Multi-decadal trend and space-time variability of Indian Ocean sea level since the 1960s: Effects of external forcing vs internal climate modes

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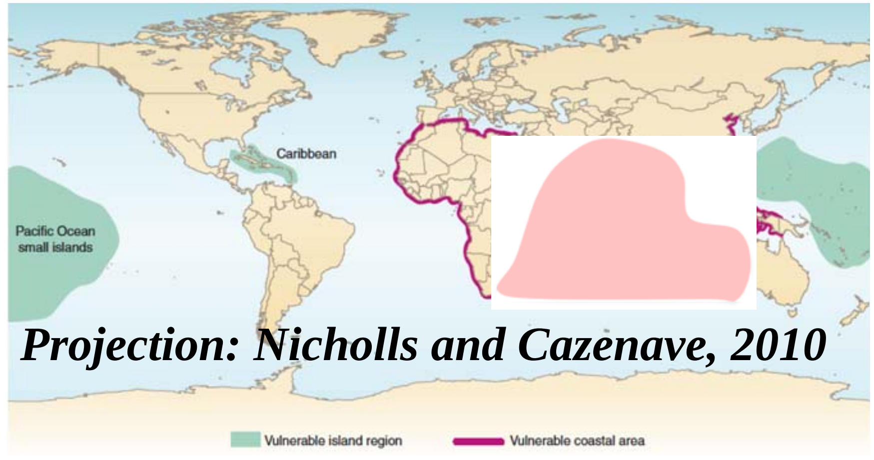
1. Background

- The Indian Ocean (IO) rim: one of *most vulnerable* regions to future SLC;
- ***Strong societal demand*** **for decadal (*P>10yrs*) predictions of IO SL;**
- ***Challenge:*** **natural internal climate variability is large:** *climate modes+model bias dominate uncertainties for 10-30yr prediction (e.g., Hawkins & Sutton 2009*);

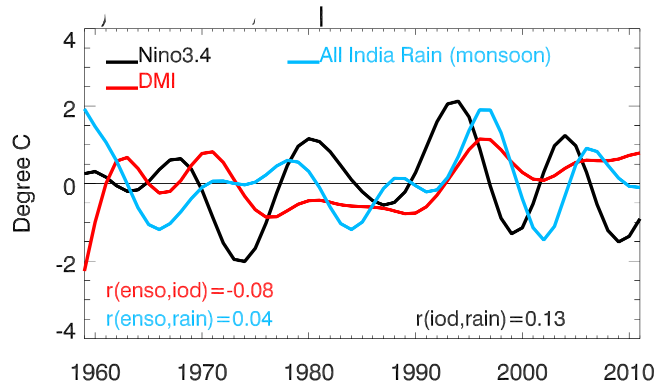


- ***Yet, quantitative understanding of the effects of climate modes vs external forcing on IO sea level is very Limited.***

Goal

- ❑ ***Understand the IO regional, decadal sea level variations associated with climate modes since the 1960s*** *(when more reliable observations are available);*

- ❑ ***Quantify the effects of external forcing (natural +anthropogenic) on IO SLC.***



Major climate modes affects IO:
Decadal ENSO ~IPO;
Decadal DMI (IOD);
Decadal all India rain (monsoon)

2. Approach

Observational analysis **using a relatively new approach -** ***Bayesian dynamical linear model (dlm)*** **- combined with** ***analysis of large ensemble experiments*** **from two climate models:** ***NCAR CESM1*** **40-member ensemble & Max-Plank Institute (MPI) model 100-member ensemble.**

The Bayesian dlm:

Observation equation:

$$Y(t) = b_0(t)+b_1(t)X_1(t)+ \ldots + b_M(t)X_M(t) + \varepsilon(t), \quad \varepsilon(t) \sim N(0,V(t)), \quad (1)$$

State equation: controls dynamical evolution of b_i

$$b_i(t)= b_i(t-1)+w(t), \qquad w(t) \sim N(0,W(t)). \qquad (2)$$

Posterior **predictive distribution of** b_i **at each time step** ***t*** **is updated based on its previous step** ***t-1*** **distribution (i.e.,** ***prior*****) and the probability of** ***Y*** **conditional on** b_i **at time** ***t*** **(i.e.,** ***likelihood*****) using Bayes theorem** *(Petris et al. 2009).*

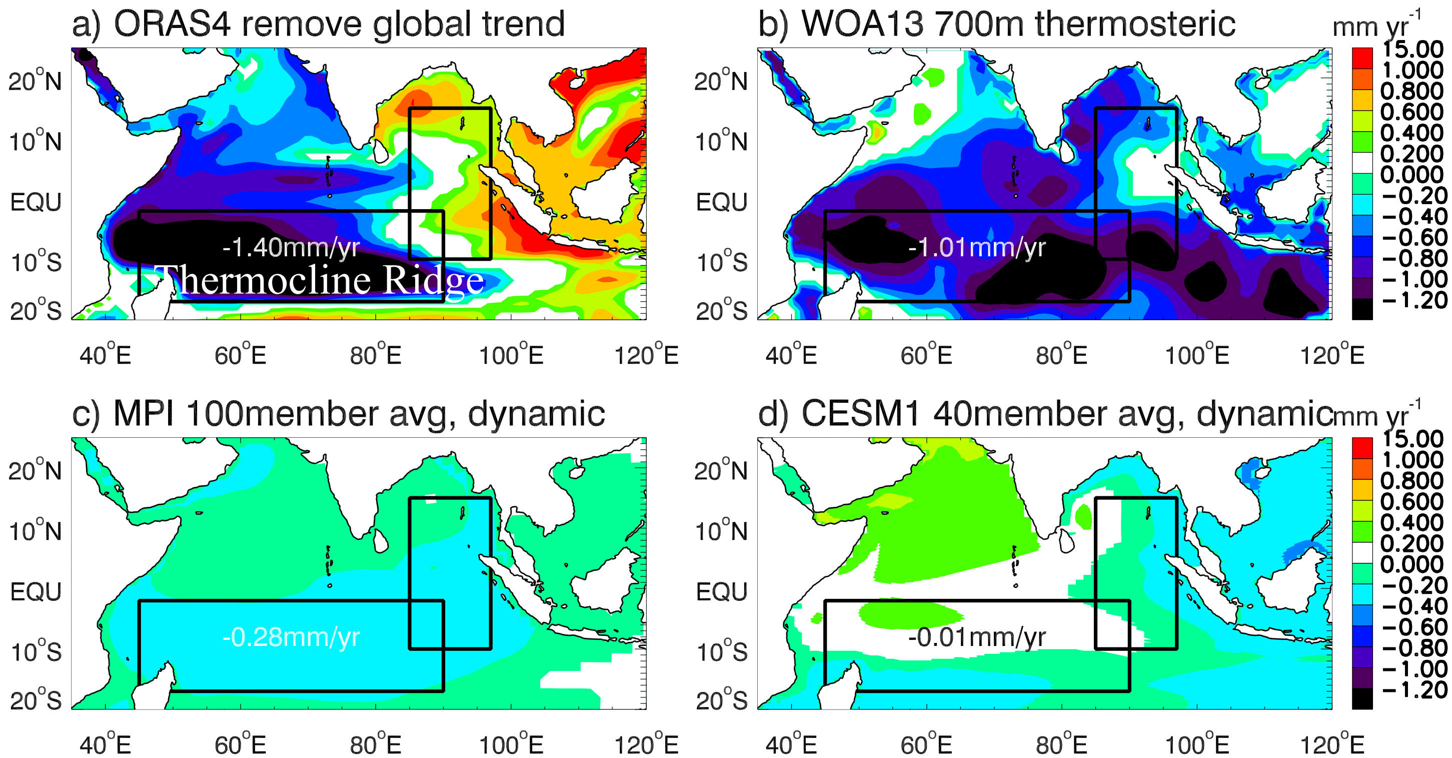
B_i is obtained by applying Kalman filtering and smoothing: measure ***changing relation between predictors X_i*** (*IPO, IOD & Indian monsoon rainfall*) and ***response variable Y - SLA*** ("non-static" or "dynamical").

3. Results: external forcing vs internal variability

(a) Multi-decadal sea level (SL) trend: 1959-2005

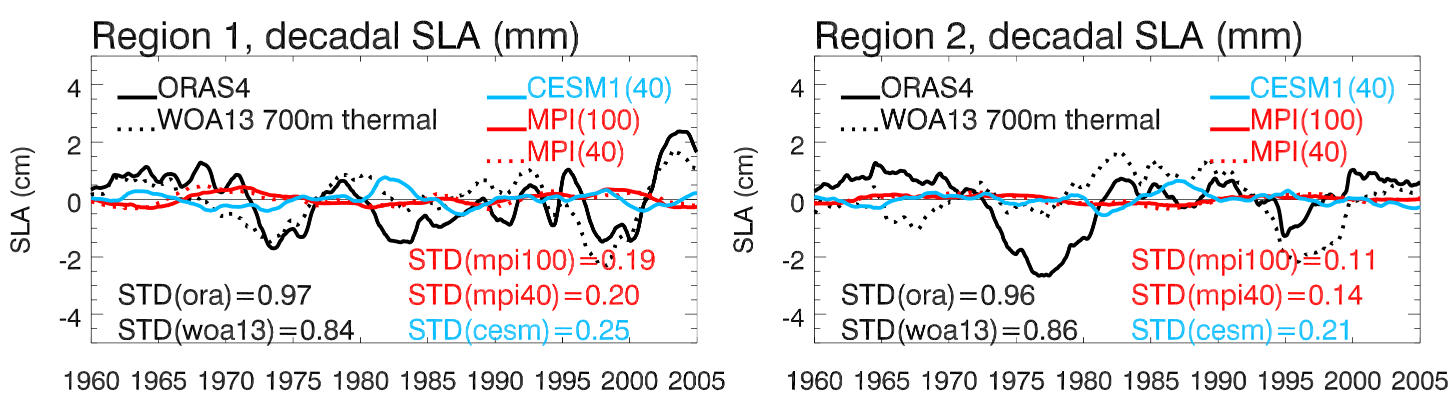
MPI 100avg:
External Forcing:
20~30%

CESM: Low east;
high west.
Partly bias?
Gent et al. (2011)



(b) Decadal SL anomaly (SLA): remove linear trend

MPI 100avg:
10~20%
MPI 40: higher
CESM 40: higher



(b) EOF1: decadal SLA associated with climate modes

EOF1: 8yrlp WOA13 700m therm. sla (mm)& that associated with climate modes

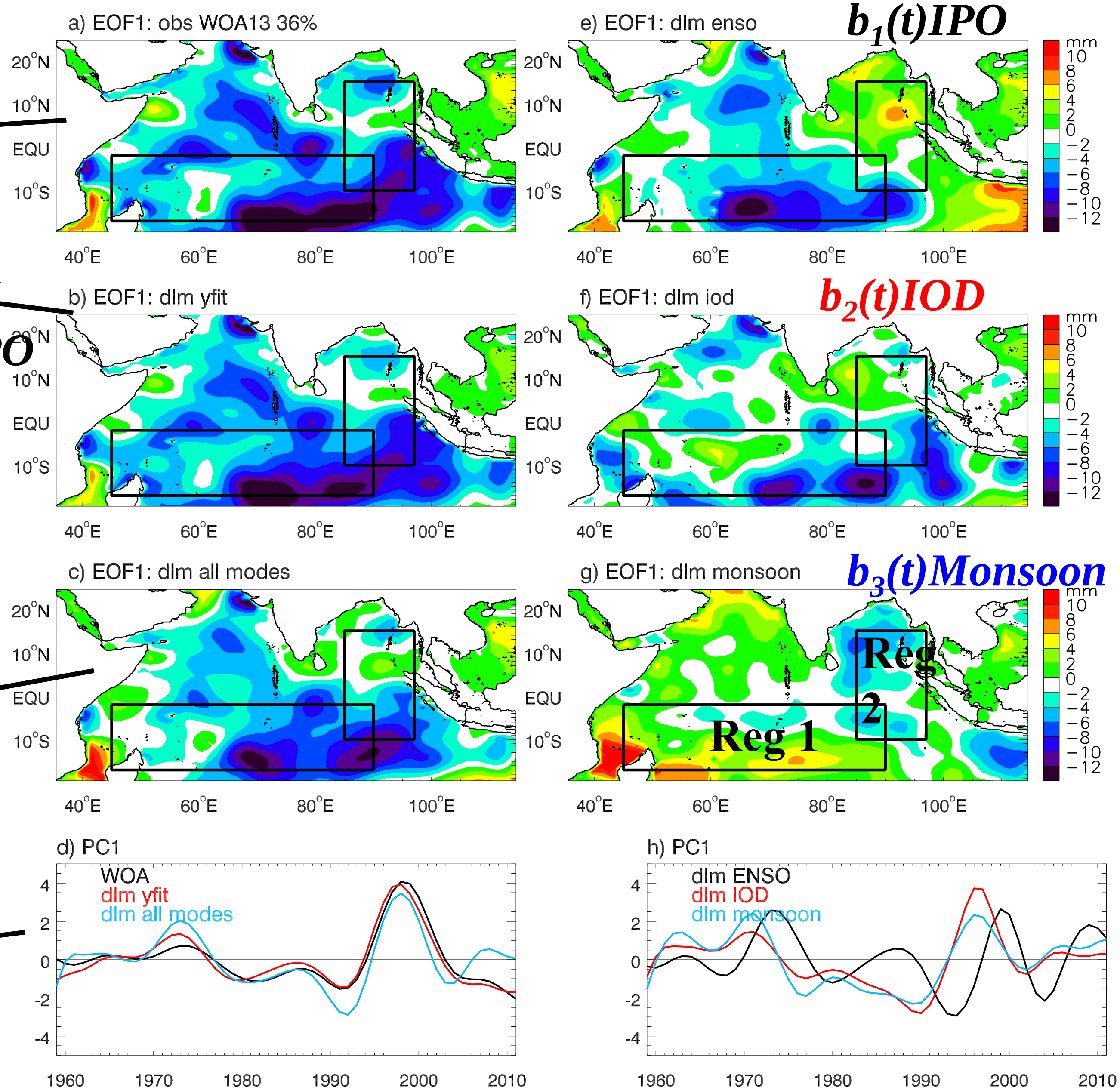
Obs: Woa13

dlm simulation

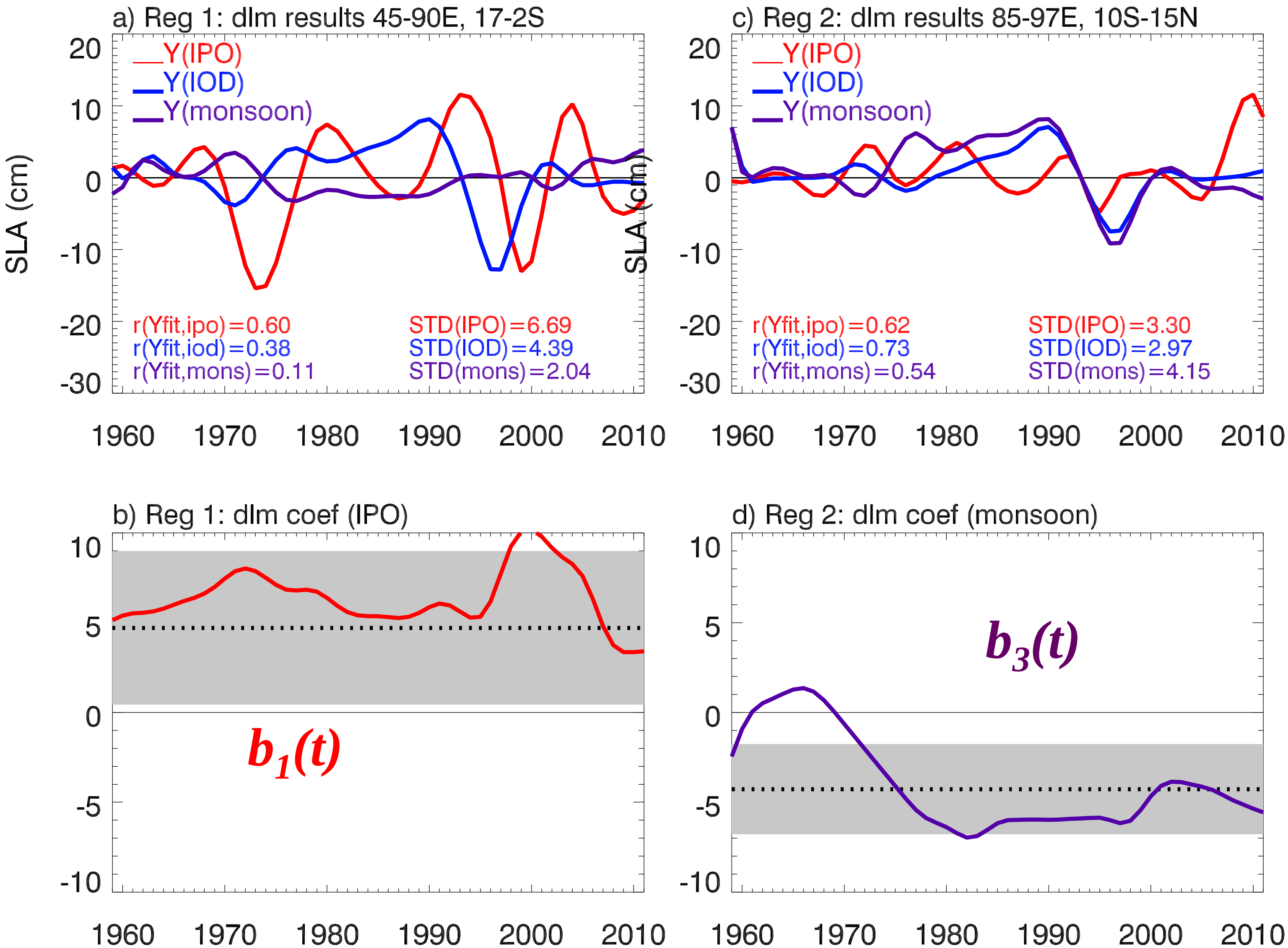
Yfit $= b_0(t)+b_1(t)IPO + b_2(t)IOD + b_3(t)Monsoon$

Effects of all clim. Modes

PC1



Decadal SLA associated with climate modes: 2 regions



4. Summary

- ***Spatial patterns of multi-decadal trend (1959-2005):***

climate modes (IPO+IOD+monsoon) are the major cause; external forcing (natural + anthropogenic) **may have contributed to (20~30%) over the Thermocline ridge region based on MPI 100ens;**

- ***Decadal (8yr lowpass) variability:***

IPO plays a larger role overall, with IOD having comparable contributions; since the 1980s, off-EQ Indian summer monsoon convection has a large contribution near the eastern IO coasts through wind-driven ocean circulation; external forcing contributes to 10~20% of observed STD in key regions based on MPI 100ens.

Acknowledgement

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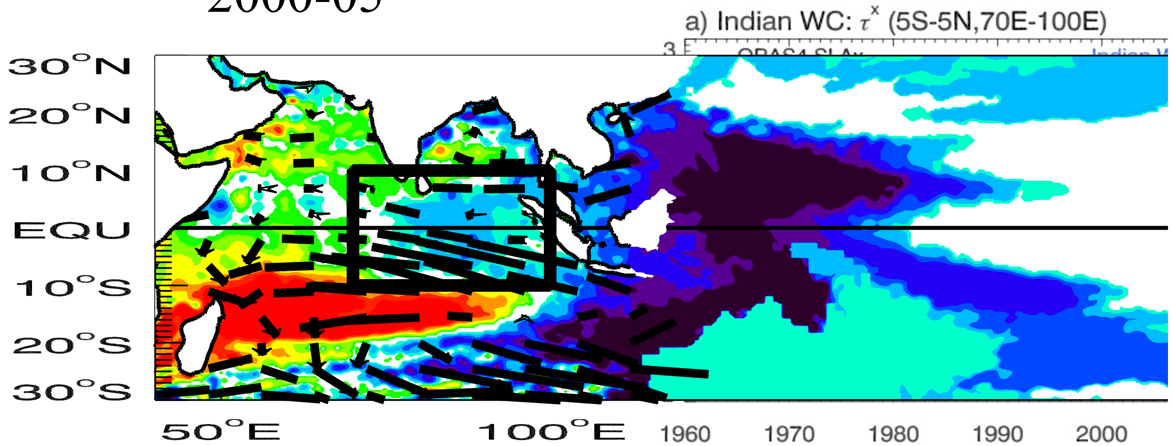
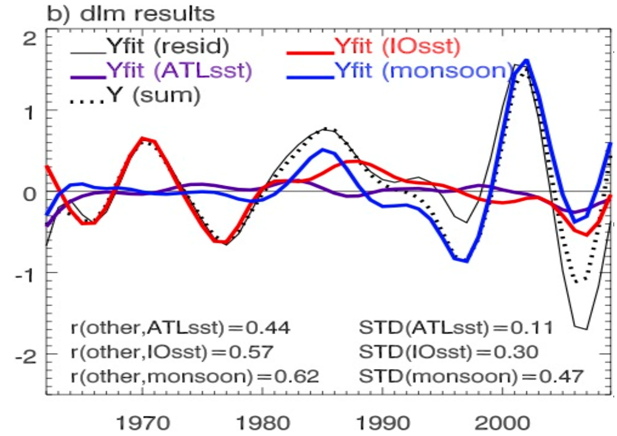
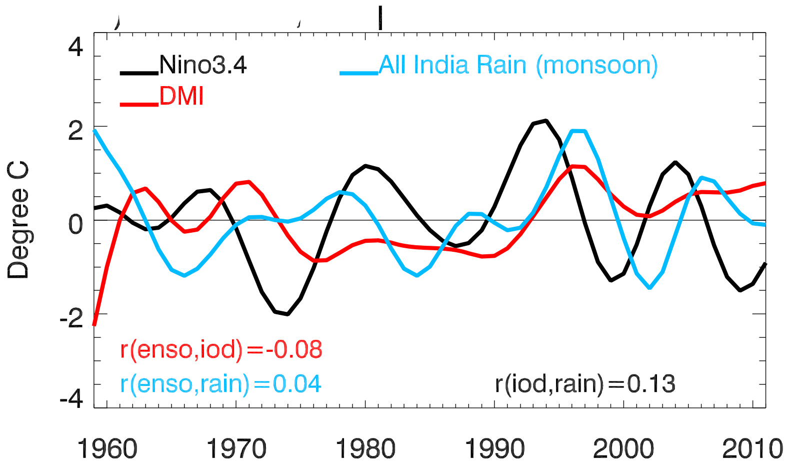
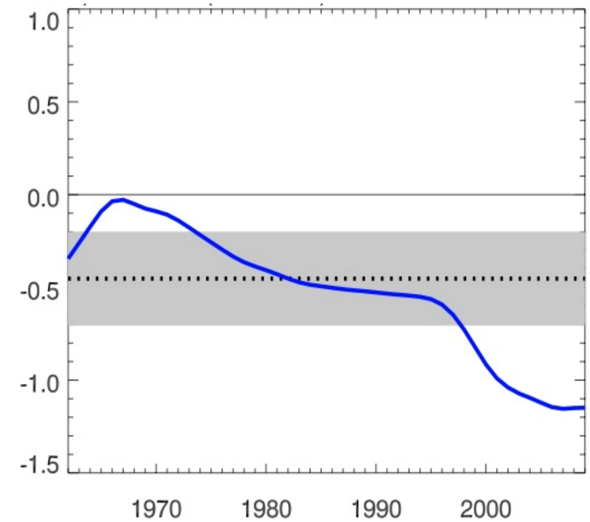
2000-05

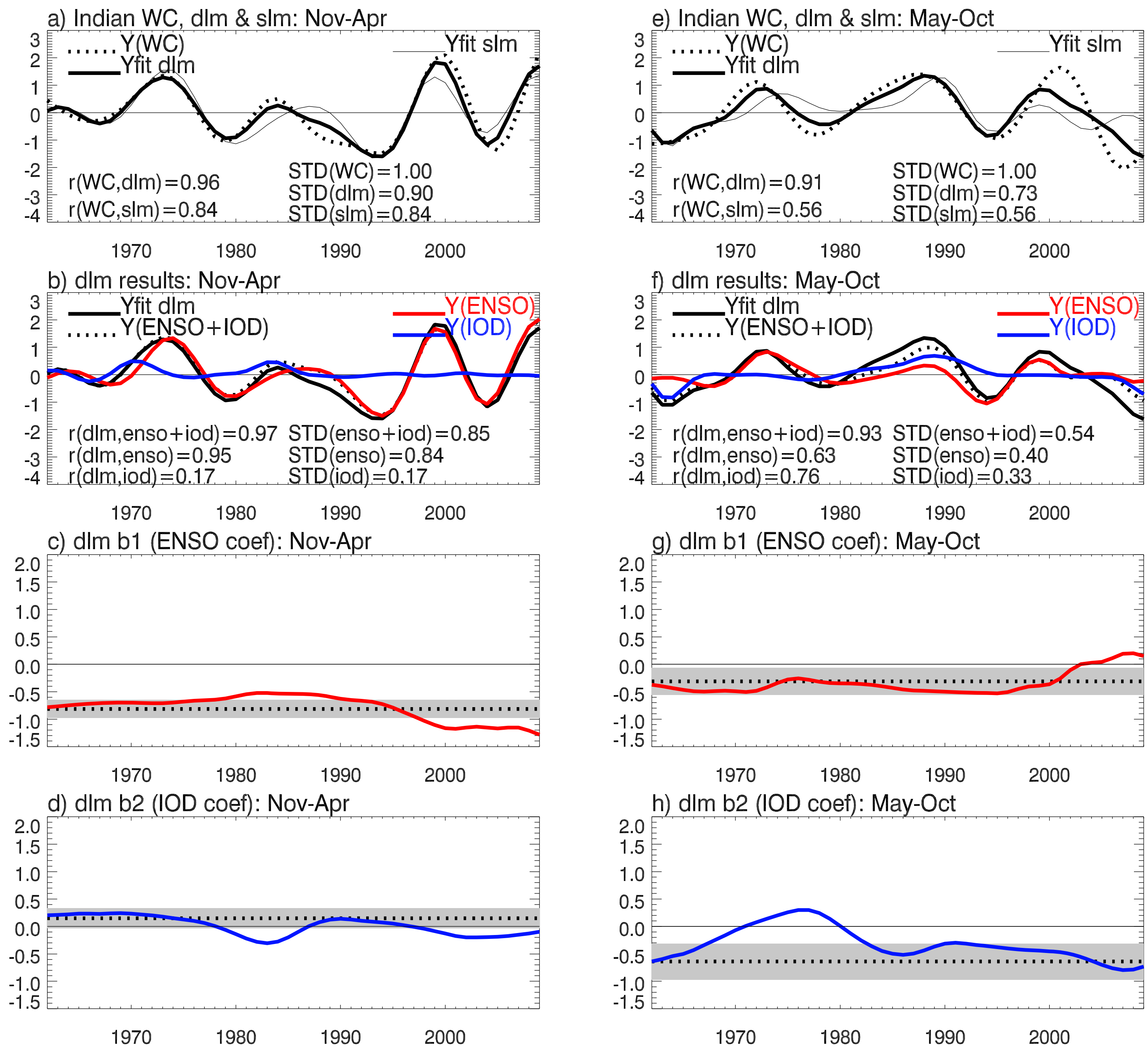


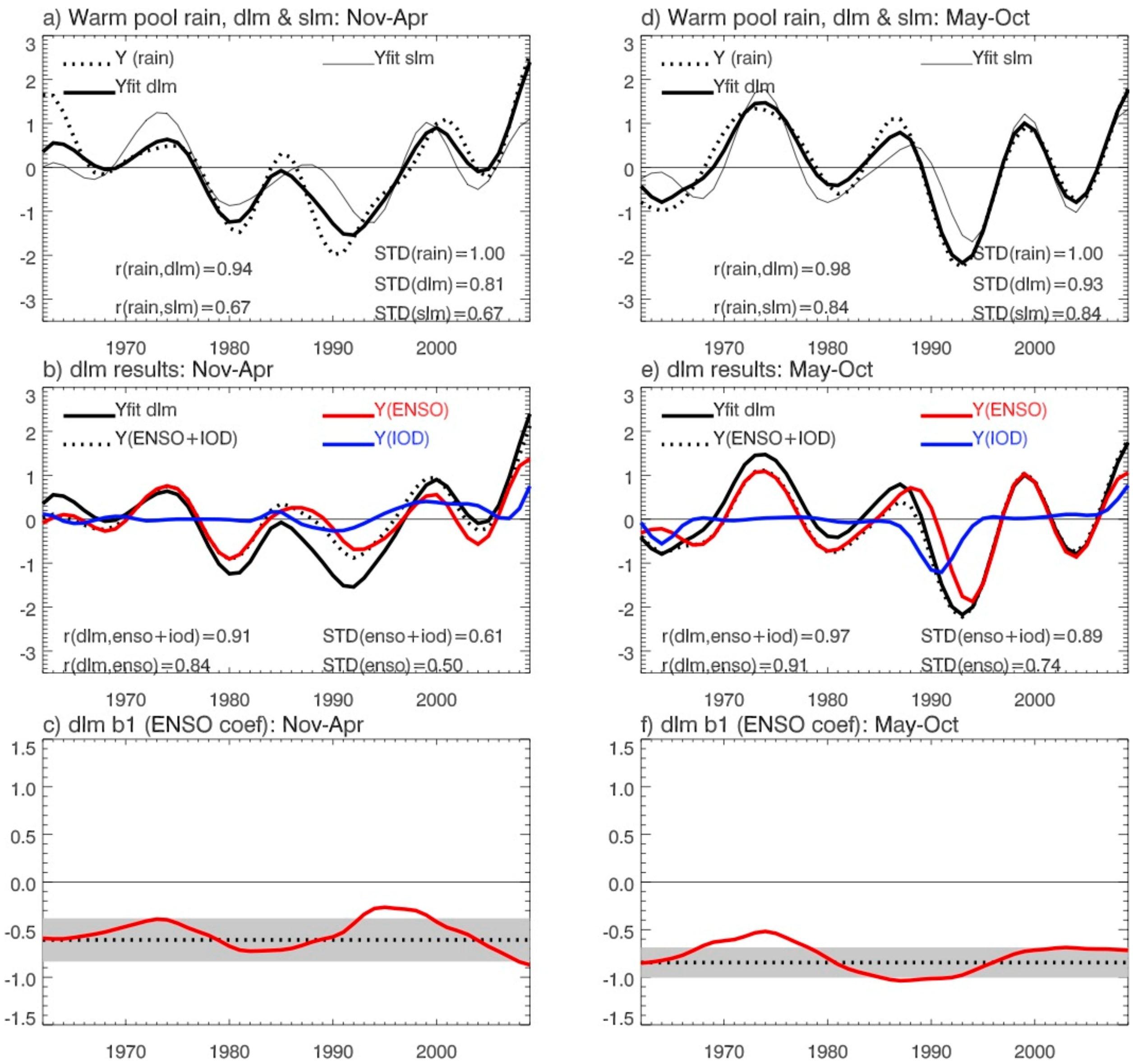


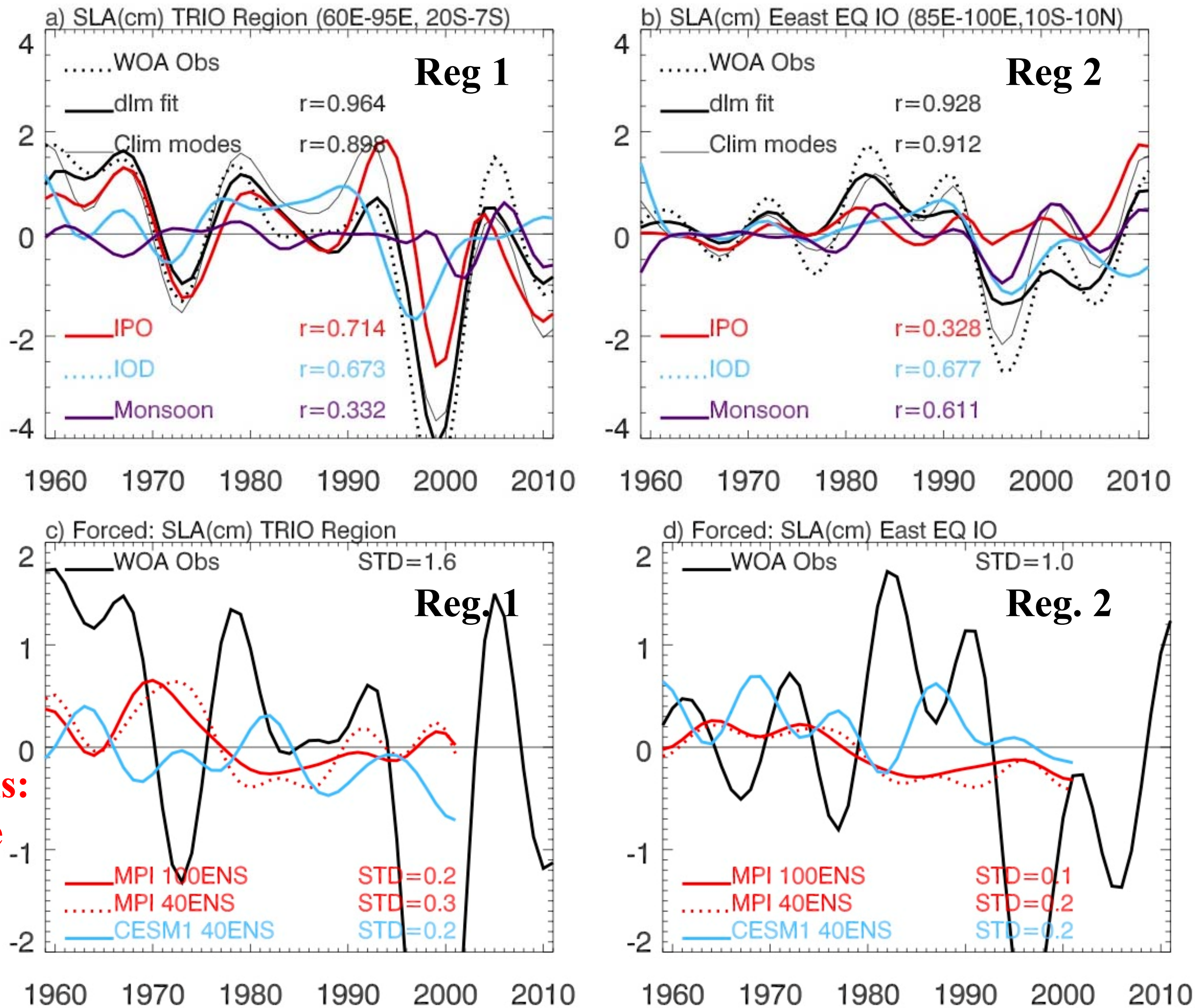


dlm coef: monsoon




a) Indian WC, dlm & slm: Nov-Apr
Y(WC)
Yfit dlm
Yfit slm
r(WC,dlm)=0.96
r(WC,slm)=0.84
STD(WC)=1.00
STD(dlm)=0.90
STD(slm)=0.84
e) Indian WC, dlm & slm: May-Oct
Y(WC)
Yfit dlm
Yfit slm
r(WC,dlm)=0.91
r(WC,slm)=0.56
STD(WC)=1.00
STD(dlm)=0.73
STD(slm)=0.56
b) dlm results: Nov-Apr
Yfit dlm
Y(ENSO+IOD)
Y(ENSO)
Y(IOD)
r(dlm,enso+iod)=0.97
r(dlm,enso)=0.95
r(dlm,iod)=0.17
STD(enso+iod)=0.85
STD(enso)=0.84
STD(iod)=0.17
f) dlm results: May-Oct
Yfit dlm
Y(ENSO+IOD)
Y(ENSO)
Y(IOD)
r(dlm,enso+iod)=0.93
r(dlm,enso)=0.63
r(dlm,iod)=0.76
STD(enso+iod)=0.54
STD(enso)=0.40
STD(iod)=0.33
c) dlm b1 (ENSO coef): Nov-Apr
g) dlm b1 (ENSO coef): May-Oct
d) dlm b2 (IOD coef): Nov-Apr
h) dlm b2 (IOD coef): May-Oct
1970
1980
1990
2000


a) Warm pool rain, dlm & slm: Nov-Apr
Y (rain)
Yfit dlm
Yfit slm
r(rain,dlm)=0.94
r(rain,slm)=0.67
STD(rain)=1.00
STD(dlm)=0.81
STD(slm)=0.67
b) dlm results: Nov-Apr
Yfit dlm
Y(ENSO+IOD)
Y(ENSO)
Y(IOD)
r(dlm,enso+iod)=0.91
r(dlm,enso)=0.84
STD(enso+iod)=0.61
STD(enso)=0.50
c) dlm b1 (ENSO coef): Nov-Apr
d) Warm pool rain, dlm & slm: May-Oct
Y (rain)
Yfit dlm
Yfit slm
r(rain,dlm)=0.98
r(rain,slm)=0.84
STD(rain)=1.00
STD(dlm)=0.93
STD(slm)=0.84
e) dlm results: May-Oct
Yfit dlm
Y(ENSO+IOD)
Y(ENSO)
Y(IOD)
r(dlm,enso+iod)=0.97
r(dlm,enso)=0.91
STD(enso+iod)=0.89
STD(enso)=0.74
f) dlm b1 (ENSO coef): May-Oct
1970
1980
1990
2000



10-20% of Obs

Clim. Models: considerable difference