Indian Ocean Dipole in Various Coupled GCM Simulations

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Broad Objectives

- To understand the diversity in the IOD evolutions among various coupled GCMs.
- To understand the independent nature of IOD and ENSO through sensitivity experiments with a realistic high resolution SINTEX-F CGCM.
- Identification of processes that lead to model biases in other models.

IOD in Different CGCM studies

- Iizuka et al. 2000 JMA AGCMT106+MOM2(0.5x0.5) Realistic simulation of IOD that is independent of ENSO
- Baquero-Bernal et al. (2002) ECHO-G 2.8x2.8AGCM+0.5x0.5 OGCM – ENSO independent dipole mode does not exist. No role of ocean dynamics in the IOD evolution
- Yu et al. (2004) UCLA AGCM 5x4 + MOM (0.3x0.3) IOD is ENSO forced
- Gualdi et al. 2003 SINTEX :ECAM4 t42 + OPA8.2 (0.5x2.0) IOD mostly independent of ENSO
- Kitoh (2003) MRI CGCM2 t42 AGCM + 2.5x2 MOM (0.5 near equator) Ocean dynamics plays a role in IOD evolution but IODs triggered by ENSO
- Yamagata et al. 2004 SINTEX-F1 t106 + OPA8.2 (0.5x2.0) IOD is independent of ENSO which is realistic in higher resoltuon version of SINTEX. Role of ocean waves in IOD evolution as observed.
- Behera et al. 2004 SINTEX-F1 Realistic IOD has paramount impact on East African short rains.
- Fisher et al. (2004) SINTEX t30+OPA8 Sensitivity experiments suggest independent nature of IOD
- Cai et al. 2004 CSIRO Mark3 CGCM No simultaneous correlation between IOD and ENSO but strong correlation at 1 year lag. Stronger throughflow through the Indonesian passages might be a cause.
- Lau and Nath 2004 GFDL CGCM t30 + MOM1.1 1.875x1.875 ; Independent IODs are found. IODs might be triggered by ENSO or the variability from the Southern Ocean.
- Ashok et al. 2004 GFDL CGCM – Decadal IOD mostly independent of Pacific influence.
- Tozuka et al. 2004 Role of ocean dynamics in the modulation of decadal IOD in the high resolution SINTEX-F1 simulation.
- Rao et al. 2004 As in observation abortion of IOD by ISOs in the SINTEX-F1 simulation.
- Wu and Kirtman 2004 COLA coupled GCM – discussed the Indian Ocean impact on the ENSO variability

Bernal et al. 2002

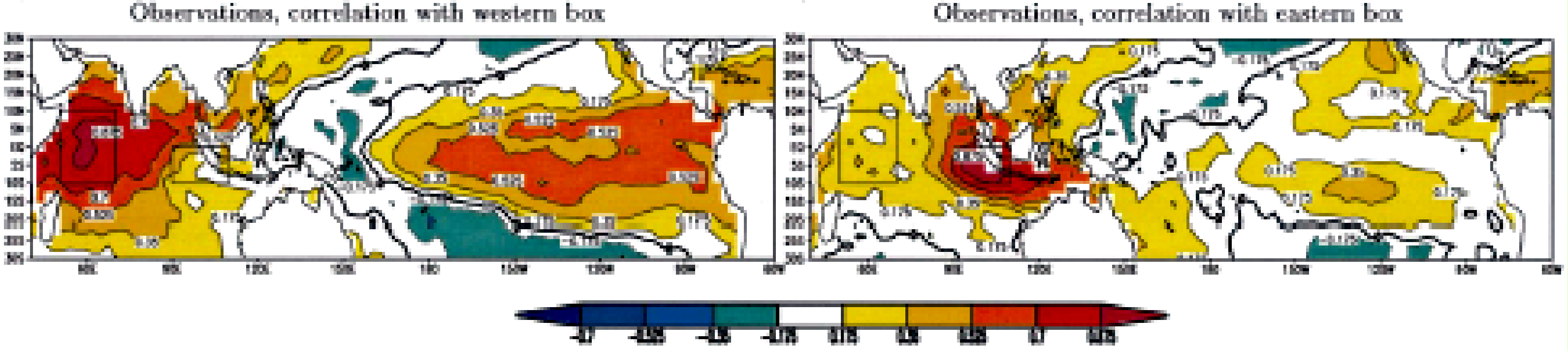


FIG. 1. Correlation of (a) WTIO box-averaged SSTAs, and (b) SETIO box-averaged SSTAs with Indo-Pacific SST anomalies for all seasons. SSTAs from the Hadley Centre observational dataset, 1949–98. Correlations exceeding (a) 0.31 and (b) 0.30 are significant at the 95% confidence level.

Boreal fall season (SON):

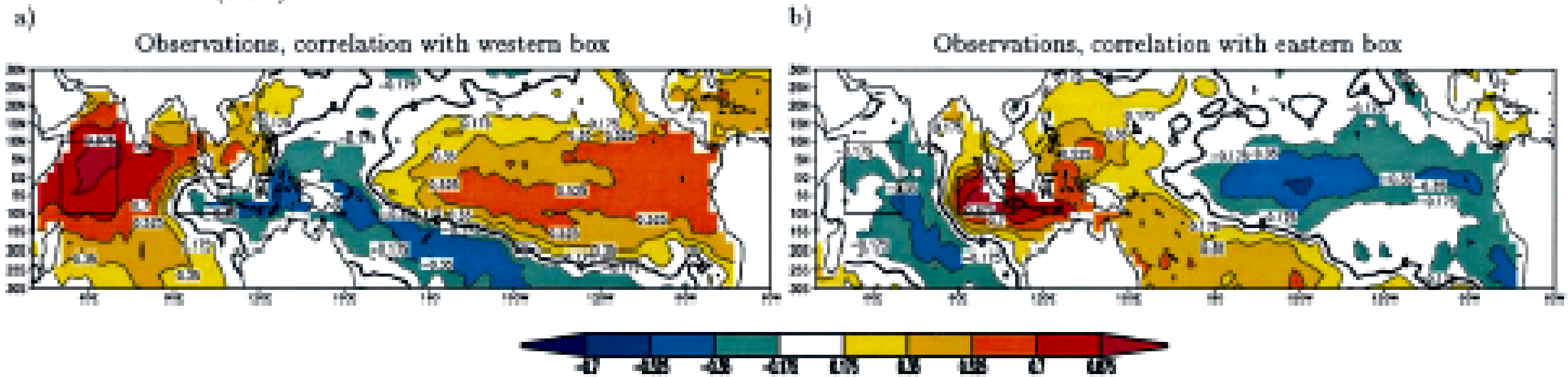


FIG. 2. Correlation of (a) WTIO box-averaged SSTAs, and (b) SETIO box-averaged SSTAs with Indo-Pacific SSTAs for SON. SSTAs from the Hadley Centre observational dataset, 1949–98. Correlations exceeding (a) and (b) 0.27 are significant at the 95% confidence level.

Boreal fall season (SON):

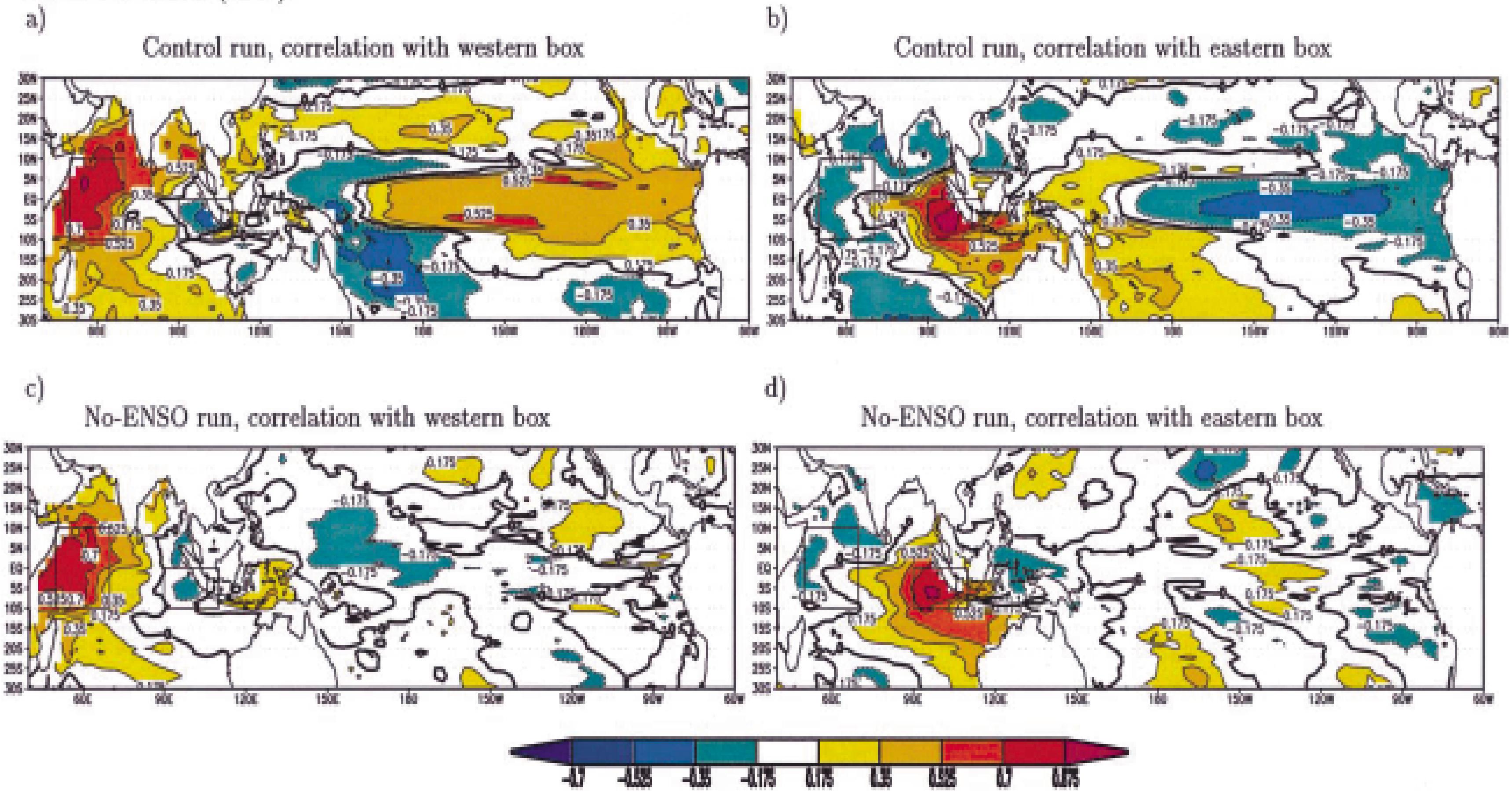


FIG. 9. Correlation of WTIO box-averaged SSTAs, SETIO box-averaged SSTAs, with Indo-Pacific SSTAs for SON. (a) and (b) SSTAs from the control run of the CGCM ECHO-G. (c) and (d) SSTAs from the no-ENSO run. In (a) and (c) correlations are with respect to the WTIO. In (b) and (d) correlations are with respect to SETIO. Correlations exceding (a), (b), (d) 0.20 and (c) 0.24 are significant at the 95% confidence level.

All seasons:

a) ECHAM4/mixed layer, correlation with western box

b) ECHAM4/mixed layer, correlation with eastern box

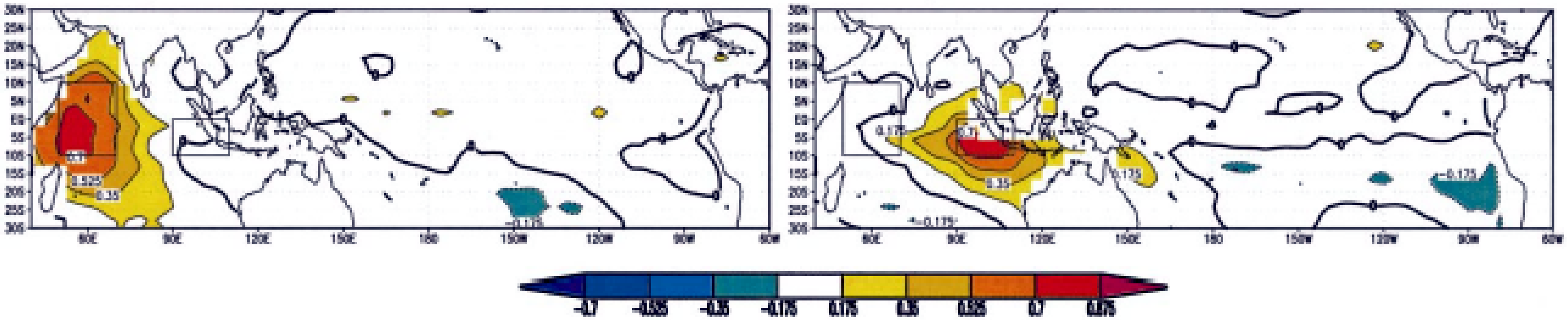


FIG. 10. Correlation of (a) WTIO box-averaged SSTAs, and (b) SETIO box-averaged SSTAs with Indo-Pacific SSTAs for all seasons. The SSTAs are from the ECHAM4/mixed layer ocean simulation. Correlations exceeding (a) 0.16 and (b) 0.20 are significant at the 95% confidence level.

Boreal fall season (SON):

a) ECHAM4/mixed layer, correlation with western box

b) ECHAM4/mixed layer, correlation with eastern box

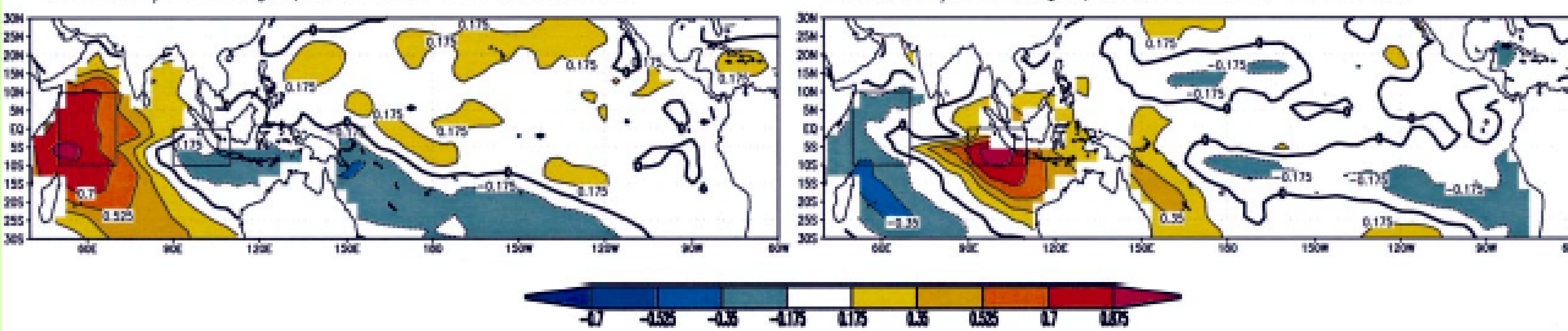
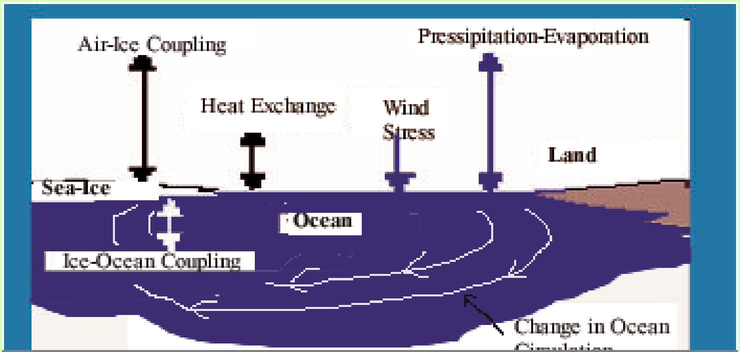


FIG. 11. Correlation of (a) WTIO box-averaged SSTAs, and (b) SETIO box-averaged SSTAs with Indo-Pacific SSTAs for SON. SSTAs are from the ECHAM4/mixed layer ocean simulation. Correlations exceeding (a) 0.20 and (b) 0.22 are significant at the 95% confidence level.

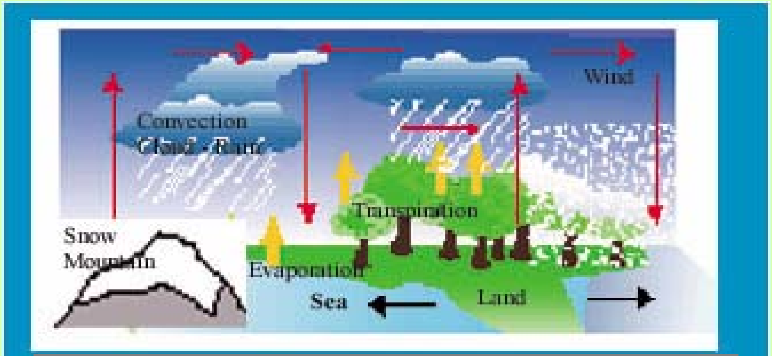
Main points drawn by Bernal et al.

- No east-west anti-correlation when considered all seasons.
- The east-west anti-correlation exists during boreal fall which is also captured by the ECHO-G coupled model.
- However, the model dipole in boreal fall is related to the ENSO
- And whatever independent dipole like variability found in the model is owing to the stochastic atmospheric forcing without any role of ocean dynamics.

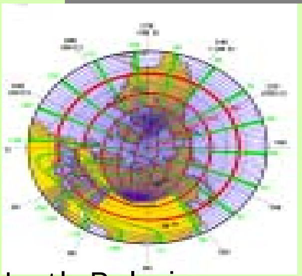
Schematic view of the present version of the SINTEX-F CGCM



OCEAN: OPA8.2 ORCAR2 Grid
2^0X1.5^0 Eq-0.5 Level 31



ATMOSPHERE: ECHAM4
T106 L19



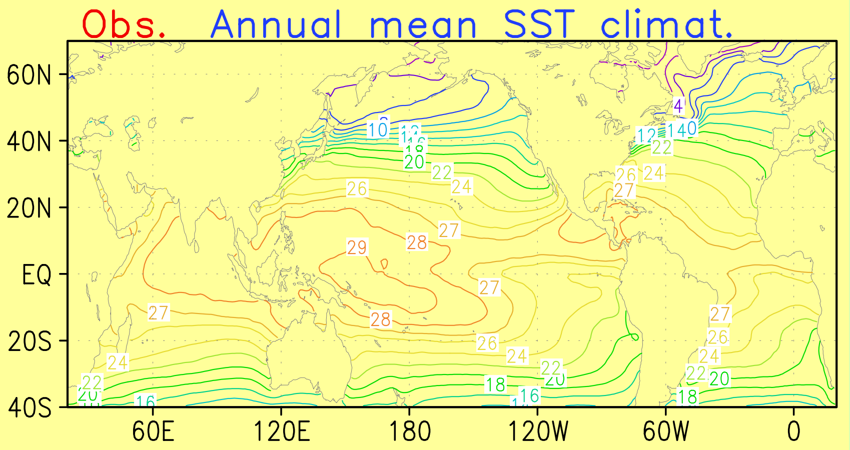
North Pole is replaced by two land points

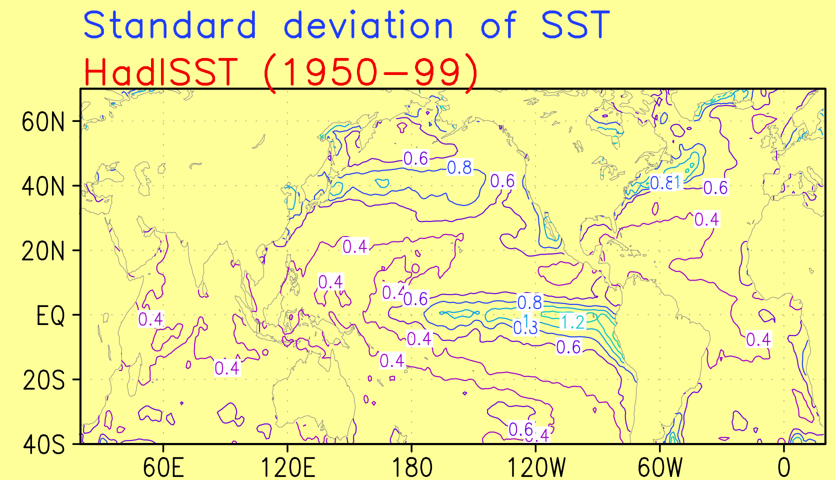
Non-flux adjustment

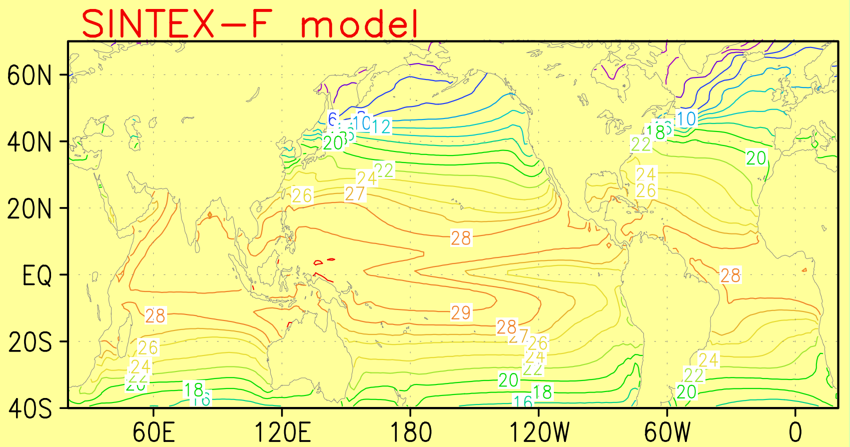
Every 2 hrs
Coupler-
OASIS2.2

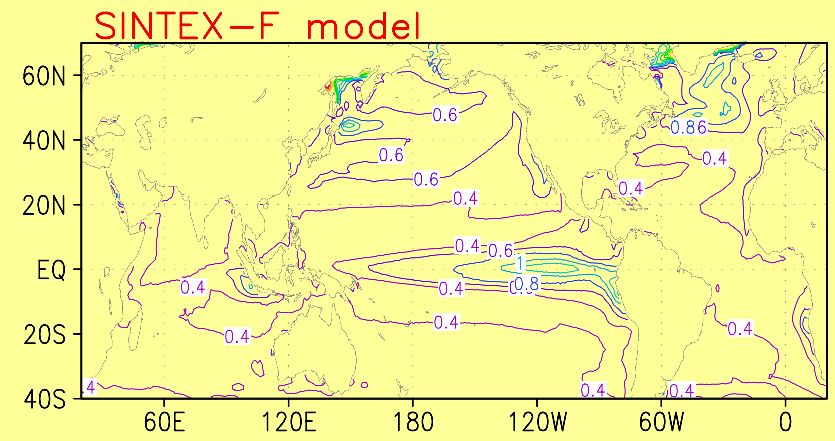
Earth Simulator

SINTEX-F CGCM Climatology

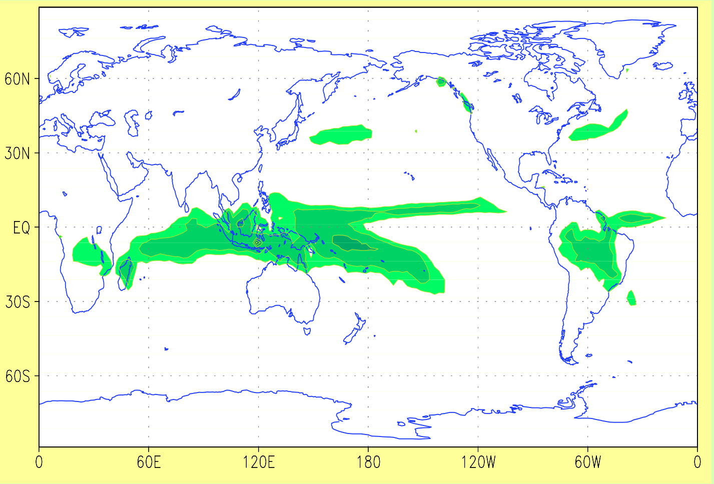


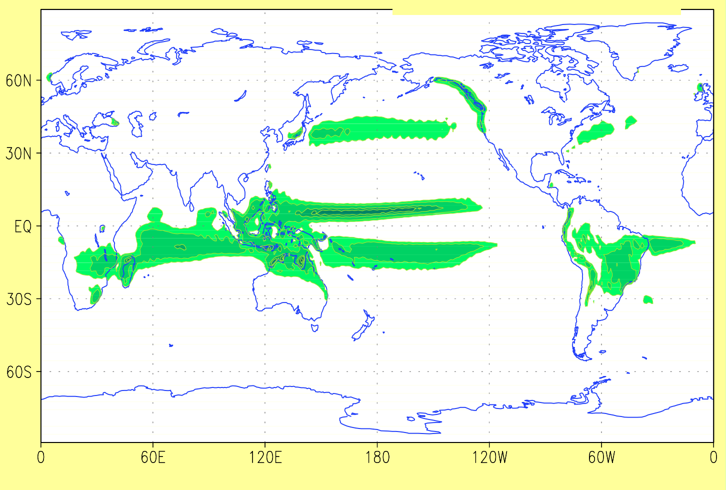




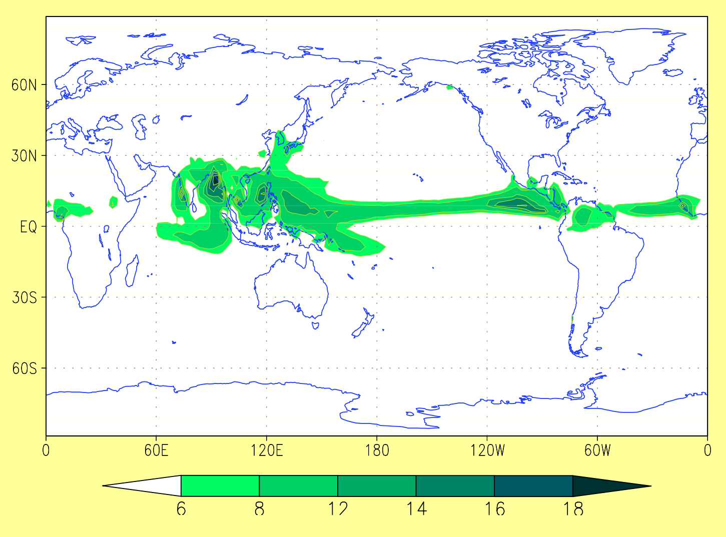


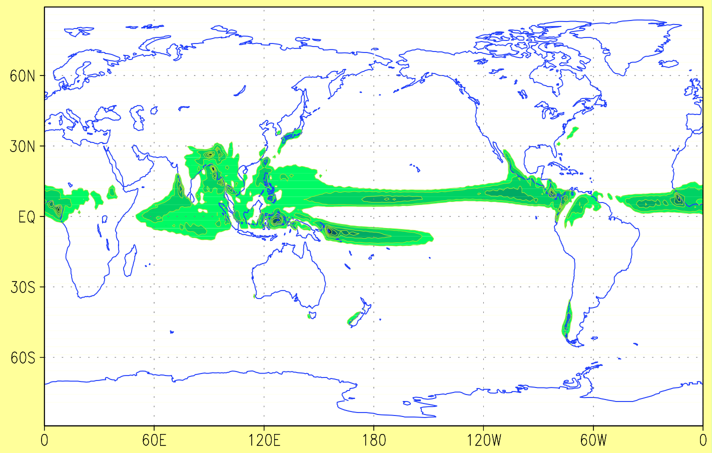
Observed Rainfall December-February) SINTEX-F1



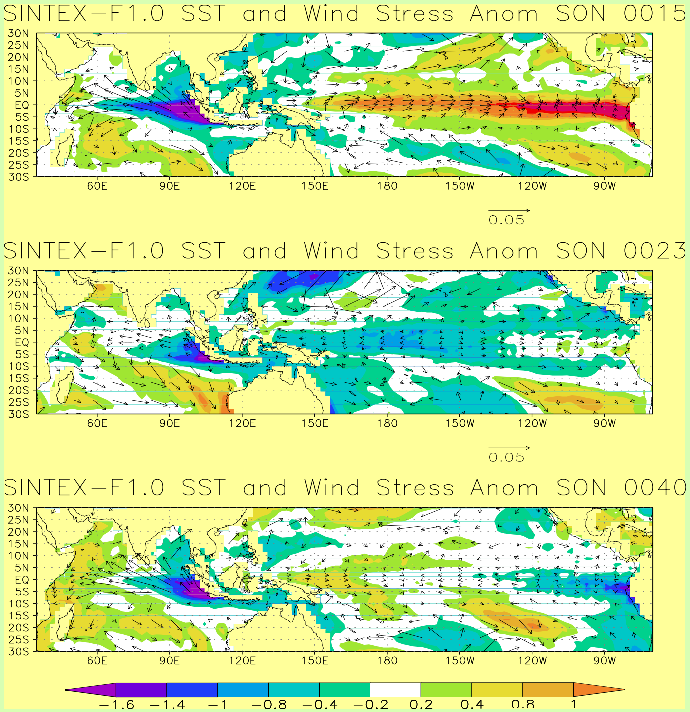


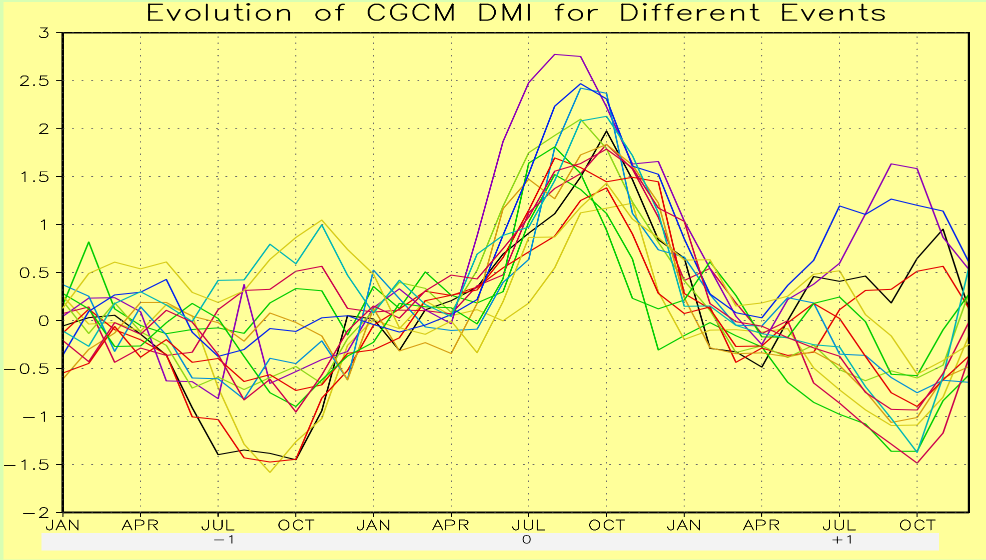
Rainfall (June-August)

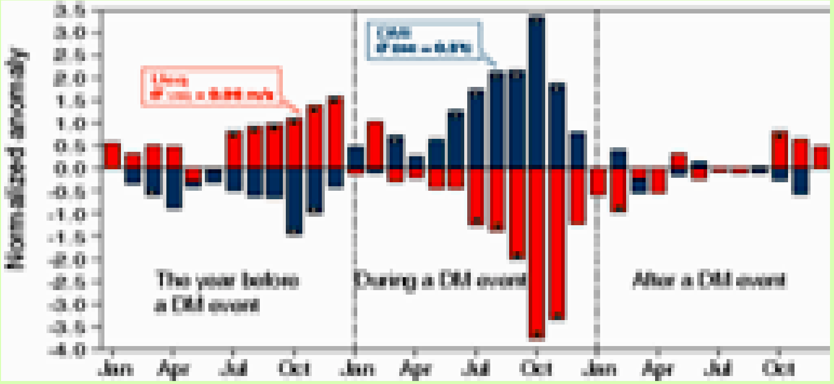




Simulated Seasonal Phase-Locking Characteristics of IOD



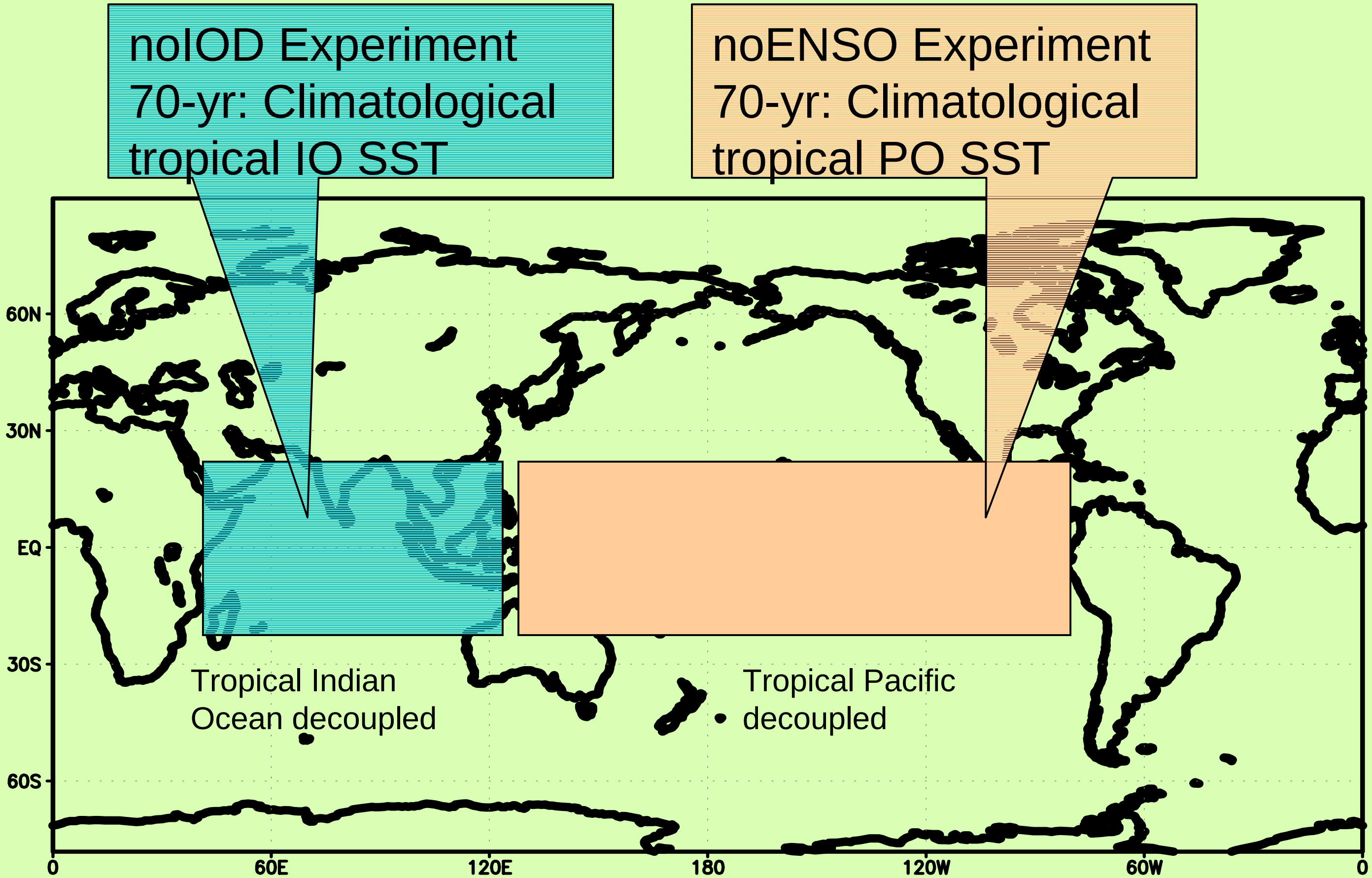




Observed (Saji et al. 1999)

Experimental Design

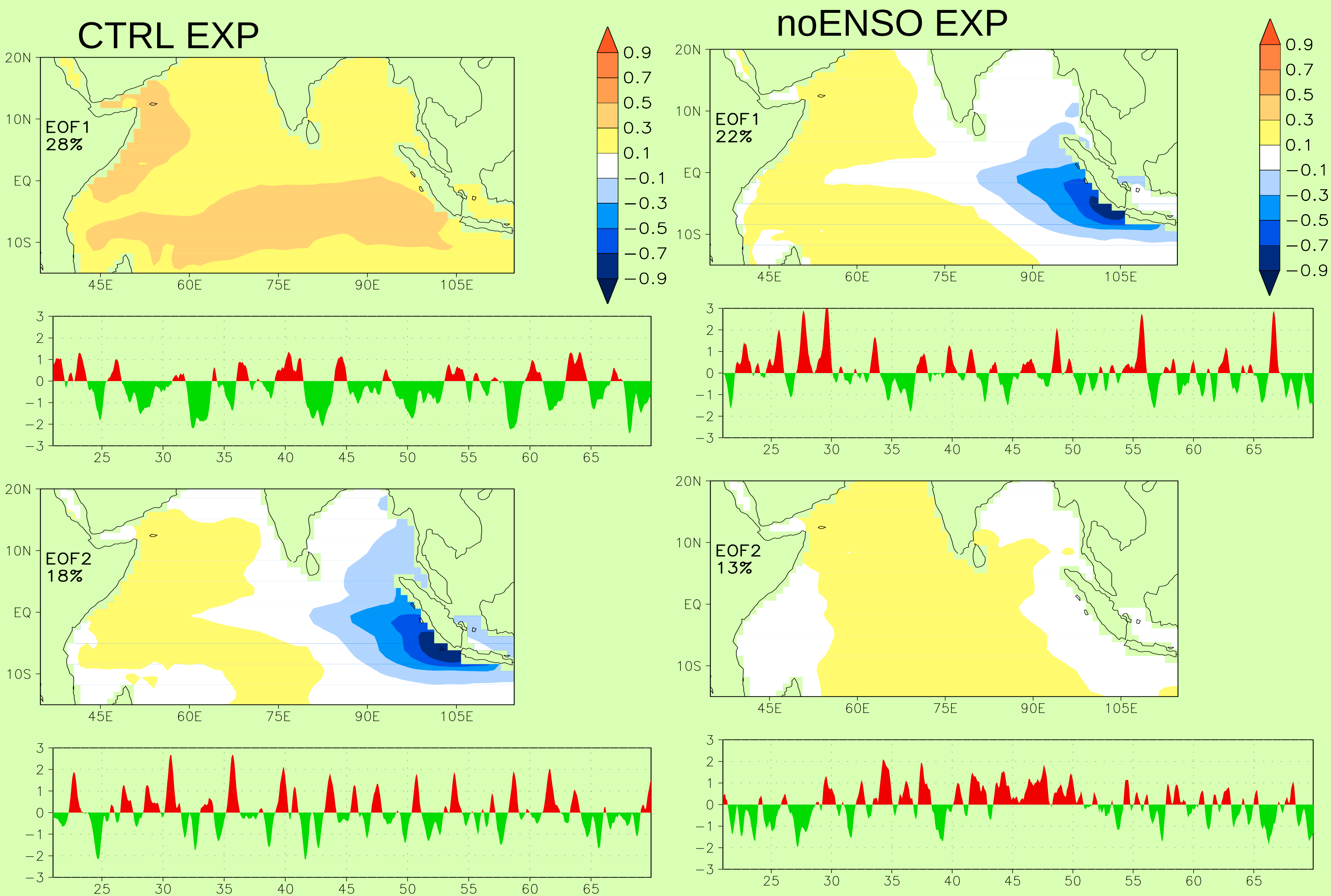
CTRL Experiment 220-yr ==> SST Climatology



Nino3 and DMI Variabilities

Standard Deviation	Nino3	DMI
CTRL EXP	0.85	0.5
IND EXP	-	0.43
PAC EXP	0.88	-

EOF Analysis



DL's dilemma

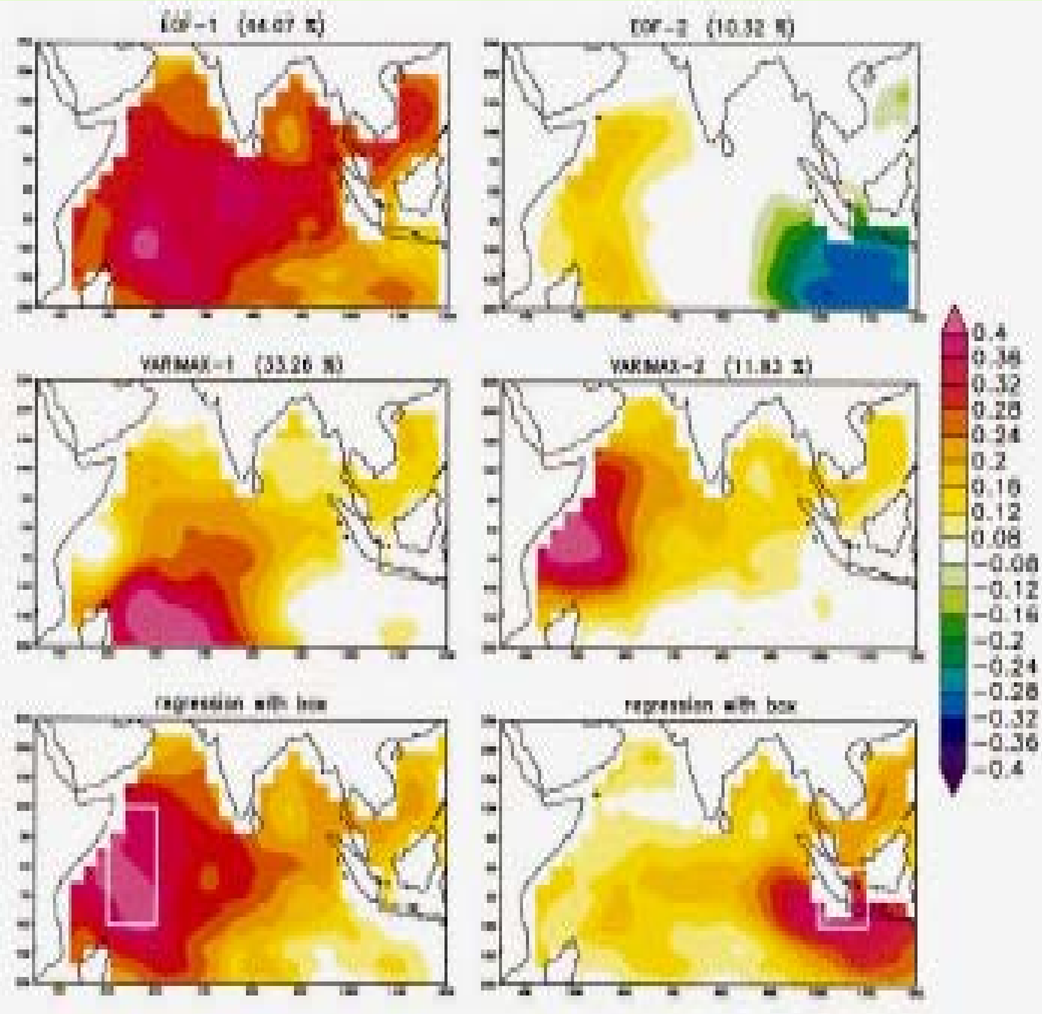
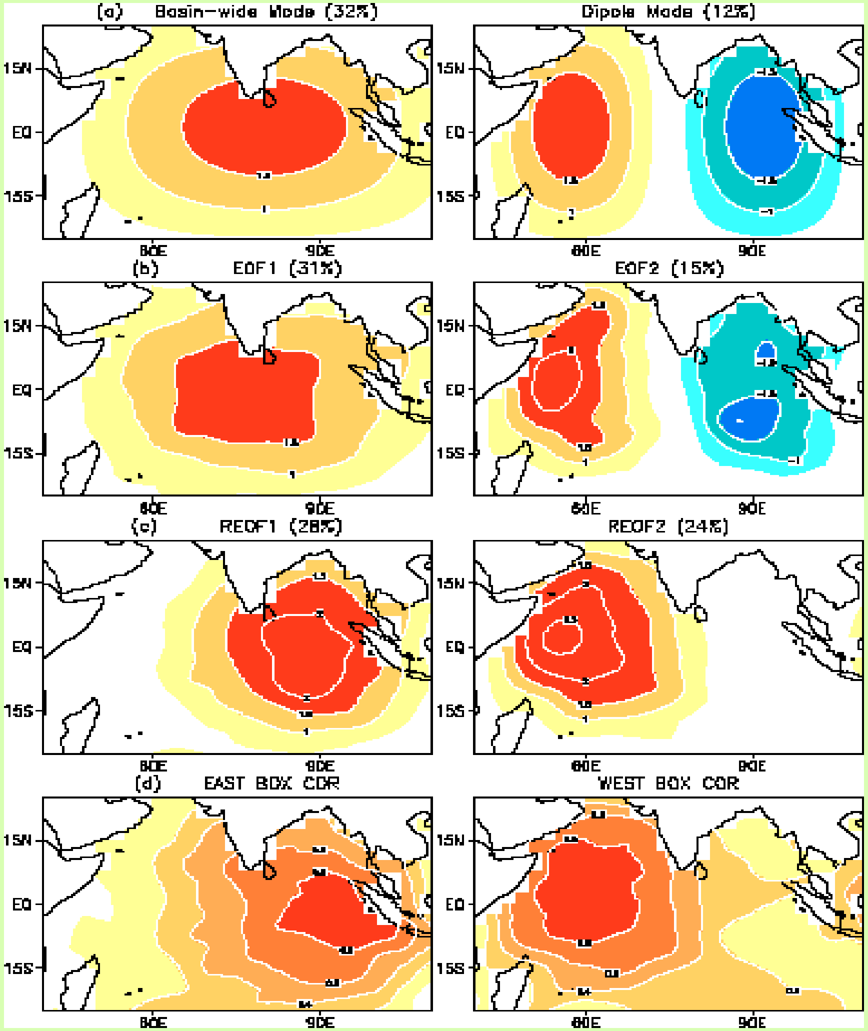


FIG. 2. The EOFs, VARIMAX patterns, and regressions of box averaged monthly mean SST in the tropical Indian Ocean. The amplitudes are in kelvins.

- The first two EOF patterns have been interpreted in terms of potential physical processes by Saji et al. (1999).
- Since the EOF-2 has an orthogonal time evolution to EOF-1, they argue that the EOF-2 can be interpreted as an El Nin˜o–independent mode of variability, which is unique to the tropical Indian Ocean.
- **However, the VARIMAX representation and the regressions provide no indication for the existence of a dipole mode, as suggested by EOF-2.**

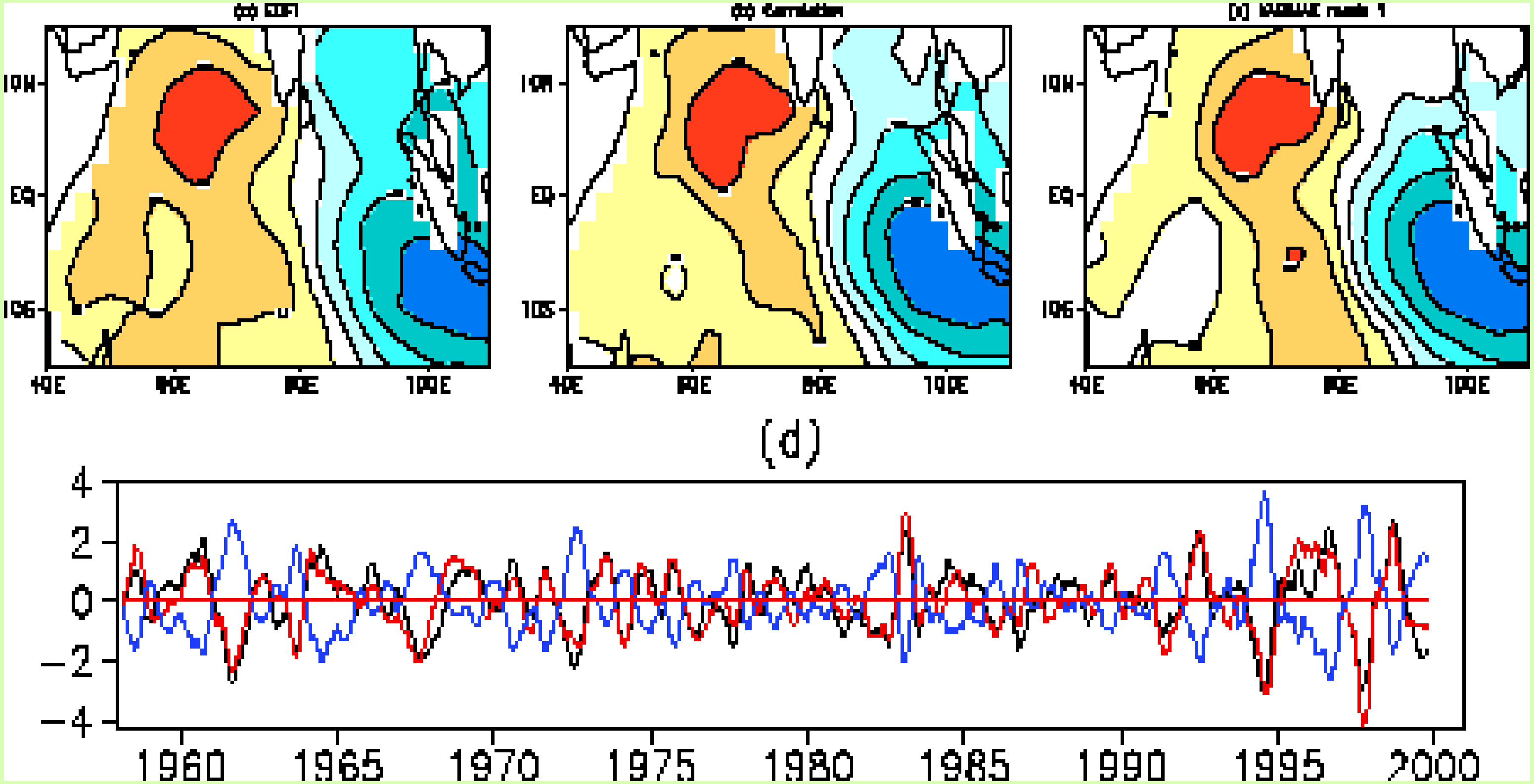
Synthetic example that shows the failure of VARIMAX



BRSY 2003

- The spatial structures of the modes, constructed using the trigonometric cosine and sine functions, are spatially orthogonal.
- The time evolutions of both modes are characterized by random white noises that are uncorrelated.
- Partitioned in variance that the monopole mode clearly dominates the dipole mode, just as in the observations.
- To make the experiment more realistic, we added higher modes having as much variance as the two synthetic modes put together.

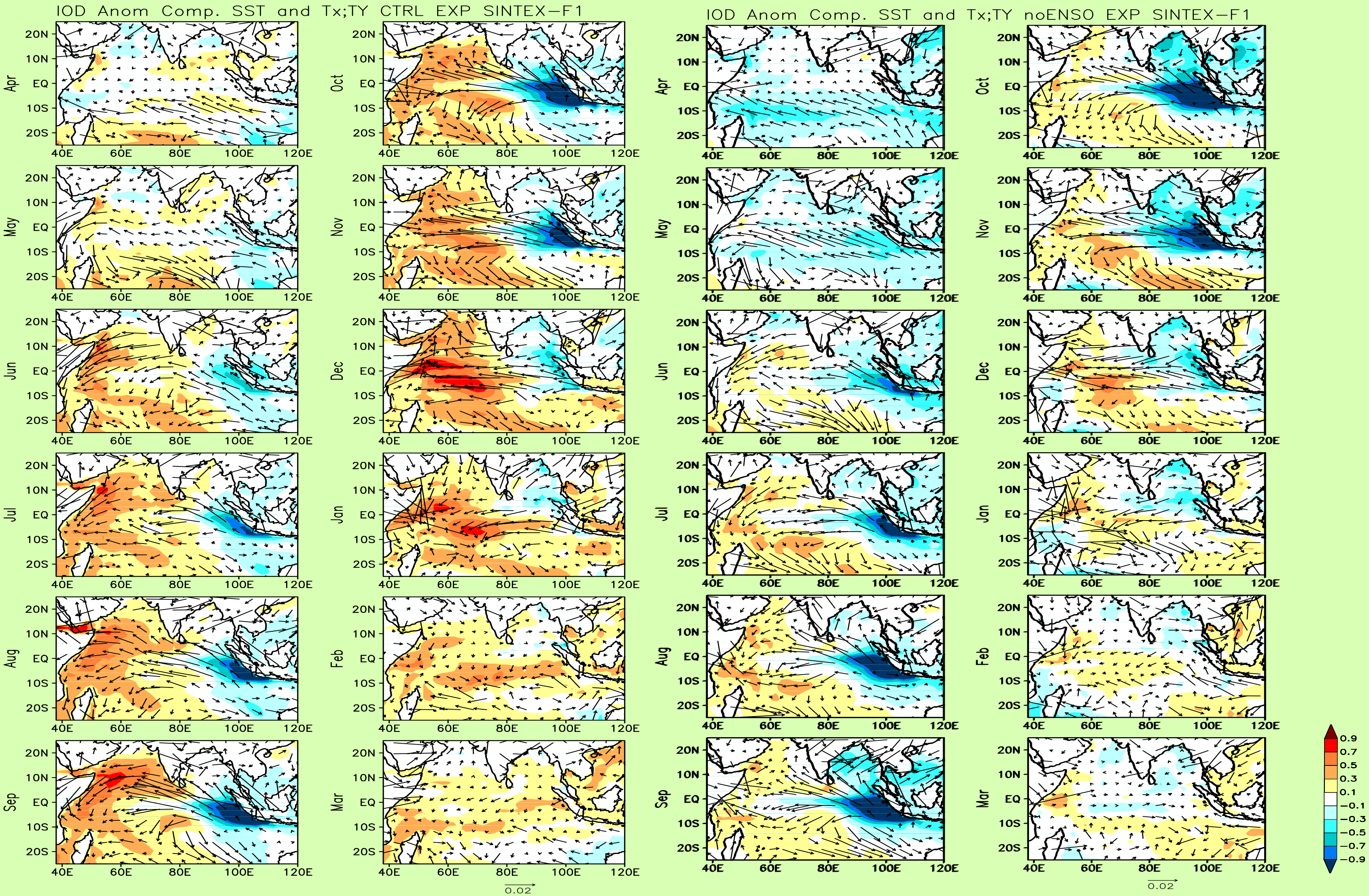
Dipole is the dominant mode in EOF, Regression and VARIMAX analyses in the reduced data set



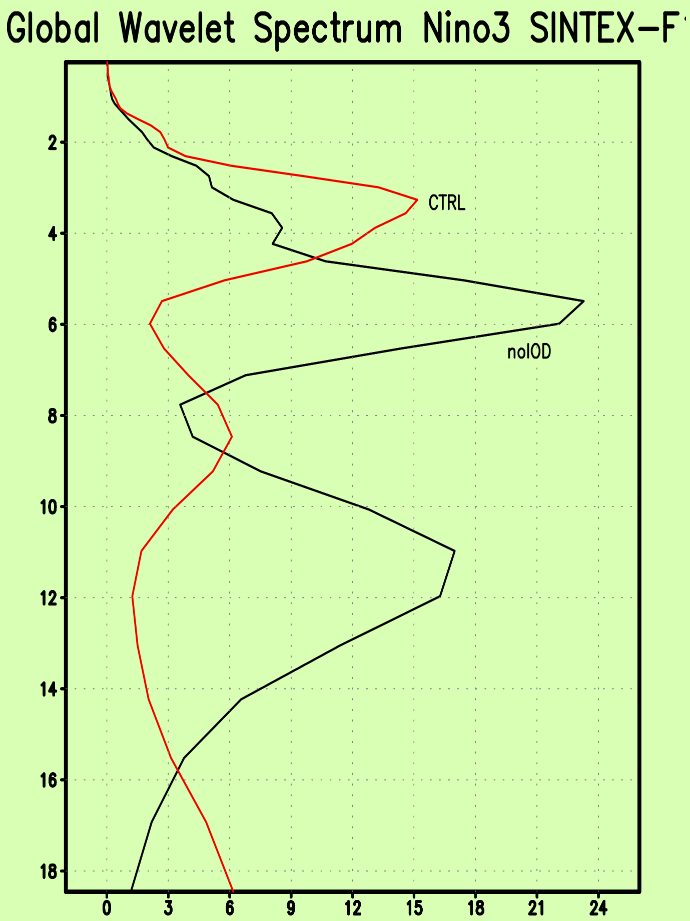
Composite of SST and Wind Stress Anomalies in SINTEX-F1

CTRL EXP

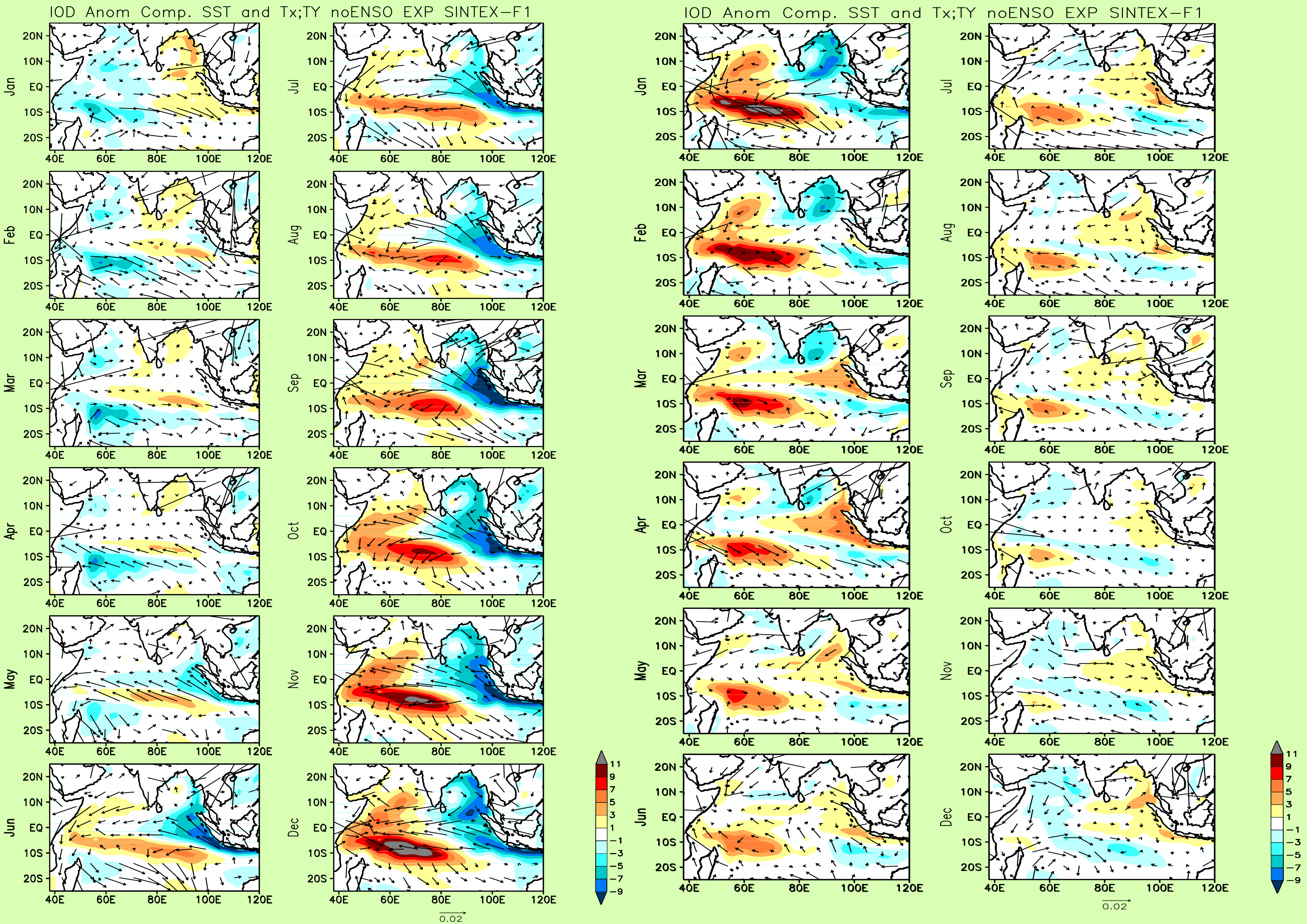
noENSO EXP



Wavelet Power Spectrum



Composite of Heat Content and Wind Stress Anomalies in noENSO EXP – A Cycle of Biennial Oscillation

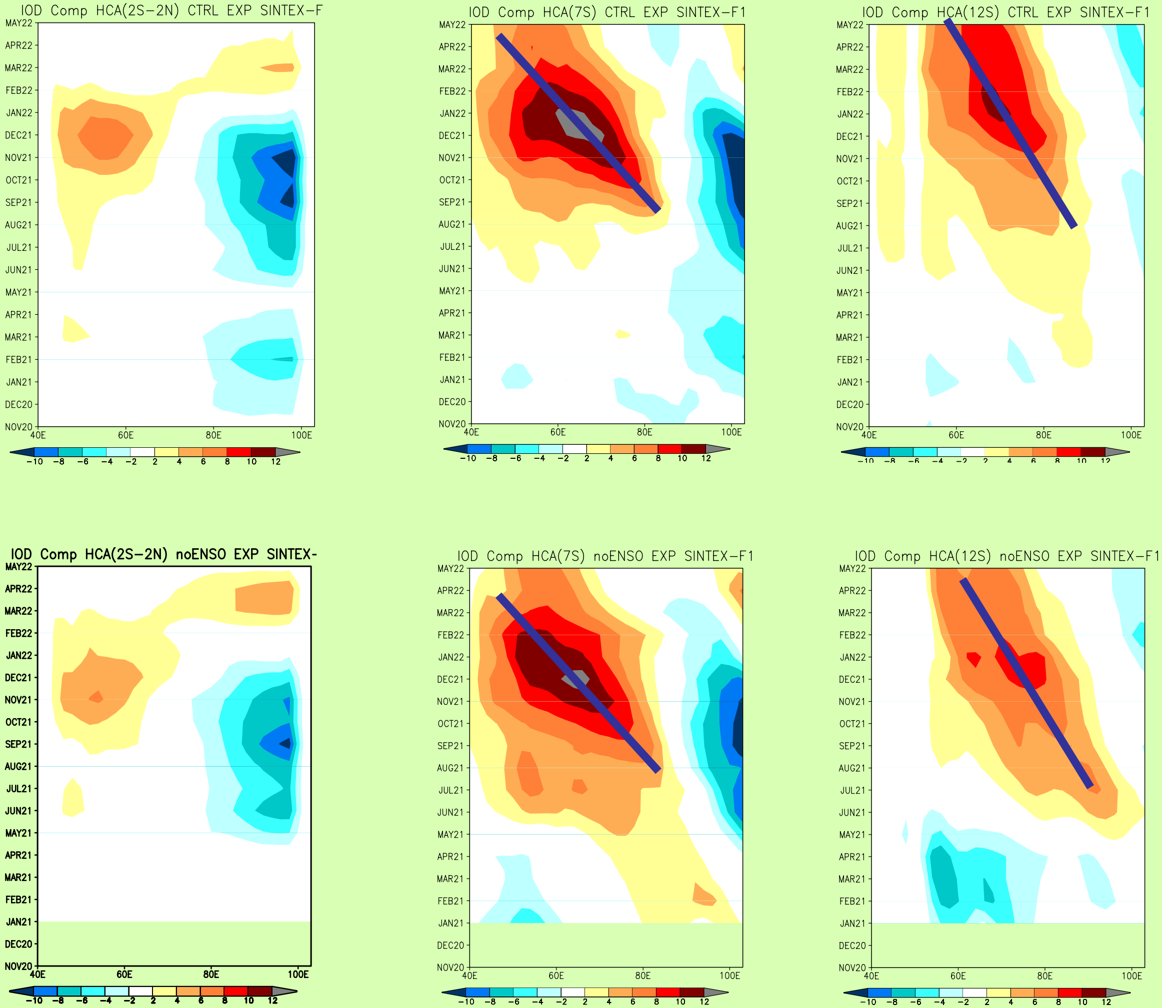


Heat Content Anomalies on tropical Indian Ocean

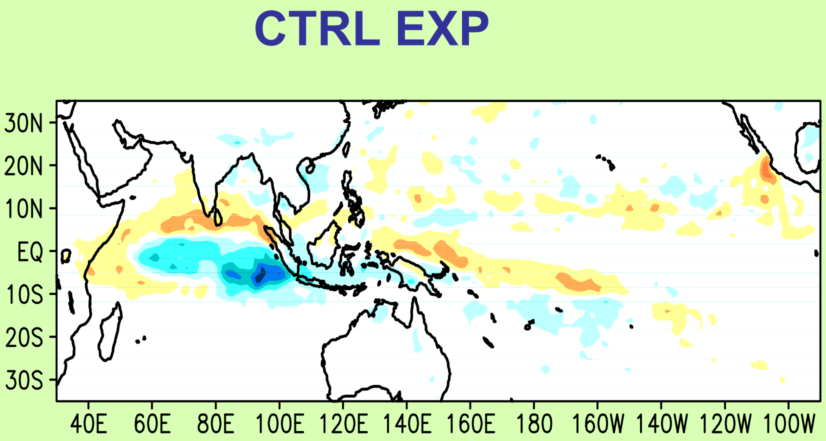
Eq | 7S | 12S

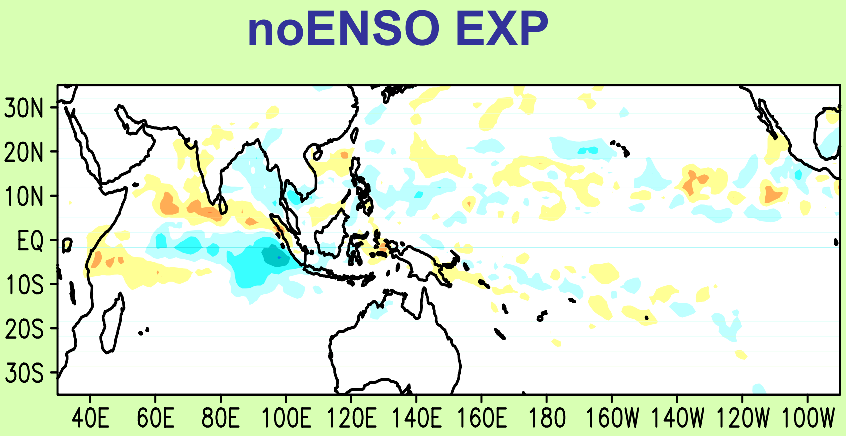
CTRL EXP

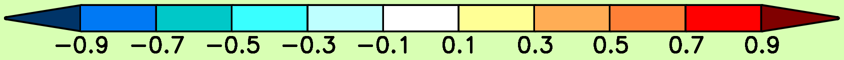
noENSO EXP

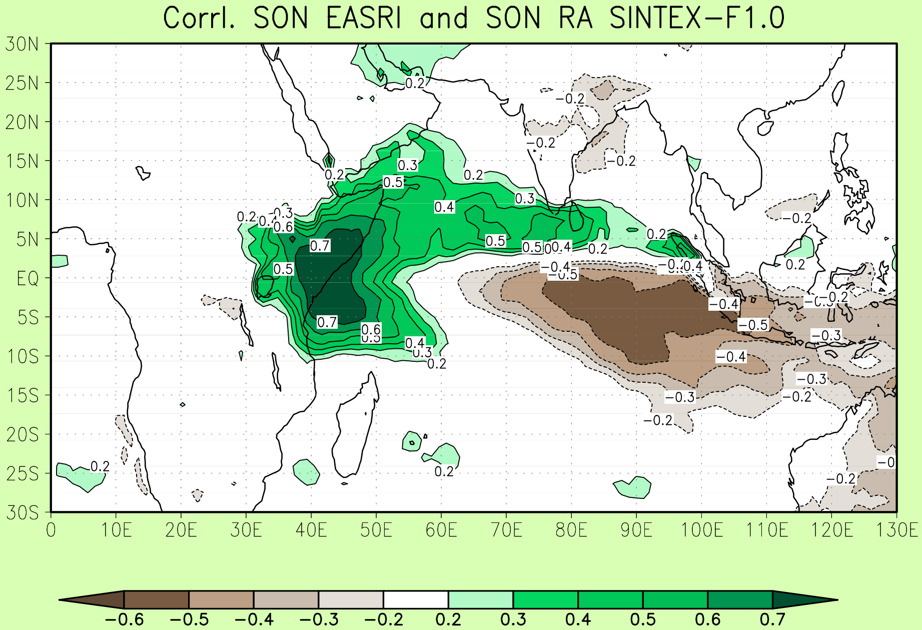


Composite of Rainfall Anomalies for September-November during IOD events

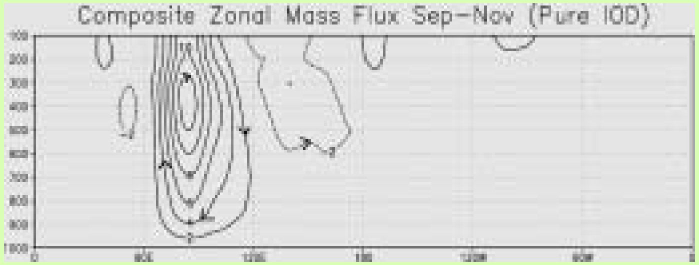








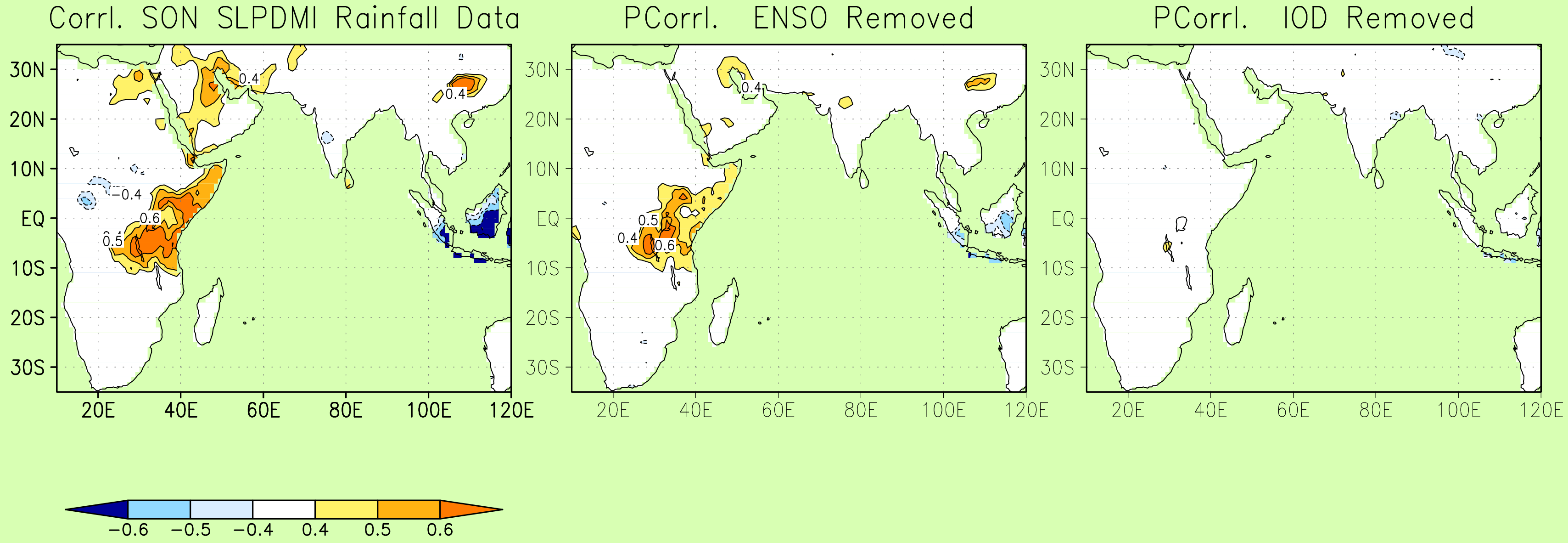
Observed Walker cell during pure IOD events – Yamagata et al. 2002



Model East African Short Rains Correlation with DMI and ENSO

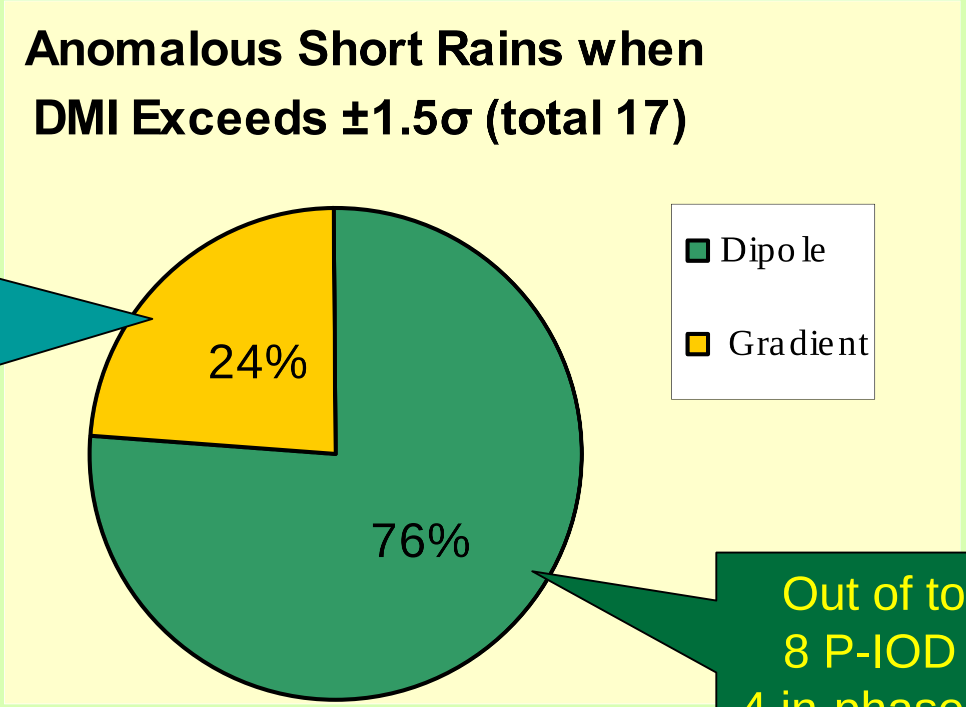
	EASR-DMI	EASR-Nino3
Correlation (whole year)	**0.45**	0.08
Correlation (Sep-Nov season)	**0.65**	**0.28**

Correlation and Partial Correlation of SLP DMI and Rainfall in Data



Behera et al. 2003,2004

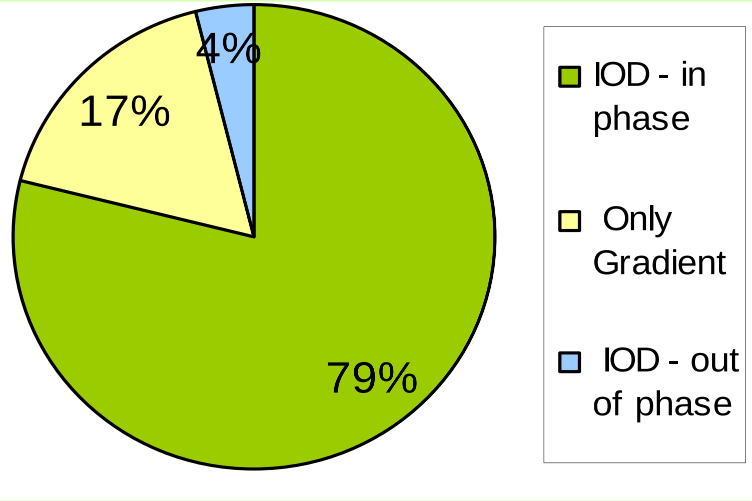
Predictability of the Short Rains from Observation

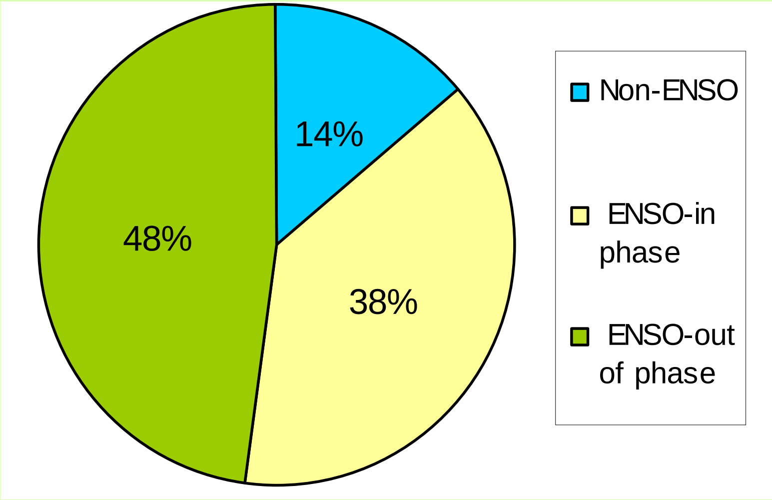


Out of total 4 years:
3 La Nina and
1 El Nino
In case of the El Nino the EASR was negative when DMI was positive

Out of total 13 years:
8 P-IOD and 5 N-IOD
4 in-phase ENSO events that exceed ±1.5σ

Predictability in SINTEX-F1





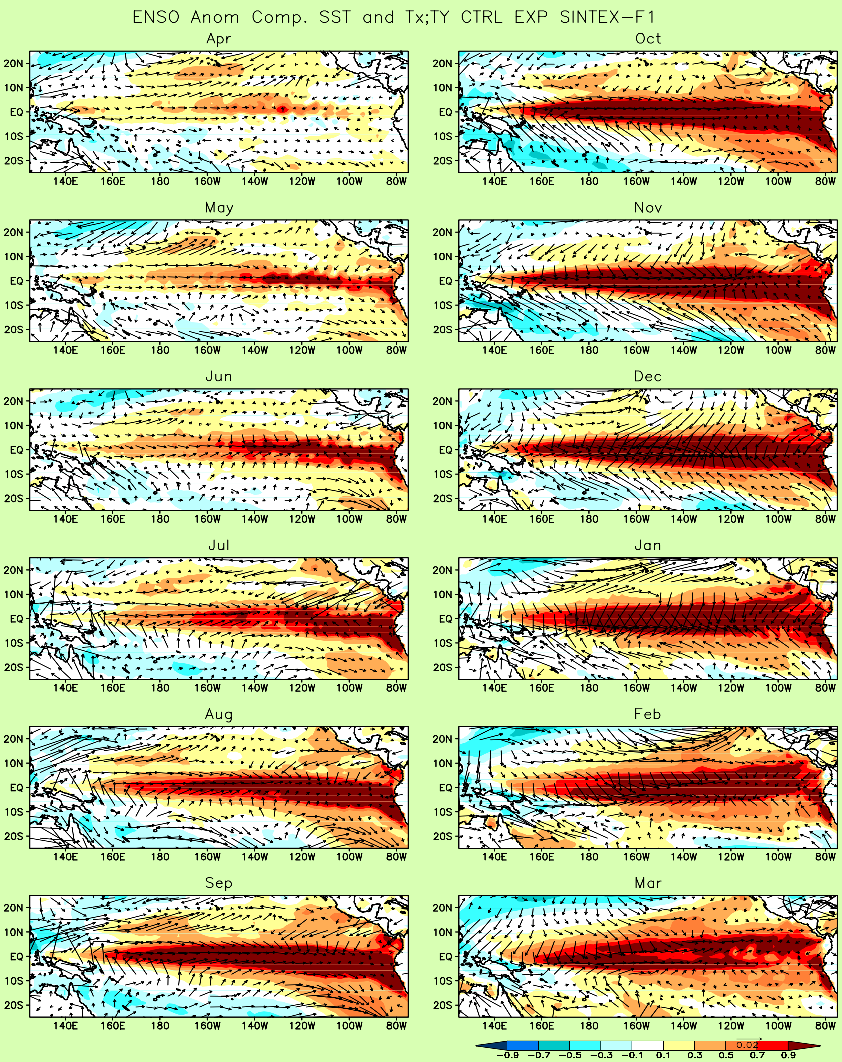
Pie diagram of the model DMI phase relation with a significant year of short rains (left panel). In phase relation here means a positive DMI during a flood year and *vice versa*. The percentage association is derived from a total of 52 events in which the short rains index exceeded $\pm 1.5\sigma$ level in the model simulation. The corresponding phase association between the short rains and Niño3 index is shown on the right panel. An El Niño event with Niño3 index above 0.5σ level accompanied by floods in East Africa is considered here as an in-phase event and *vice versa*.

Conclusions

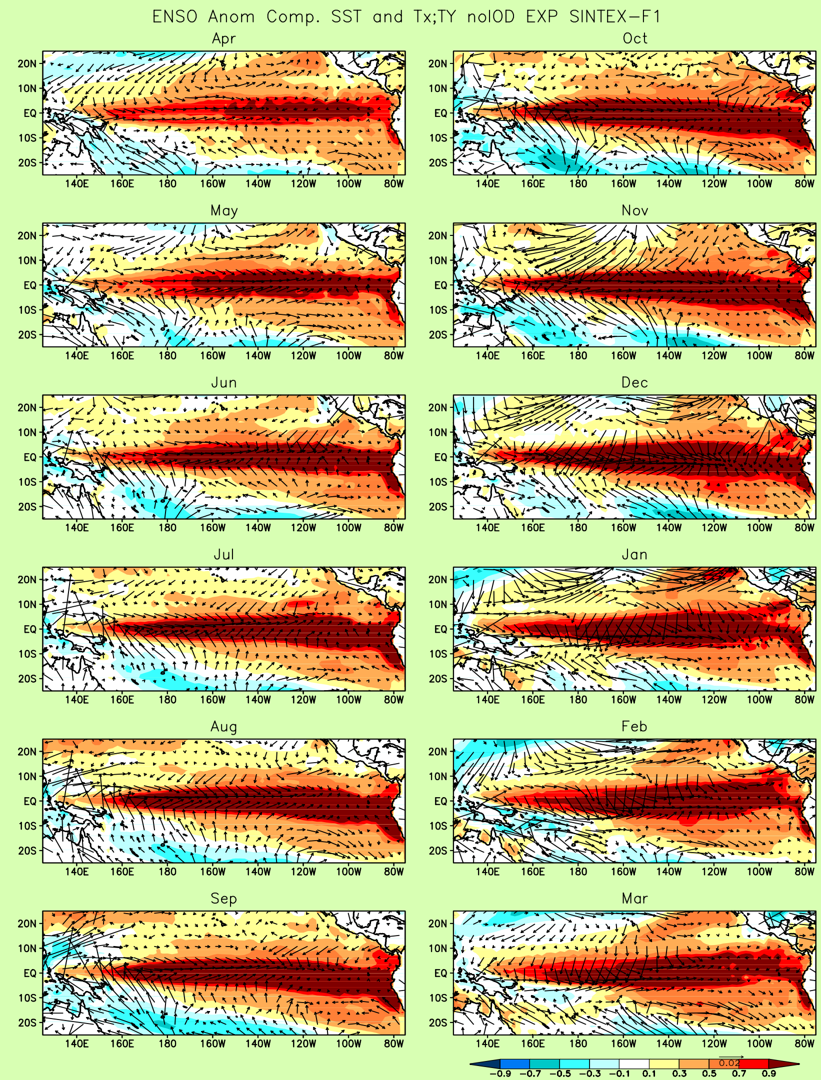
- Sensitivity experiments using the realistic SINTEX-F model confirms the hypothesis that IOD can evolve independent of ENSO.
- The dipole mode becomes the dominant mode of variability in the absence of air-sea coupling in the Pacific. This confirms the statistical analyses using synthetic and observed data.
- The paramount impact of IOD on East African short rains is confirmed.
- These preliminary results are encouraging to investigate underlying mechanisms responsible for independent evolution of IOD.

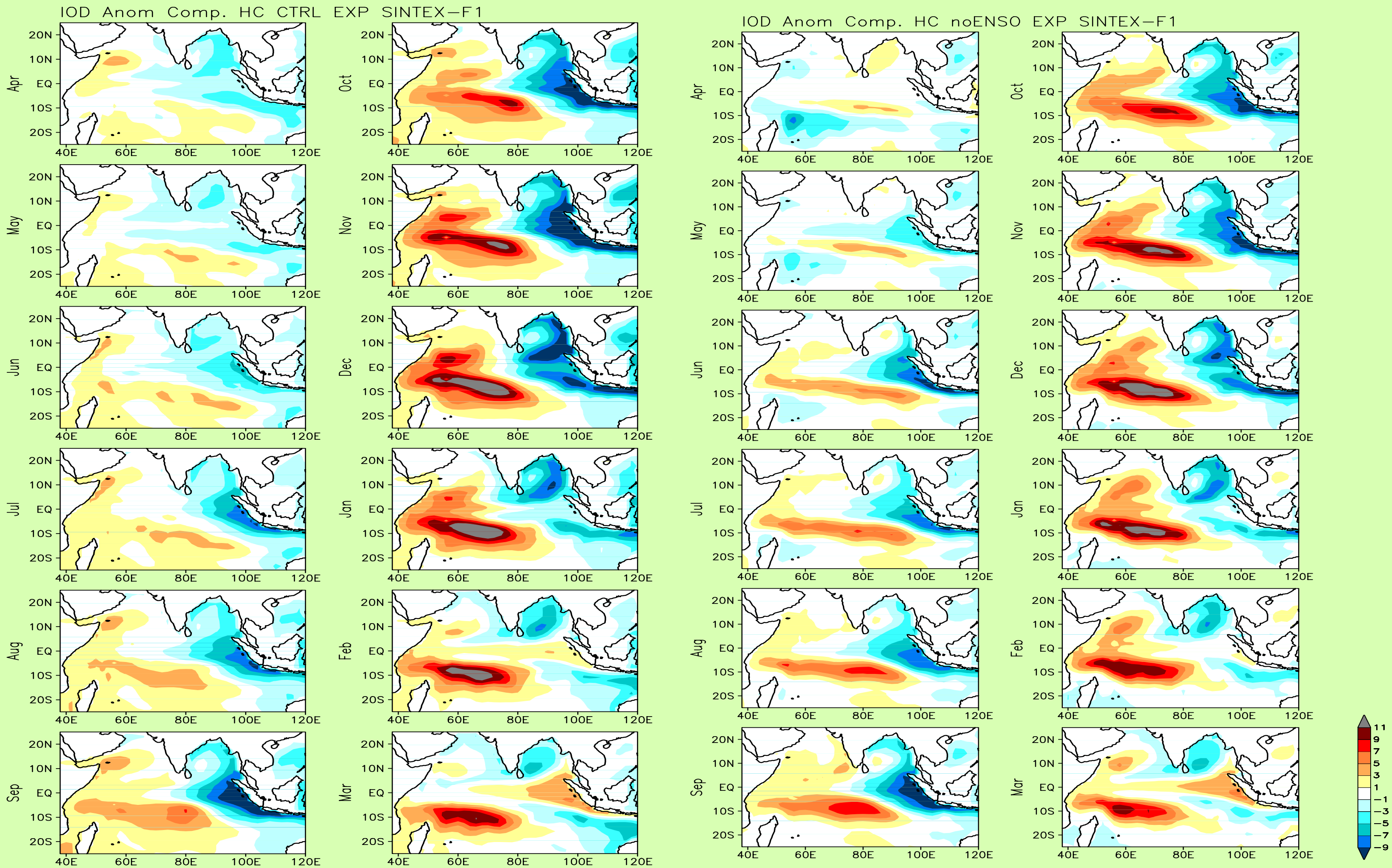
Composite of SST and Wind Stress Anomalies in the Pacific Ocean

CTRL EXP



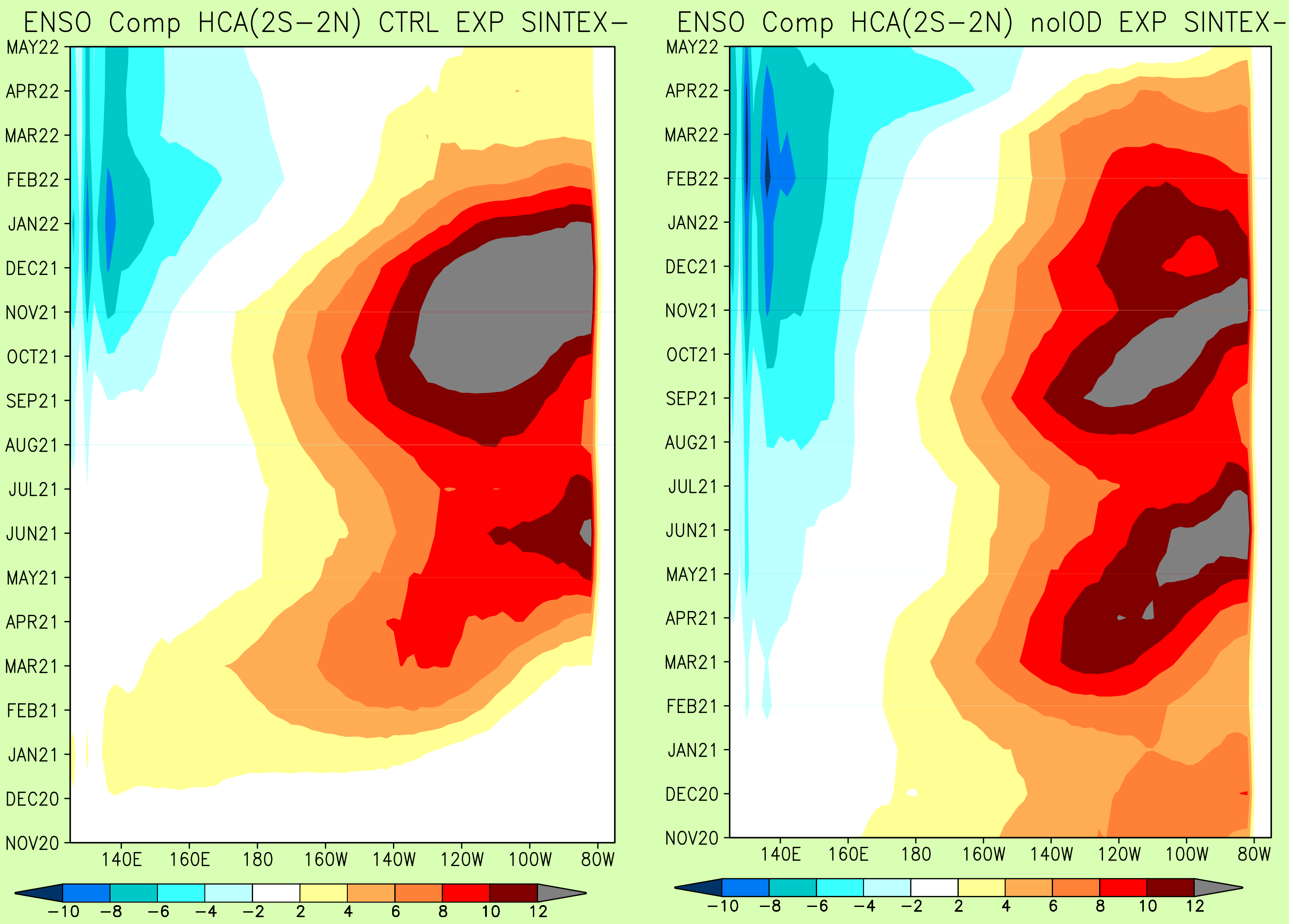
noIOD EXP



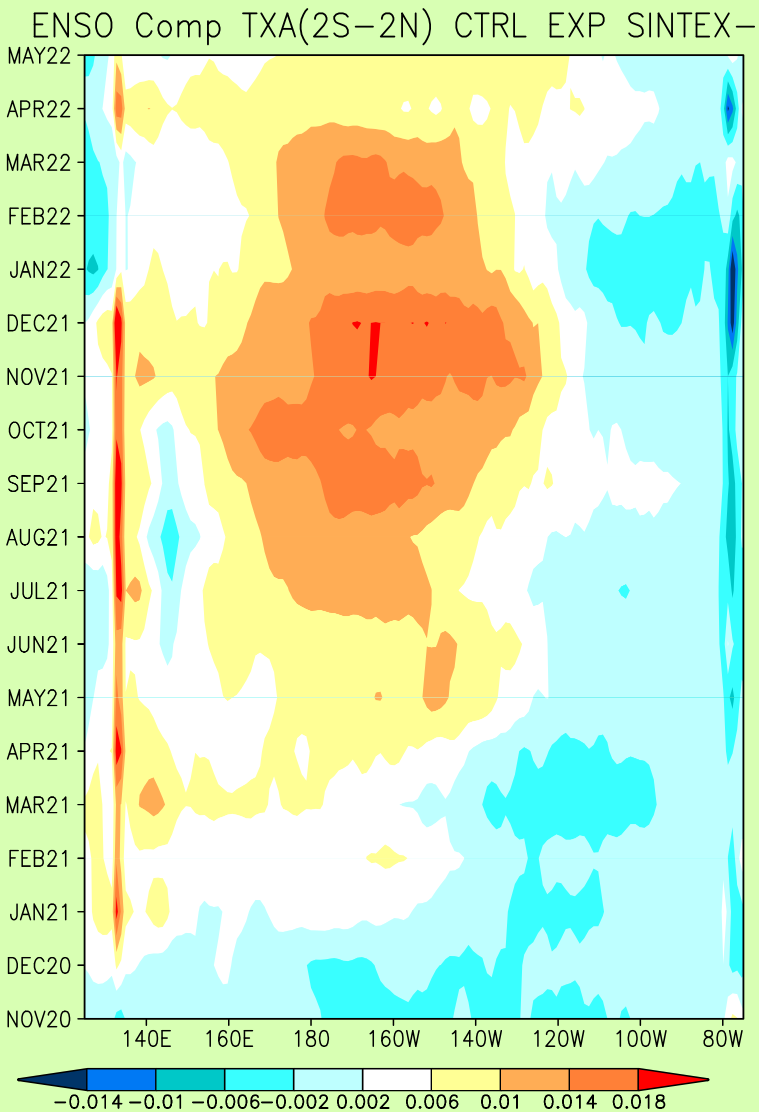


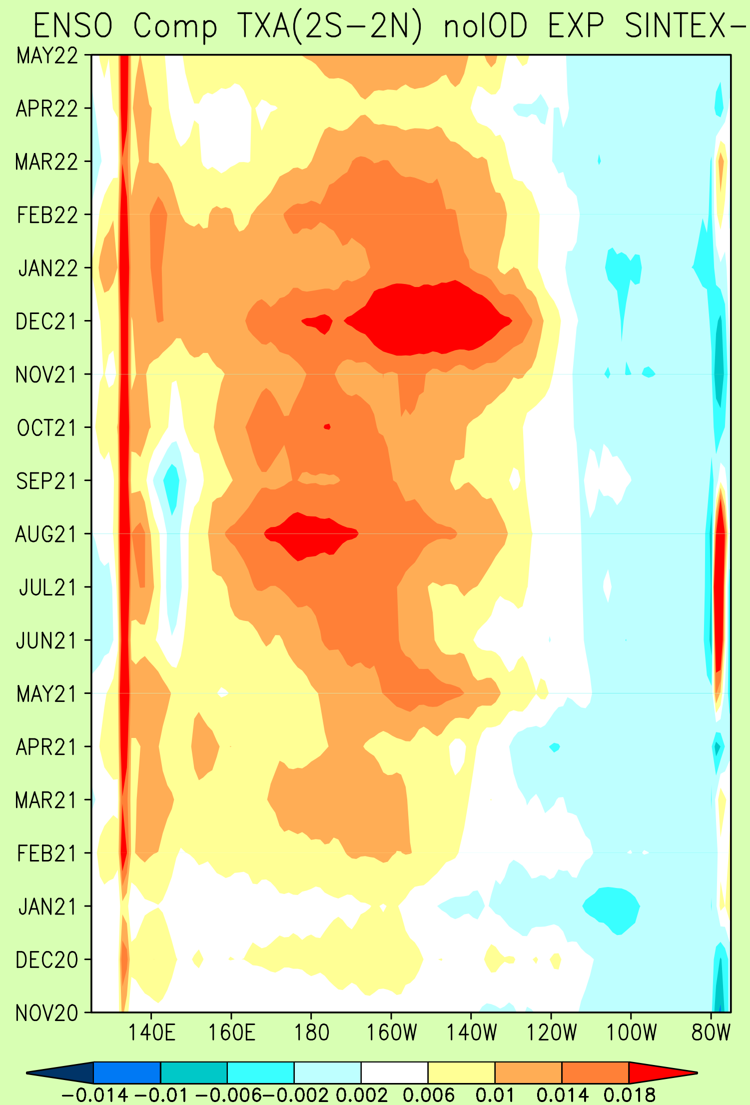
IOD Anom Comp. HC CTRL EXP SINTEX-F1
IOD Anom Comp. HC noENSO EXP SINTEX-F1
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
20N
10N
EQ
10S
20S
40E
60E
80E
100E
120E
11
9
7
5
3
1
−1
−3
−5
−7
−9

Heat Content Anomalies on Equatorial Pacific

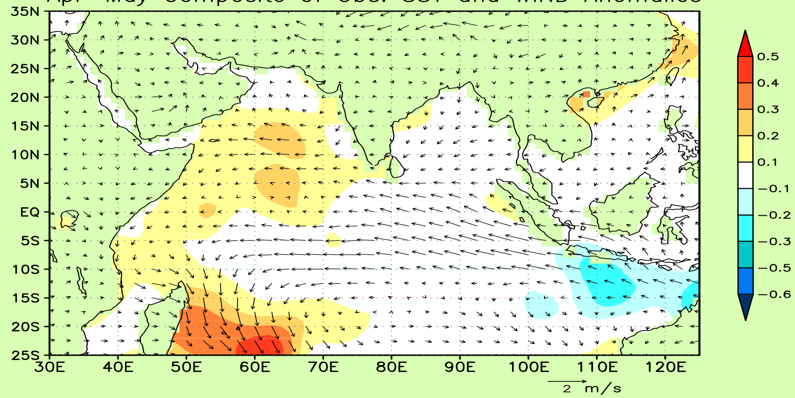


Zonal Wind Stress Anomalies on Equatorial Pacific

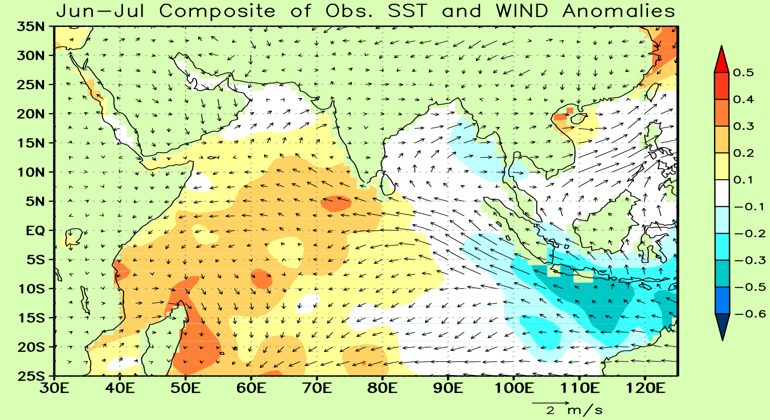




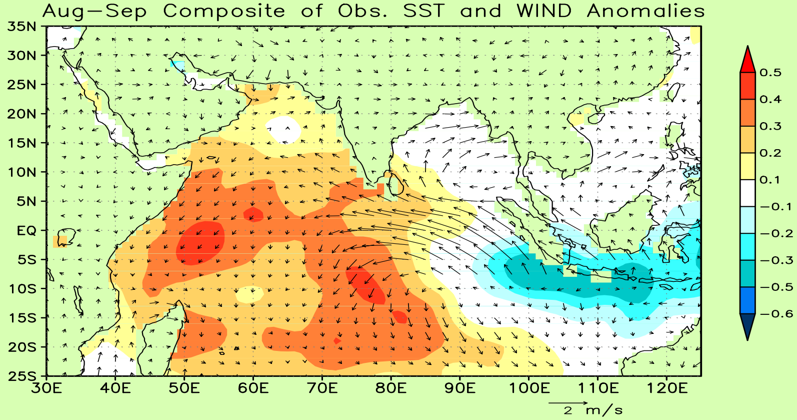
Apr–May Composite of Obs. SST and WIND Anomalies



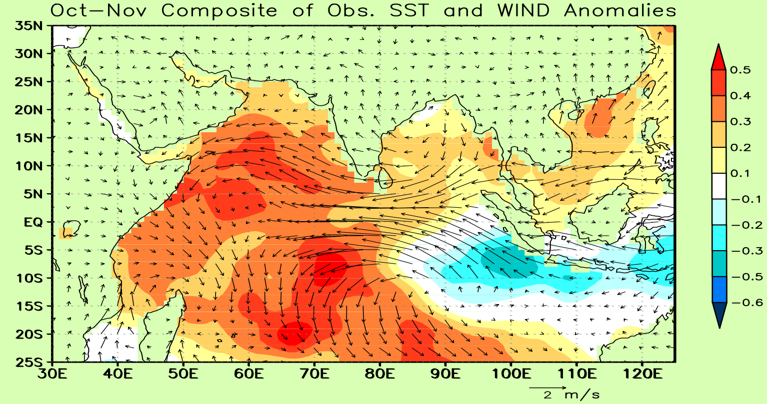
Jun–Jul Composite of Obs. SST and WIND Anomalies

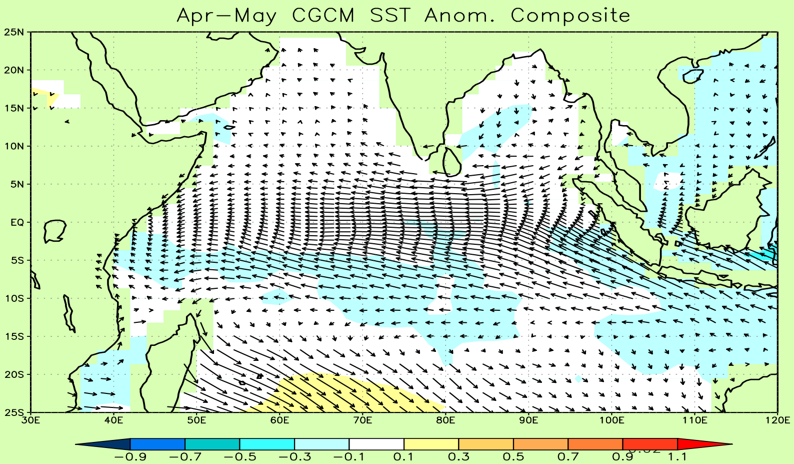


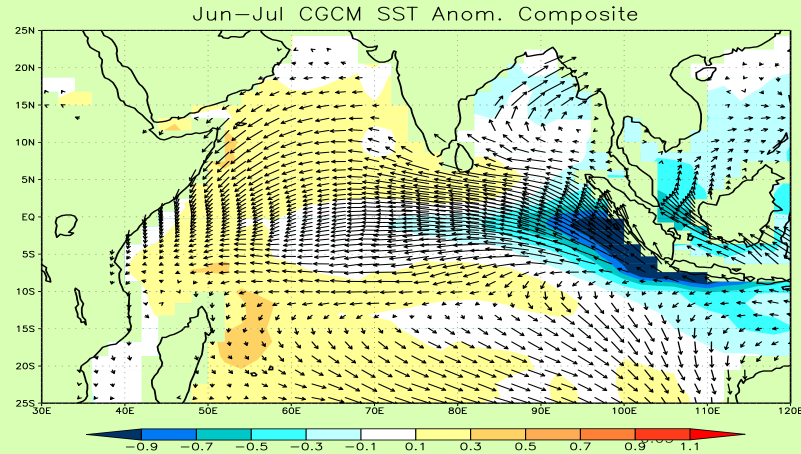
Aug–Sep Composite of Obs. SST and WIND Anomalies

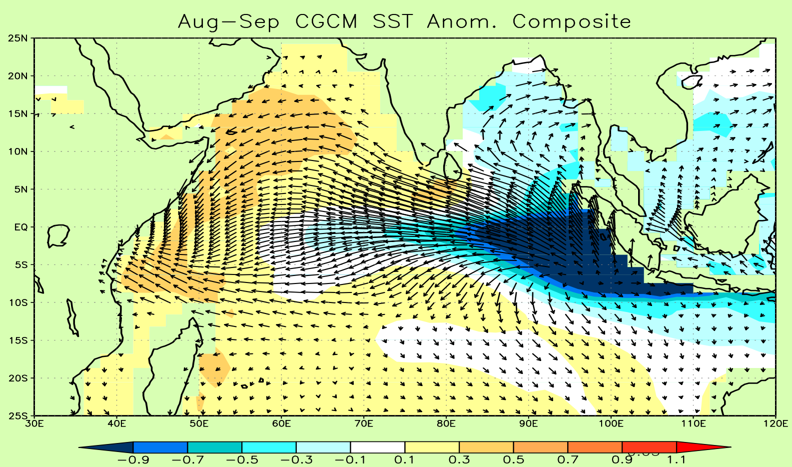


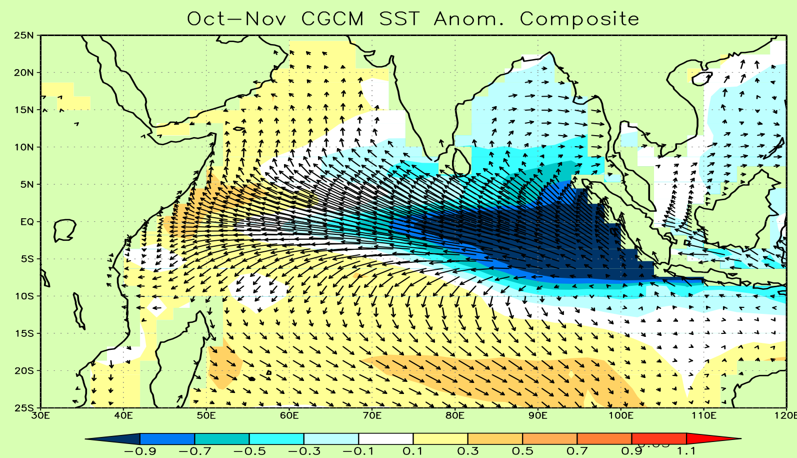
Oct–Nov Composite of Obs. SST and WIND Anomalies

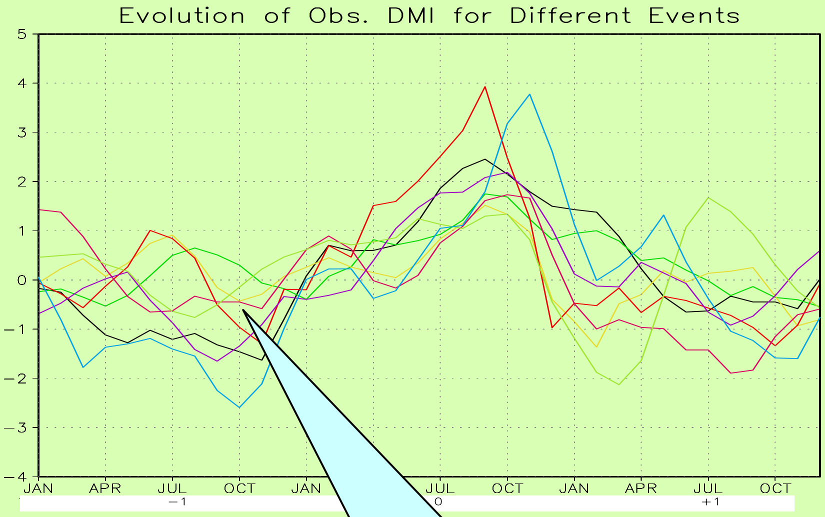


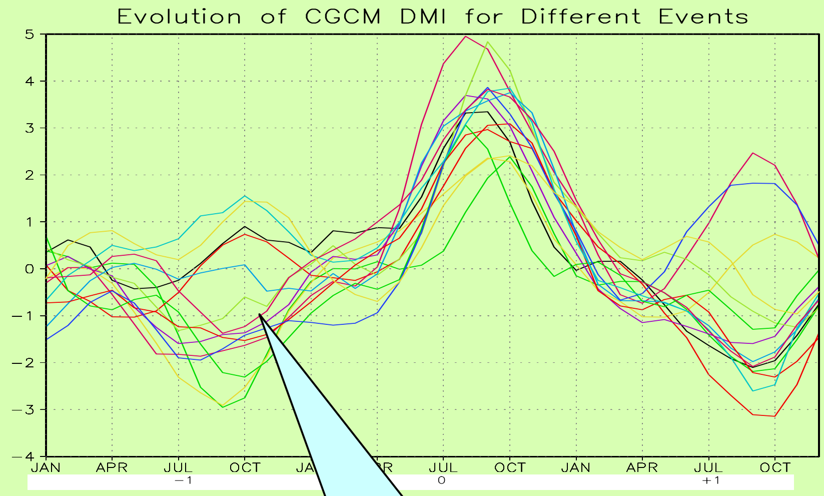

Apr–May CGCM SST Anom. Composite
25N 20N 15N 10N 5N EQ 5S 10S 15S 20S 25S
30E 40E 50E 60E 70E 80E 90E 100E 110E 120E
−0.9 −0.7 −0.5 −0.3 −0.1 0.1 0.3 0.5 0.7 0.9 1.1


Jun–Jul CGCM SST Anom. Composite
25N 20N 15N 10N 5N EQ 5S 10S 15S 20S 25S
30E 40E 50E 60E 70E 80E 90E 100E 110E 120E
−0.9 −0.7 −0.5 −0.3 −0.1 0.1 0.3 0.5 0.7 0.9 1.1


Aug–Sep CGCM SST Anom. Composite
25N 20N 15N 10N 5N EQ 5S 10S 15S 20S 25S
30E 40E 50E 60E 70E 80E 90E 100E 110E 120E
−0.9 −0.7 −0.5 −0.3 −0.1 0.1 0.3 0.5 0.7 0.9 1.1

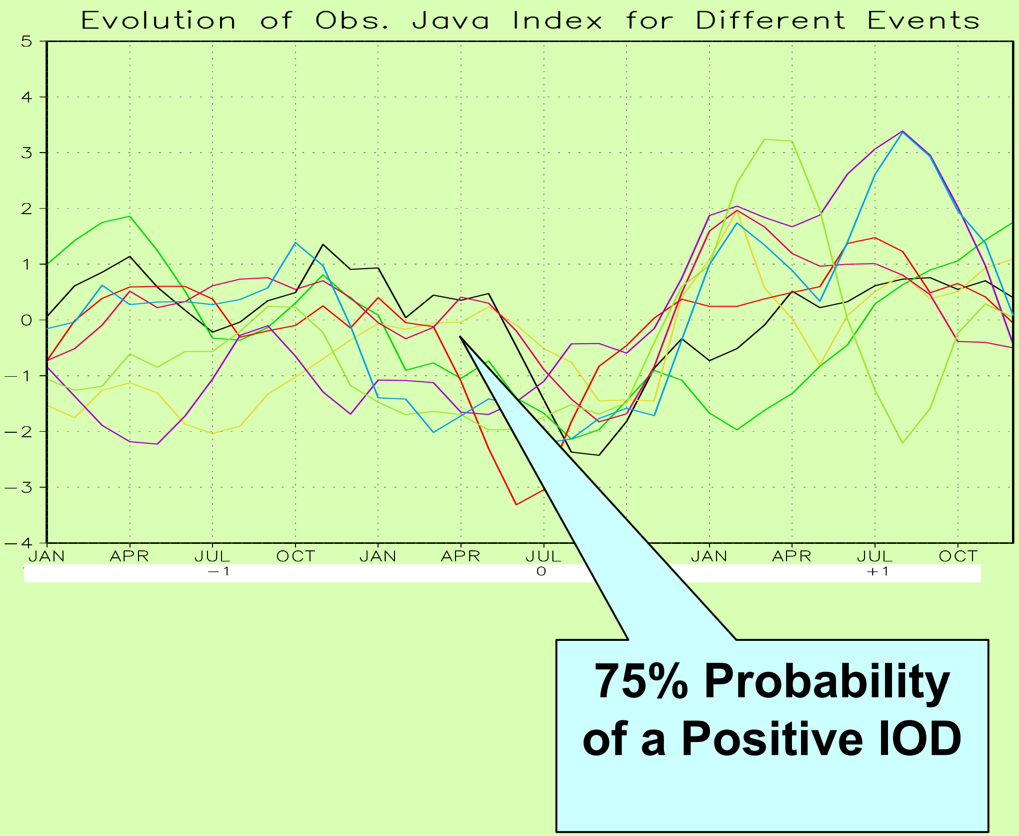

Oct–Nov CGCM SST Anom. Composite
25N 20N 15N 10N 5N EQ 5S 10S 15S 20S 25S
30E 40E 50E 60E 70E 80E 90E 100E 110E 120E
−0.9 −0.7 −0.5 −0.3 −0.1 0.1 0.3 0.5 0.7 0.9 1.1





70% Probability of a Positive IOD

60% Probability of a Positive IOD



In the model the probability is 80%