move correction) & merged satellite sea level + reconstructed data; WOD05 temp.; ICOADS winds & SLP;
- **Ocean-atmosphere Reanalysis:** Ocean – SODA; HadISST; Atmosphere - 5 wind products; HadSLP2;
- **Ocean Models & Experiments:**

  (a) HYCOM - Indo-Pacific basin (55S-55N); forced by 3day ERA40 fields for 1958-2001; QuikSCAT wind, ISCCP SW & LW fluxes, CMAP P, NCEP I air temp. & specific humidity for 2000-08;

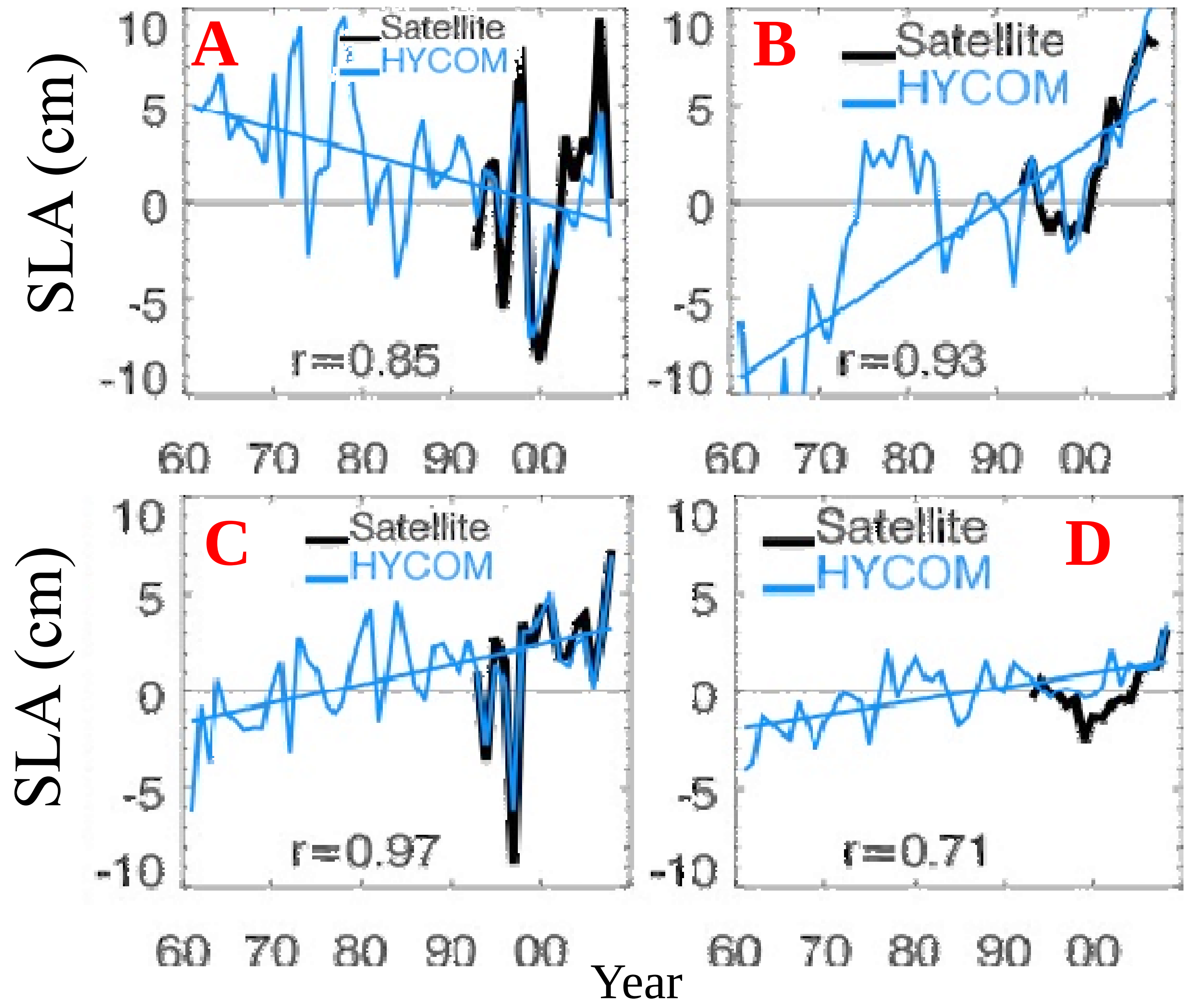
  (b) NCAR POP (CCSM4 Ocean Component) - 6hr NCEP I forcing for 1948-2004;

  (c) Linear model (LM) - MR: 3day ERA40 wind for 1958-2001; EXP: with wind in the Pacific fixed to the mean;
- **AGCMs:** **GFDL AM2.1 & GFS** - Forced by linear trend of HadISST for 1977-2006;
- **Coupled Global Climate Models**: NCAR CCSM3 & PCM (IPCC AR4)

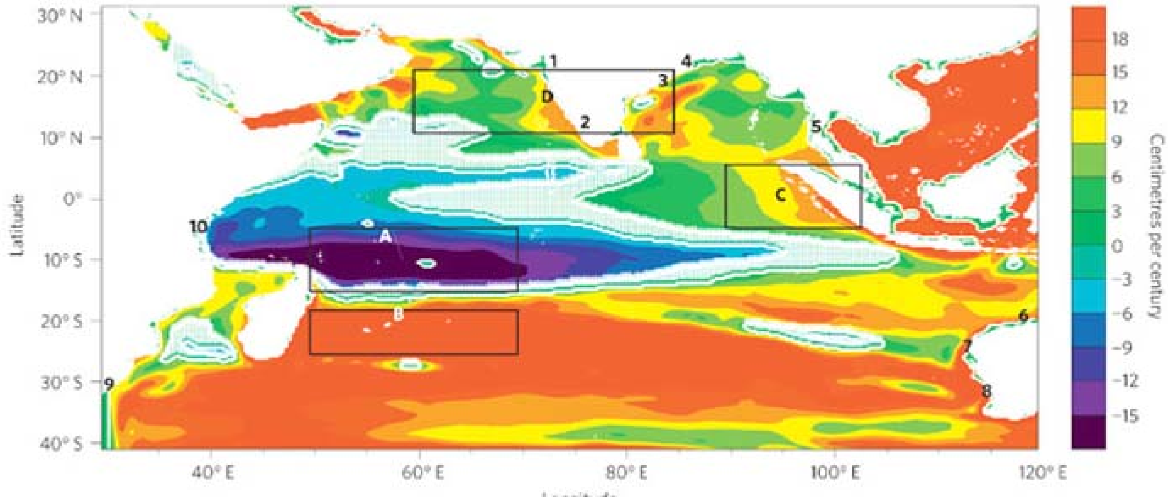
3. Results


Tide gauge
HYCOM
SLA (cm)
1 BOMBAY
TIDE GAUGE
HYCOM MR
72.8E, 18.9N
2 COCHIN
76.2E, 9.96N
3 VISHAKHAPATNAM
83.2E, 17.6N
4 PARADIP
86.7E, 20.2N
11 ZANZIBAR
39.1E, 6.15S
Seychelles
Mascarenhas
A
B
C
D
30°N
20°N
10°N
EQU
10°S
20°S
30°S
40°S
40°E
60°E
80°E
100°E
120°E
cm/century
HYCOM
SLA
Kendall
Trend:
1961-2008
10 DURBAN
31.0E, 29.8S
9 FREMANTLE
115.E, 32.0S
8 CARNARVON
113.E, 24.8S
7 PORT HEDLAND
118.E, 20.3S
6 KO TAPHAO NOI
98.4E, 7.83N
60 70 80 90 00

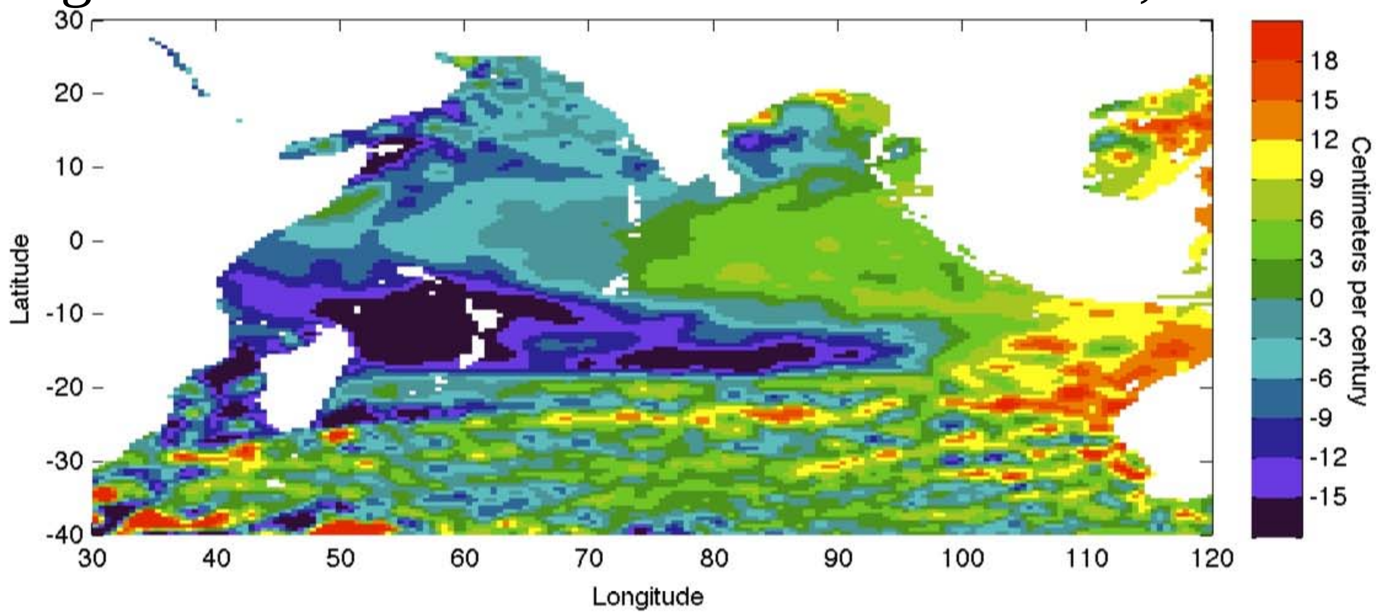
Time series of satellite/HYCOM SLA in 4 regions



HYCOM SSH trend, 1961-2008



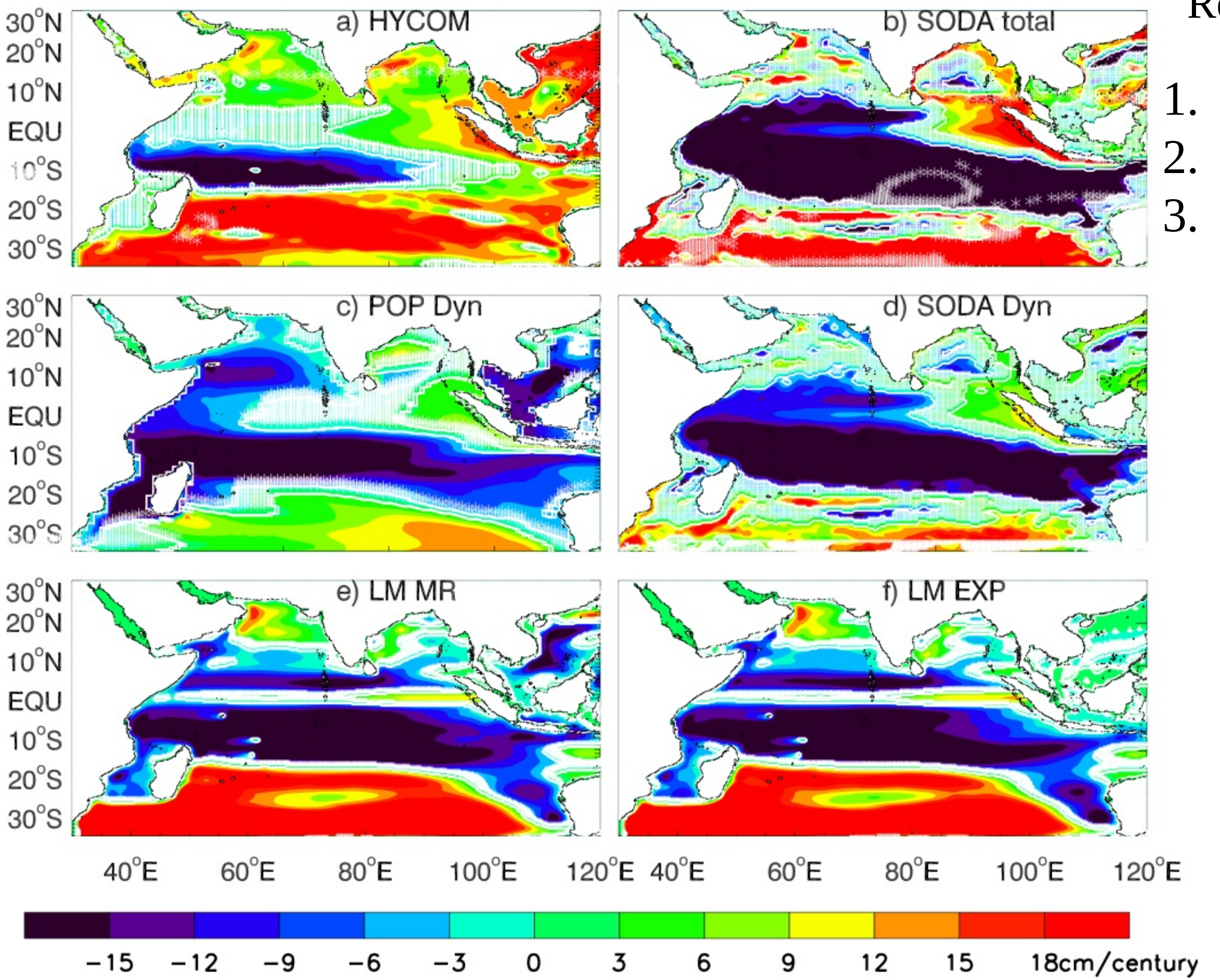
Hamlington et al. 2010: Reconstructed SSH trend, 1961-2008



SLA fall region: consistent with subsurface cooling:

Han et al. 2006; Alory et al. 2007; Trenary & Han 2008

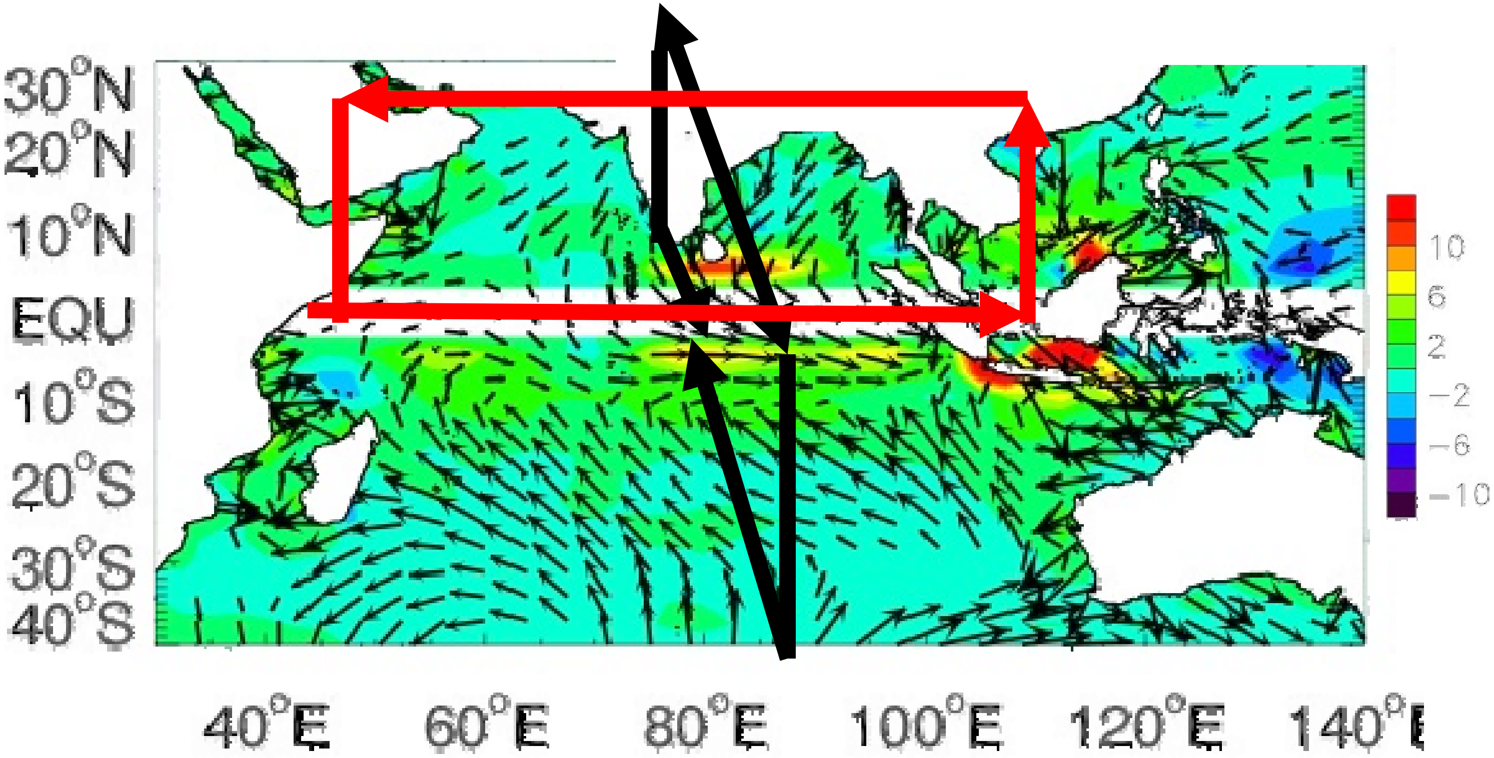
Kendall-Theil trend of SLA, 1961-2001



Reanalysis

1. Robust
2. Wind driven
3. IO wind

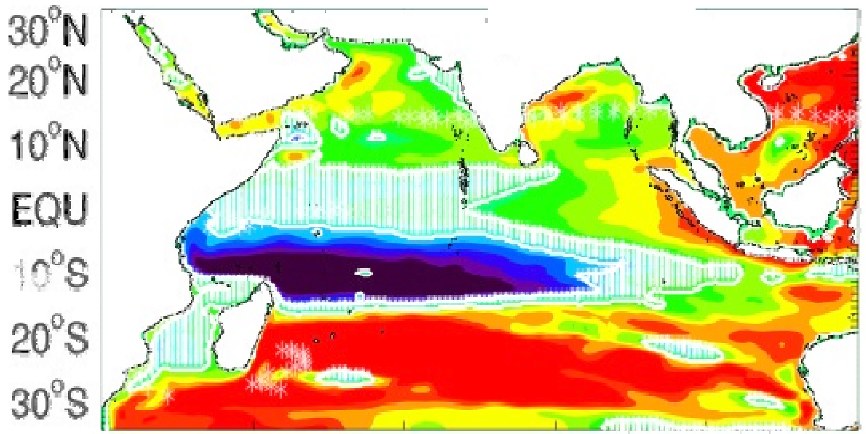
ERA40
Wind:
61-01
Trend



ERA40 wind stress & Ekman pumping velocity,

$$w_e = \frac{\partial}{\partial x}\left(\frac{\tau^y}{\rho_0 f}\right) - \frac{\partial}{\partial y}\left(\frac{\tau^x}{\rho_0 f}\right)$$

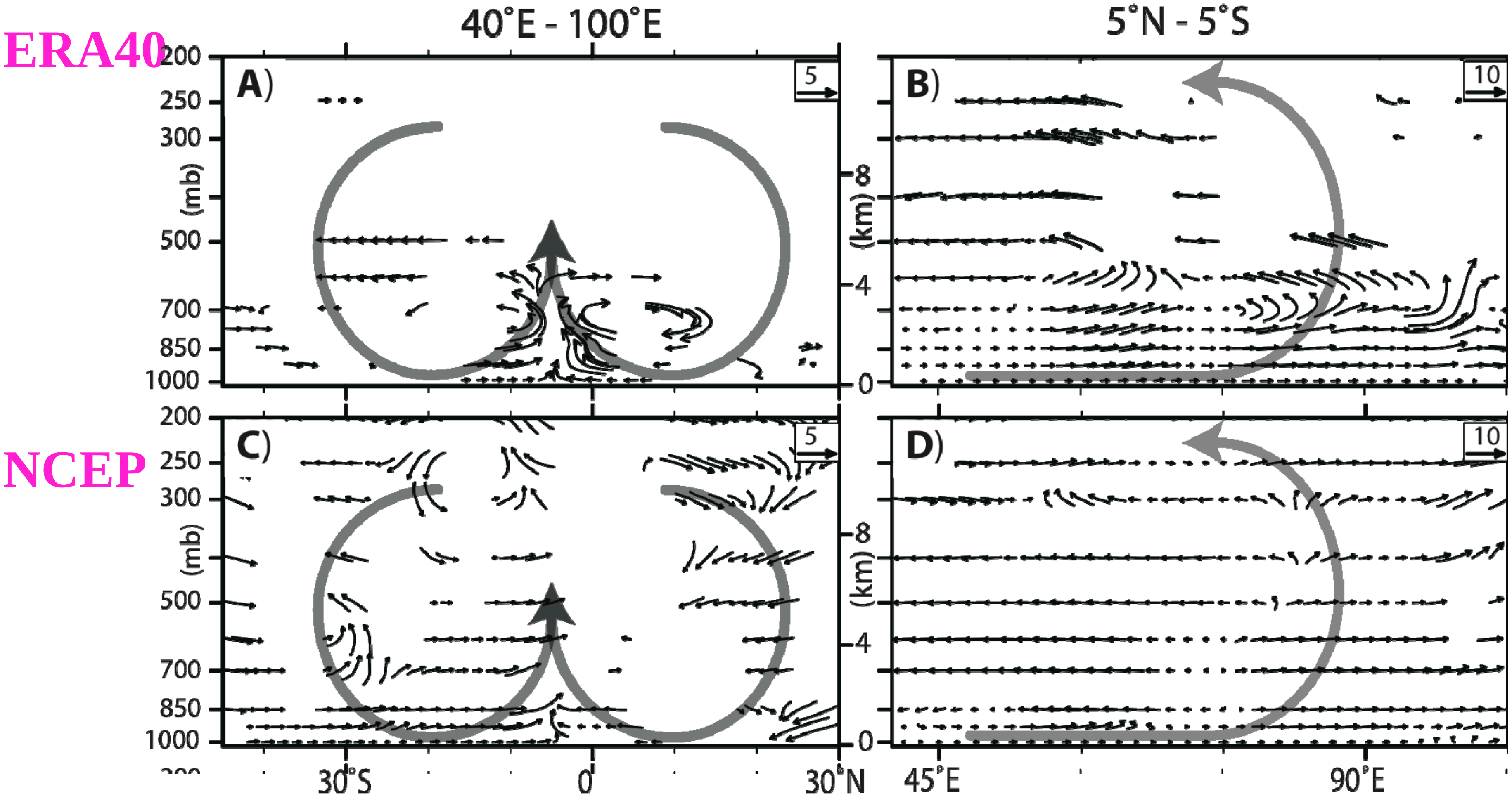
$$h \sim -\int_{\phi}^{\phi_e} w_e \, d\phi$$



Morner et al. 2004: Maldives

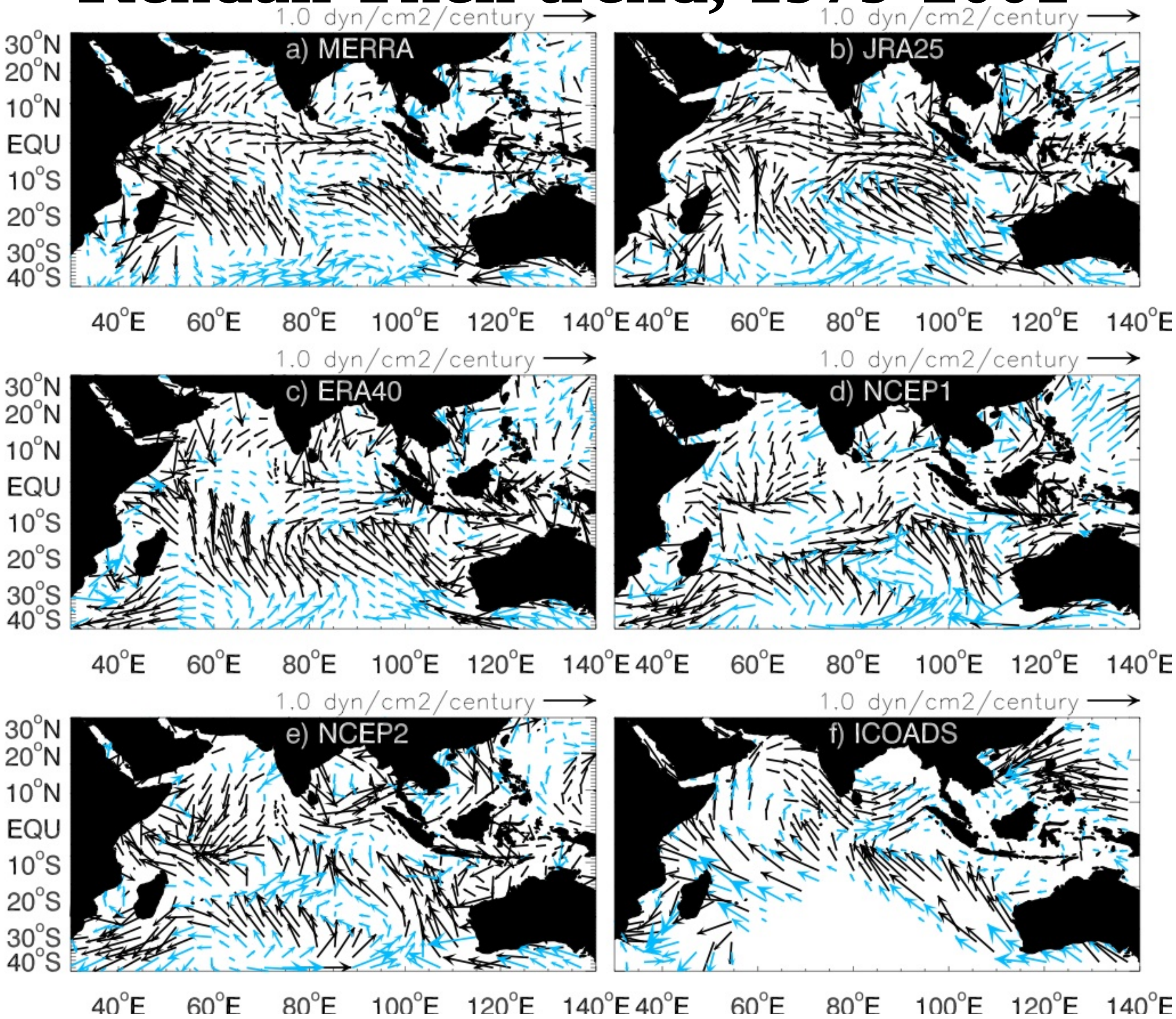
1961-2001 Kendall-Theil Trend

Local Hadley (40-100E avg) Local Walker (5S-5N avg)



Yu et al. 2010 (IO Walker Cell enhancing)

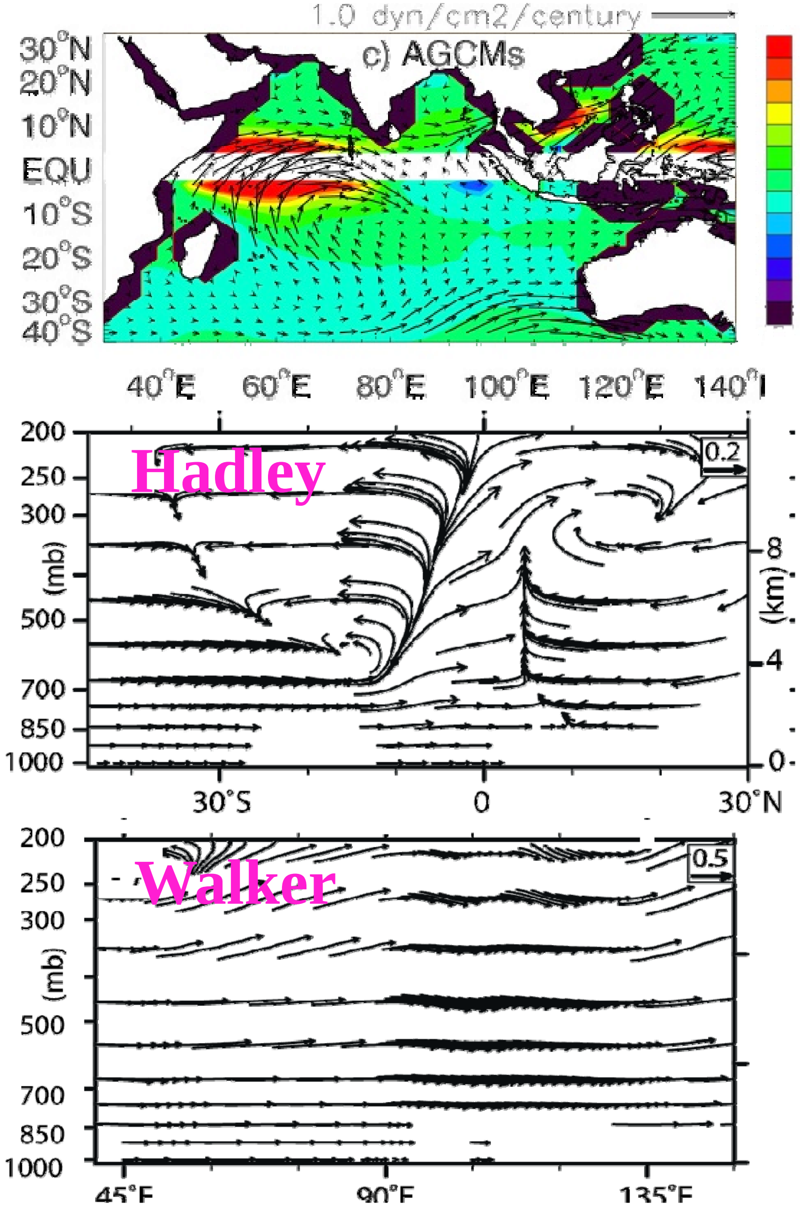
Kendall Theil trend, 1979-2001



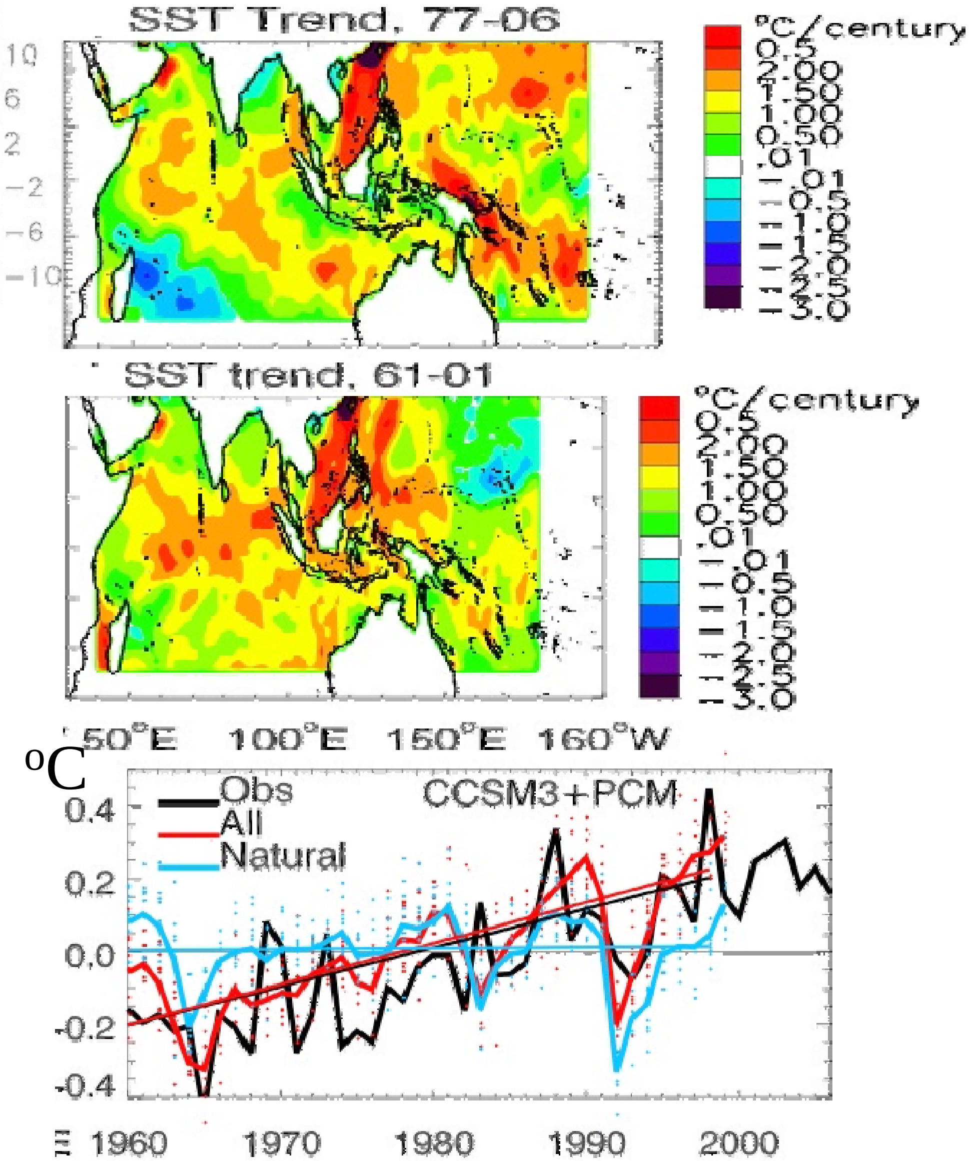
Signals exceed cross dataset differences and uncertainties.

Surface wind: Consistent with HadSLP and COADS SLP data;

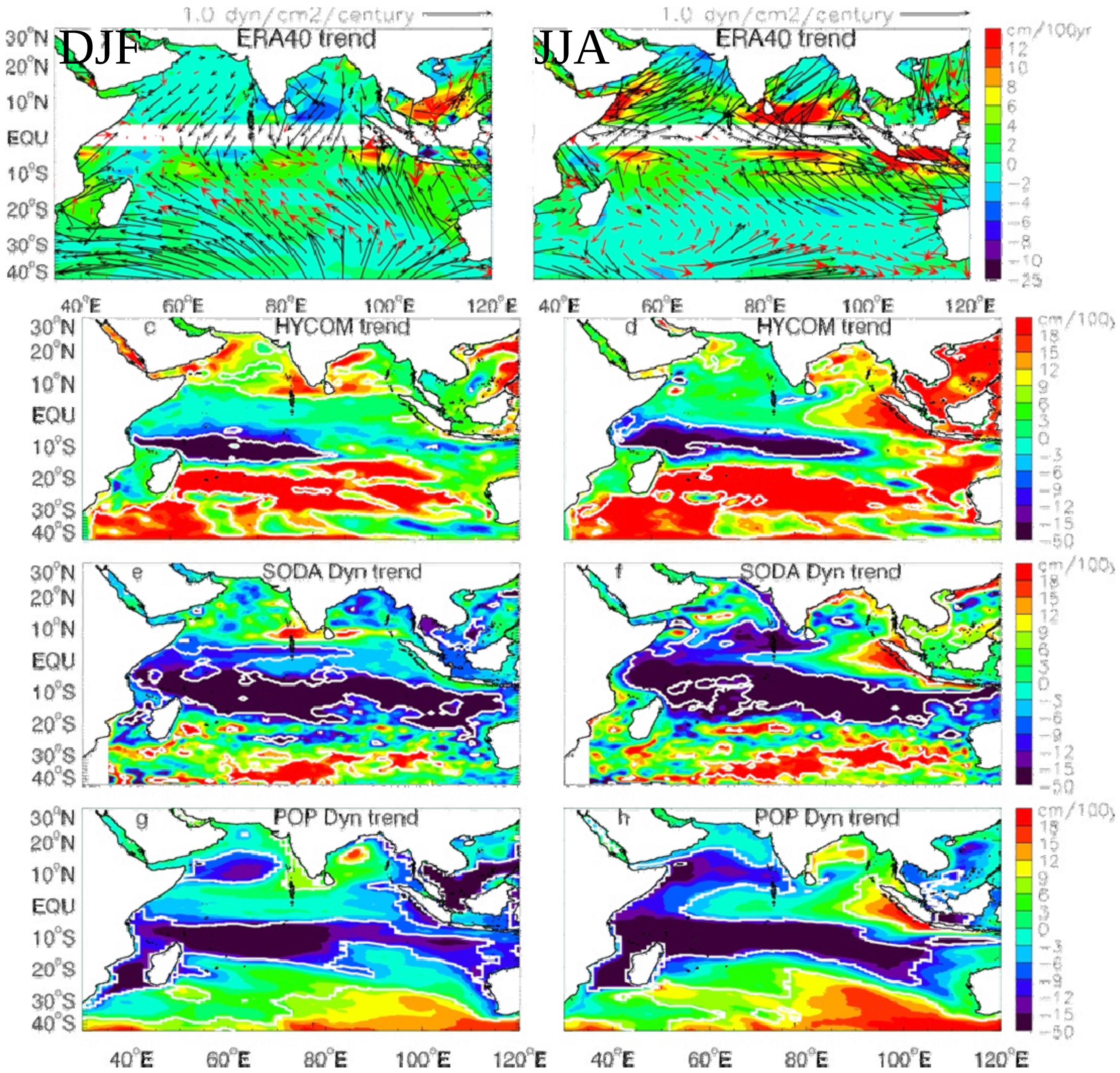
AGCMs wind stress: 60-member



Warm pool SST & trend



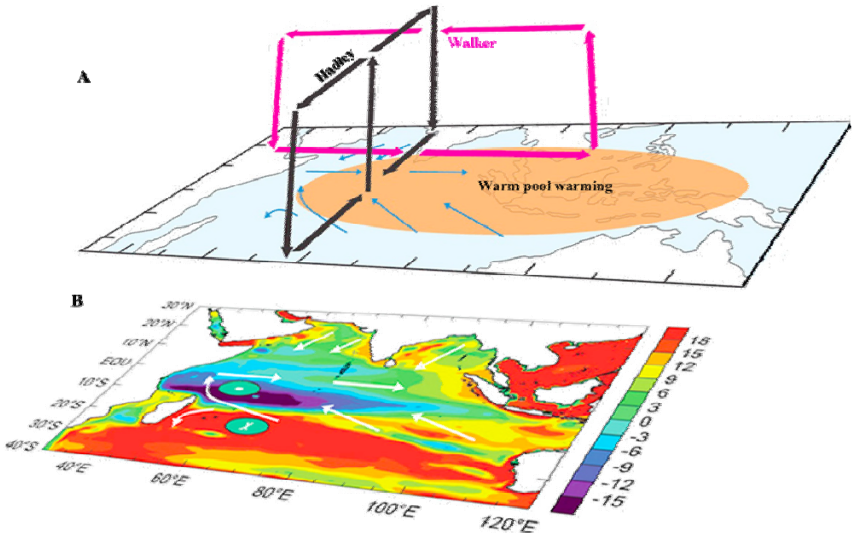
61-01 trend


DJF
JJA
1.0 dyn/cm2/century
ERA40 trend
HYCOM trend
SODA Dyn trend
POP Dyn trend
cm/100yr
30°N
20°N
10°N
EQU
10°S
20°S
30°S
40°S
40°E
60°E
80°E
100°E
120°E
c
d
e
f
g
h

4. Summary and Conclusions

•A distinct spatial pattern is detected for the IO SL change in the past few decades: SL rises in most region of the IO, but falls in the tropical SWIO near the Seychelles Islands;

•This SL pattern is driven by surface wind anomalies associated with combined enhancements of local Hadley and Walker cells of the IO region, which are PARTLY forced by warming in the Indo-Pacific warm pool;



•Both the SL and atmospheric circulation changes are robust to observational sampling and model differences; it indicates that if this pattern persists - increase stress on some coasts and islands more than others.

Caveats:

Natural variability - important;

Global mean sea level rise due to the melting Continental Ice (ice caps, glaciers, Greenland and Antarctic ice sheets):

Not included in any of the models.

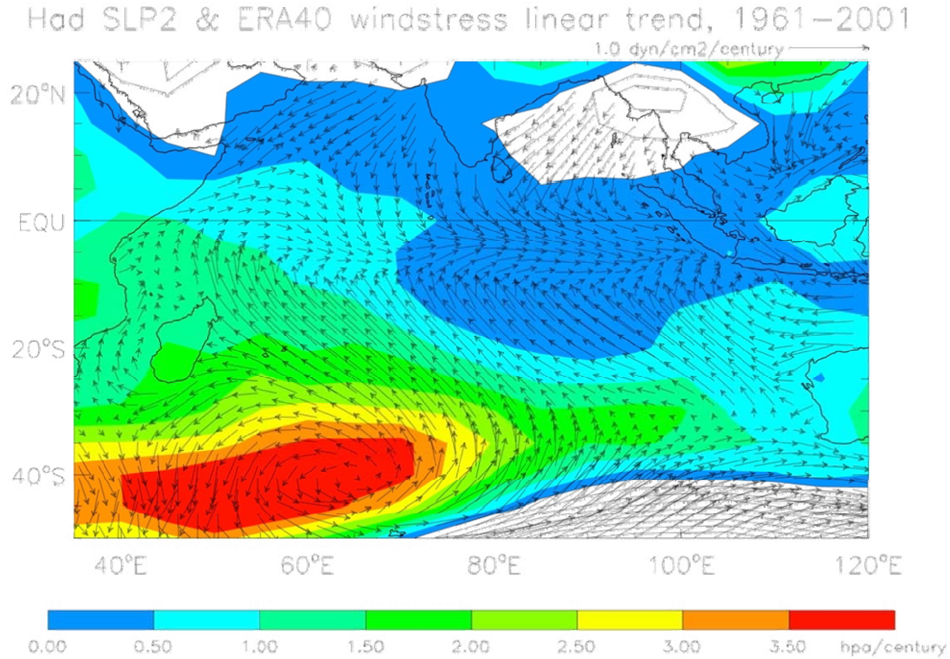
⇒Global mean sea level rise for 1961-2003:

⇒~0.69 ± 0.71 cm/century;

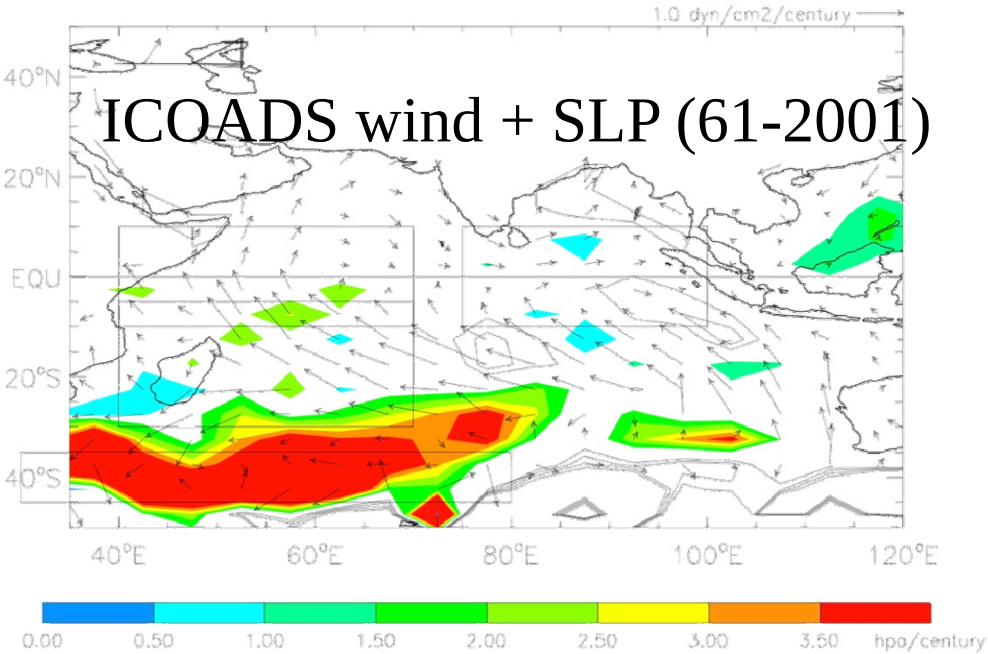
⇒Domingues et al. (2008) ~ 0.94cm/century (high end 1993-2003 period)

Acknowledgements

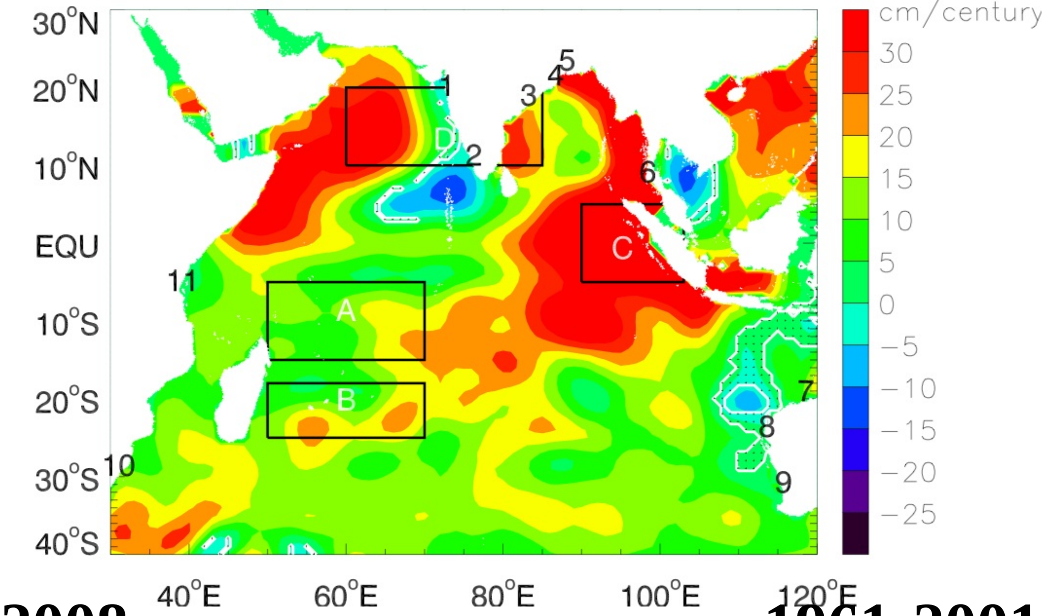
- NASA OSTST; NSF CAREER Program;
- CCR/NCAR for partial summer salary support;
- NCAR CISL for computational support;
- Drs Kevin Trenberth, A. Timmerman, Clara Deser, A. Dai.



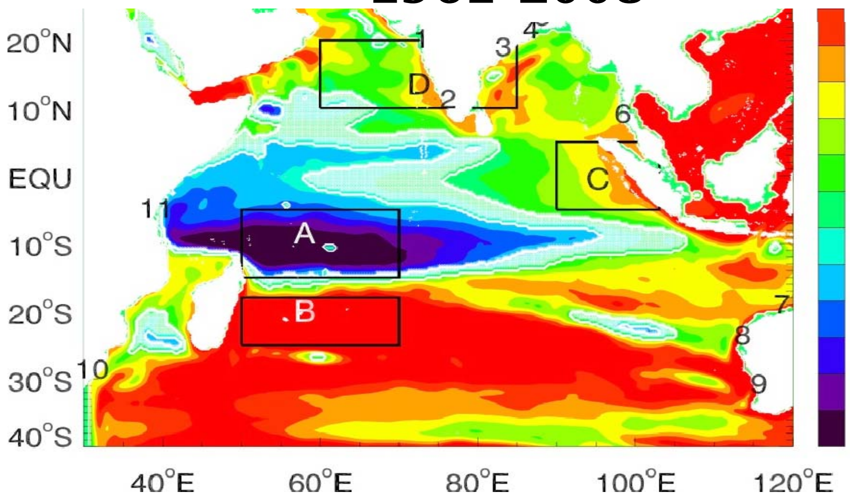
ICOADS wind + SLP (61-2001)



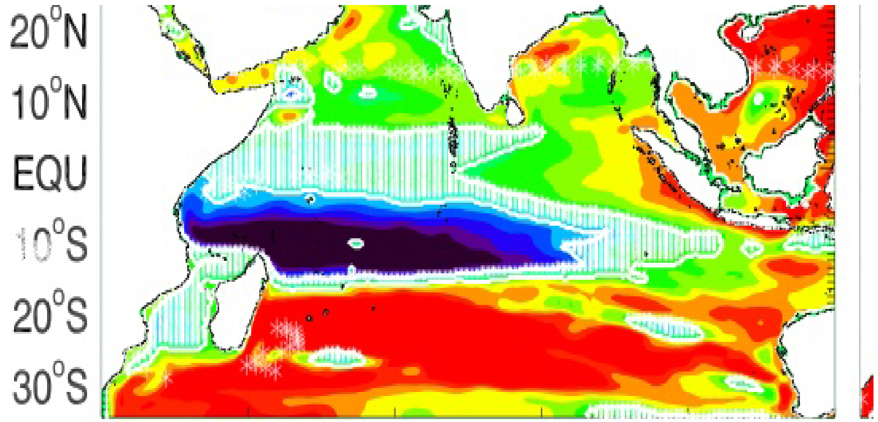
Reconstructed Sea Level trend, 1961-2001



1961-2008



1961-2001



Satellite observed (left) & HYCOM (right) SSHA trend

AVISO

HYCOM

1993-08

1993-01

2002-08