Indian Ocean dynamics and interannual variability associated with the tropospheric biennial oscillation (TBO)

Gerald Meehl

National Center for Atmospheric Research

Julie Arblaster, Johannes Loschnigg, Aixue Hu
Peter Webster, Gilbert Compo

“biennial tendency” of ENSO and IOZM/IOD = TBO

Fundamental coupled interactions involved with TBO provide dynamical framework for ENSO and IOD that are encompassed by the TBO

TBO is fundamental interannual process, with ENSO and IOD large amplitude extremes of TBO (Meehl and Arblaster, J. Climate, 2002; Meehl et al., J. Climate, 2003; Loschnigg et al., J. Climate, 2003)

Observations and models

- NCEP/NCAR reanalyses, SODA ocean data, CMAP precipitation data
- CSM1 coupled model (100 year period from control run), CCM3 atmosphere T42 18L, 2 degree NCOM ocean, cavitating fluid sea ice, LSM land surface model
- PCM coupled model (300 year period from control run), CCM3 atmosphere, 2/3 degree POP ocean, EVP dynamic and thermodynamic sea ice, LSM land surface model

1979-1999

Indian monsoon: 13 out of 21 are TBO years

about half are ENSO or IOD years

analysis of non-ENSO/IOD years shows similar but lower amplitude signals

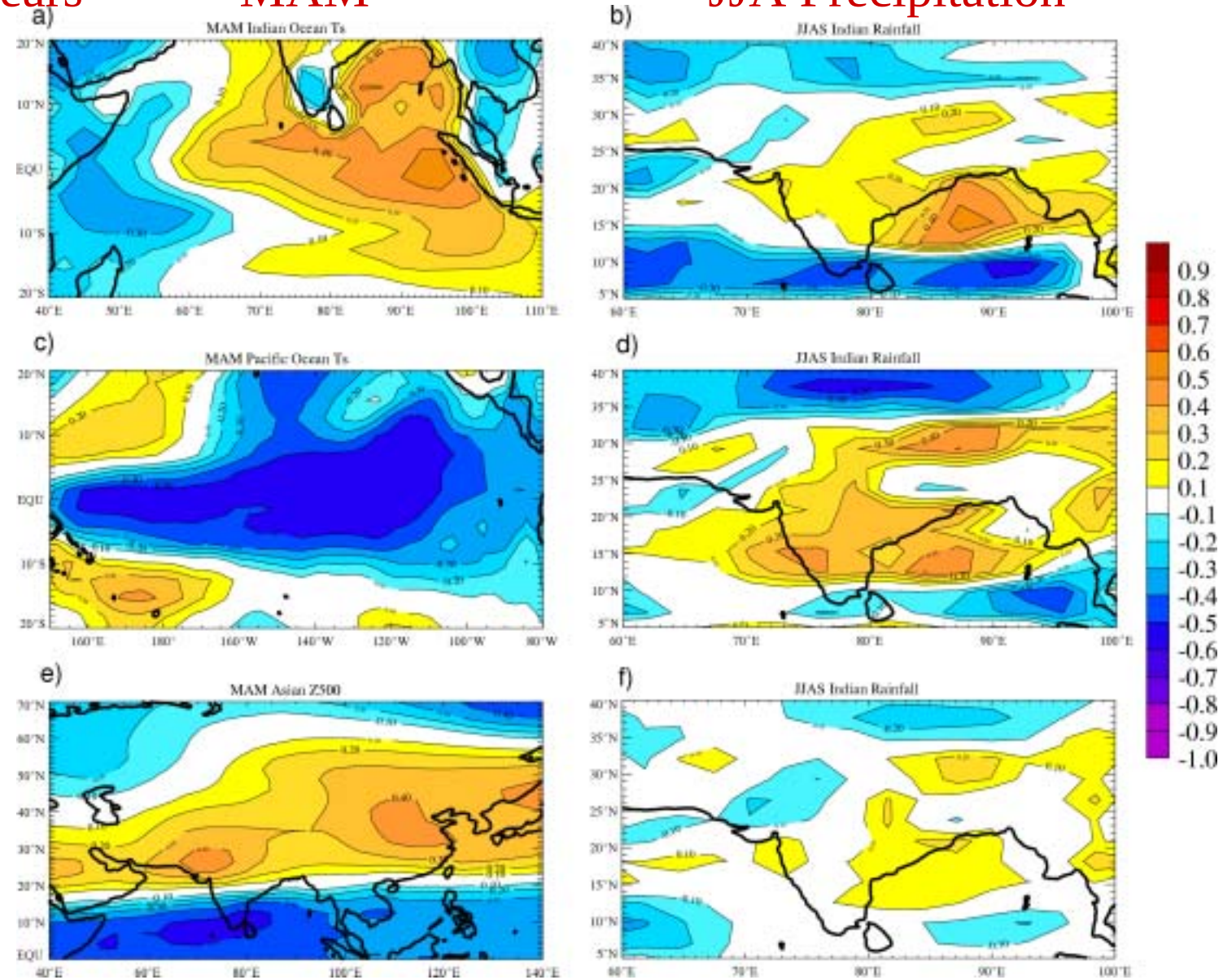
CSM1, 100 years MAM JJA Precipitation

SVD analysis

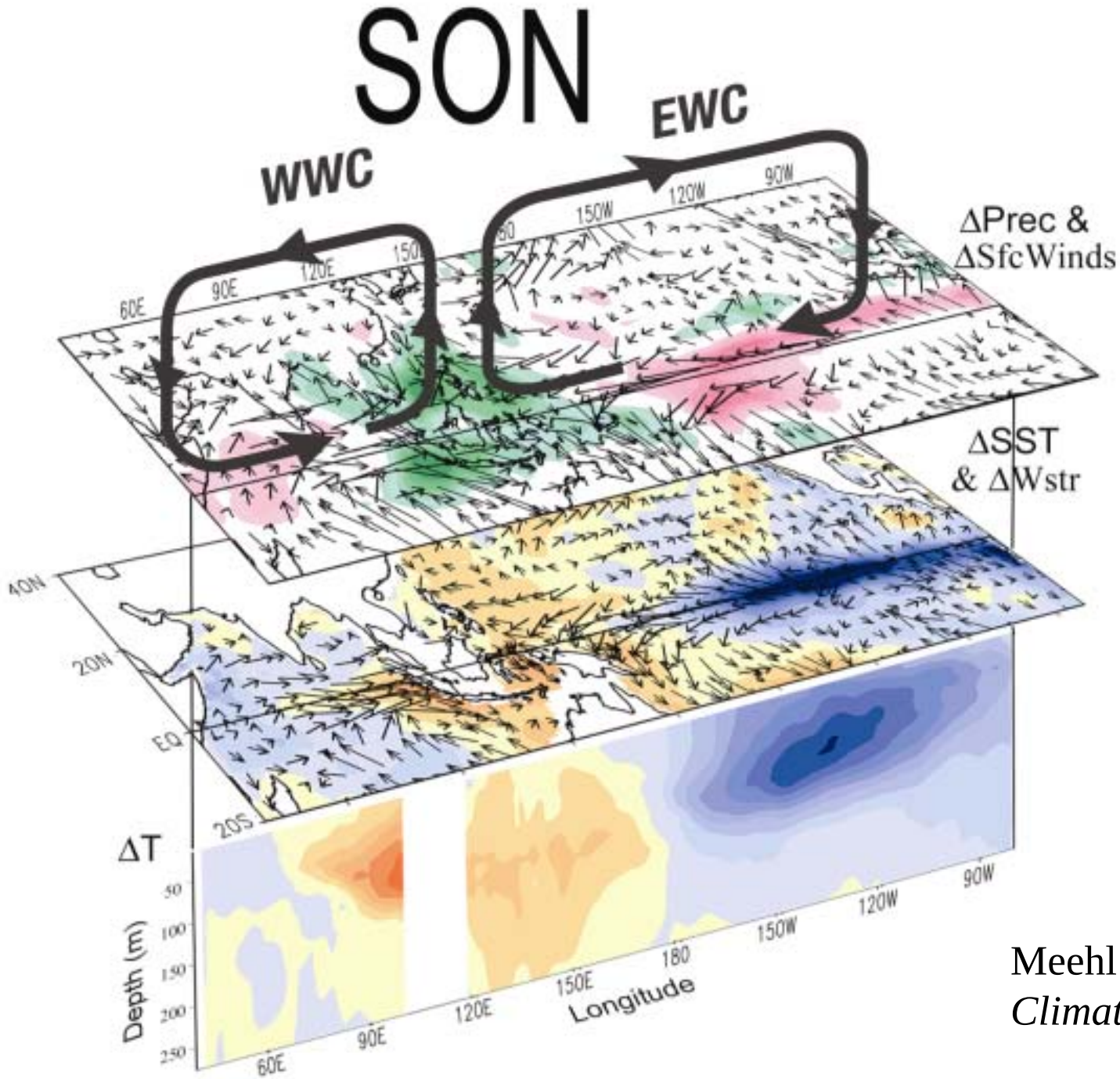
Indian SST

Pacific SST

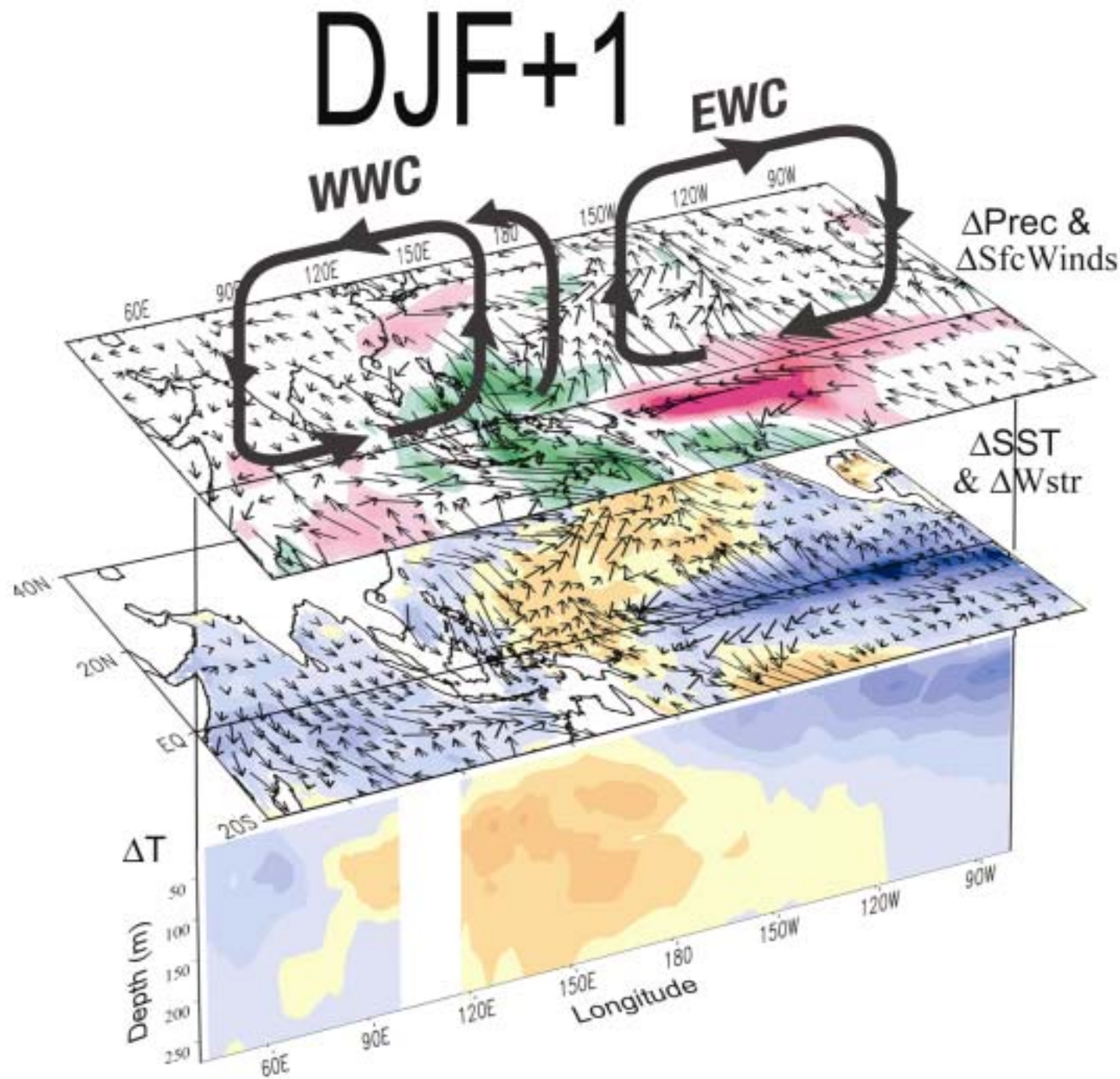
500 hPa height



Loschnigg, Meehl, Webster, Arblaster and Compo, 2003, J. Climate, 16, 1617--1642



Meehl et al., 2003: *J. Climate*, **16**, 2138-2158


DJF+1
EWC
WWC
ΔPrec &
ΔSfcWinds
ΔSST
& ΔWstr
ΔT
Depth (m)
Longitude
60E
90E
120E
150E
180
150W
120W
90W
40N
20N
EQ
20S
50
100
150
200
250

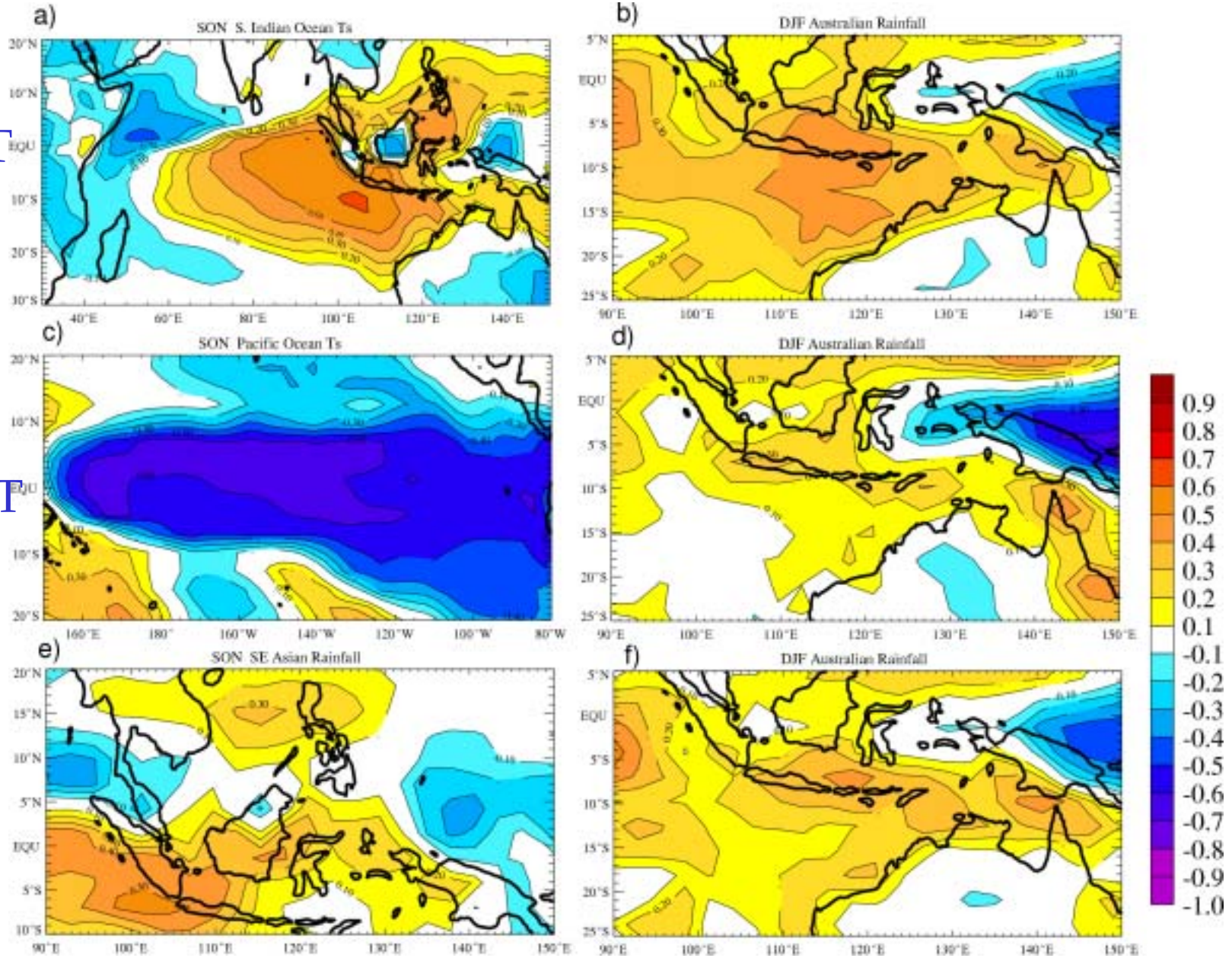
CSM1, 100 years SON DJF Precipitation

SVD

Indian SST

Pacific SST

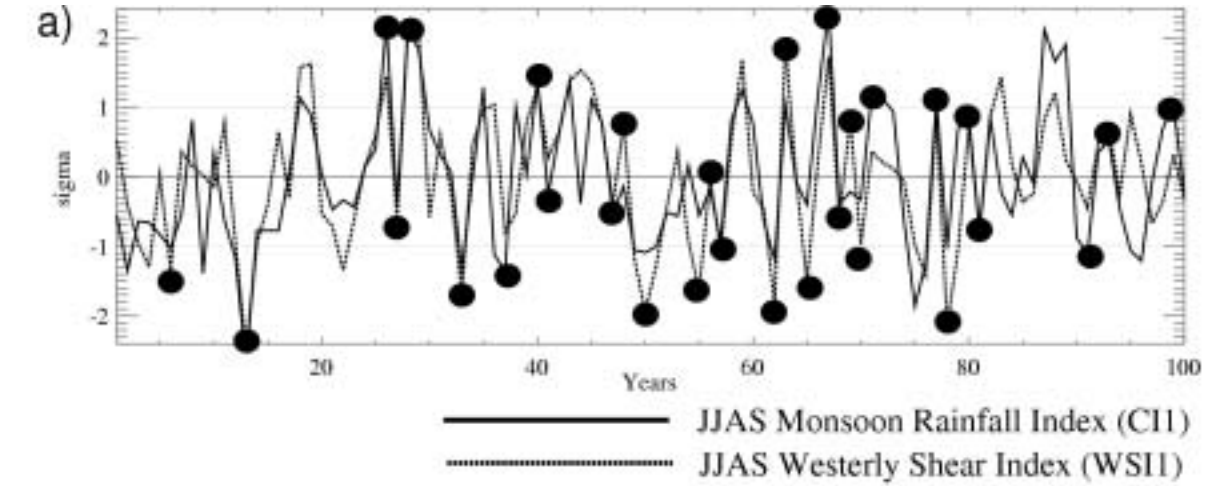
Precip

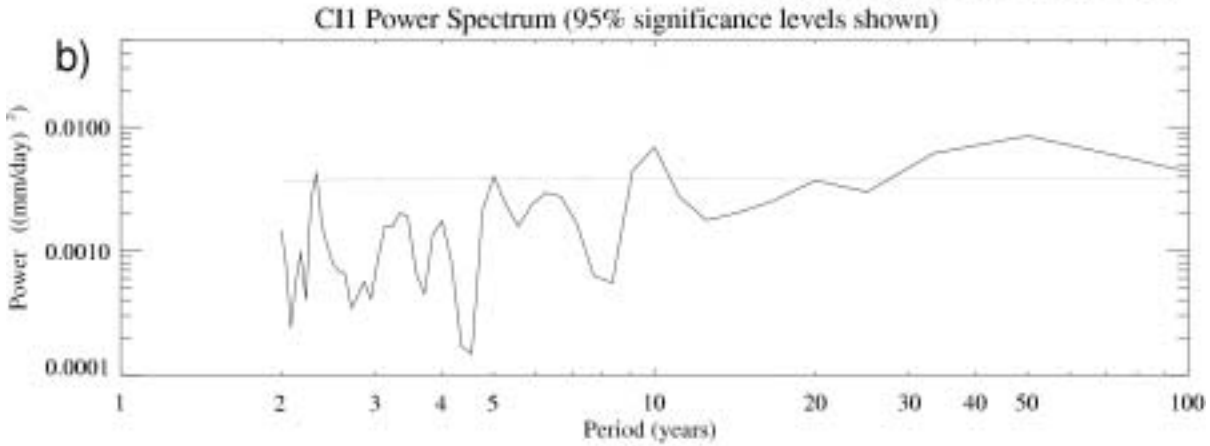


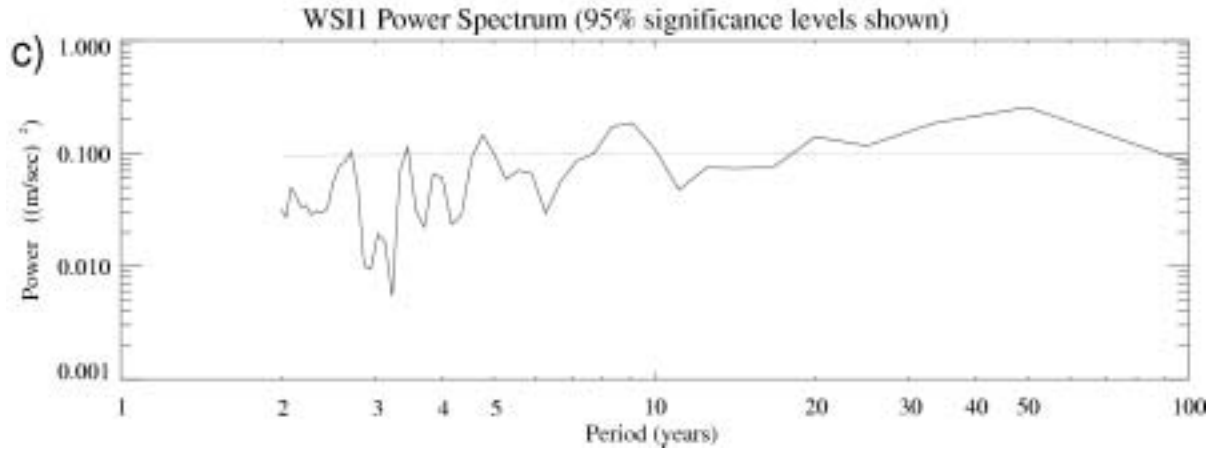
Monsoon Rainfall Index CI1: 10-25N, 70-100E (Wang and Fan, 1999)

Westerly Shear Index WSI1: 5-15N, 35-75E, $U_{850} - U_{200}$

(Webster and Yang, 1992)



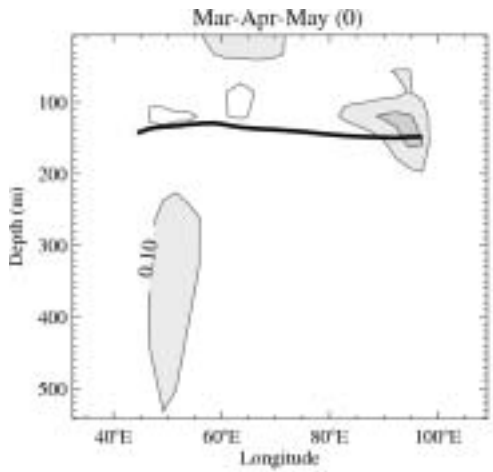


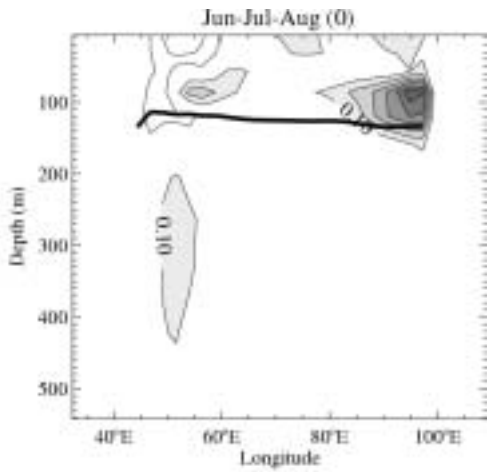


Coupled model upper ocean temperatures, equatorial section, Indian Ocean, TBO strong minus weak monsoon (dark shading = + temperatures)

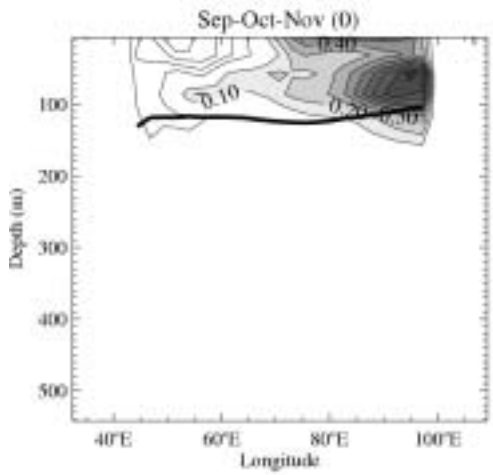
MAM_0

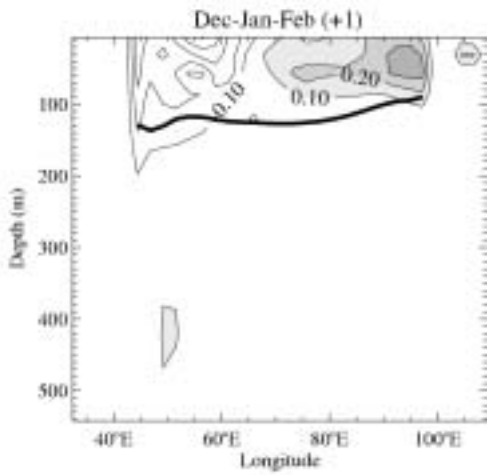
JJA_0 strong monsoon



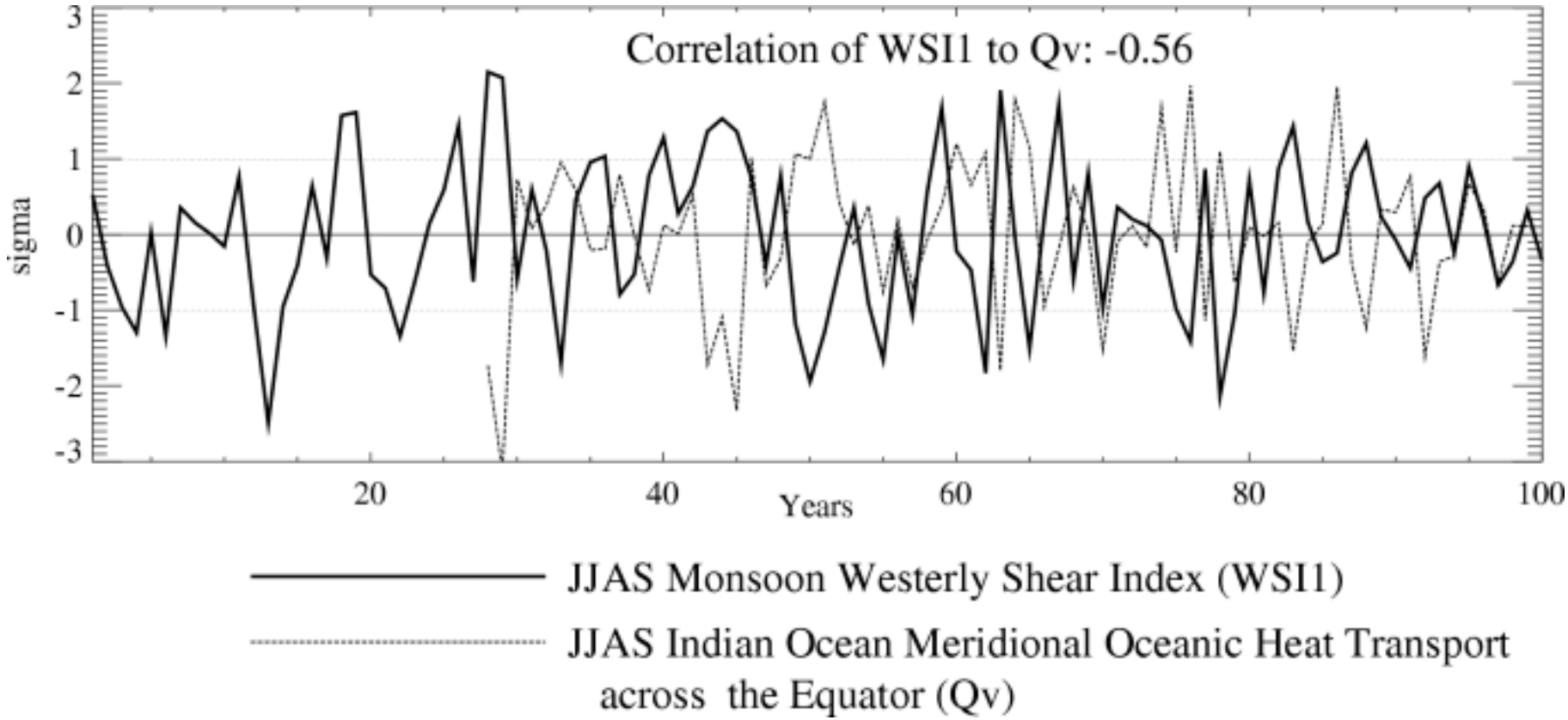


SON_0





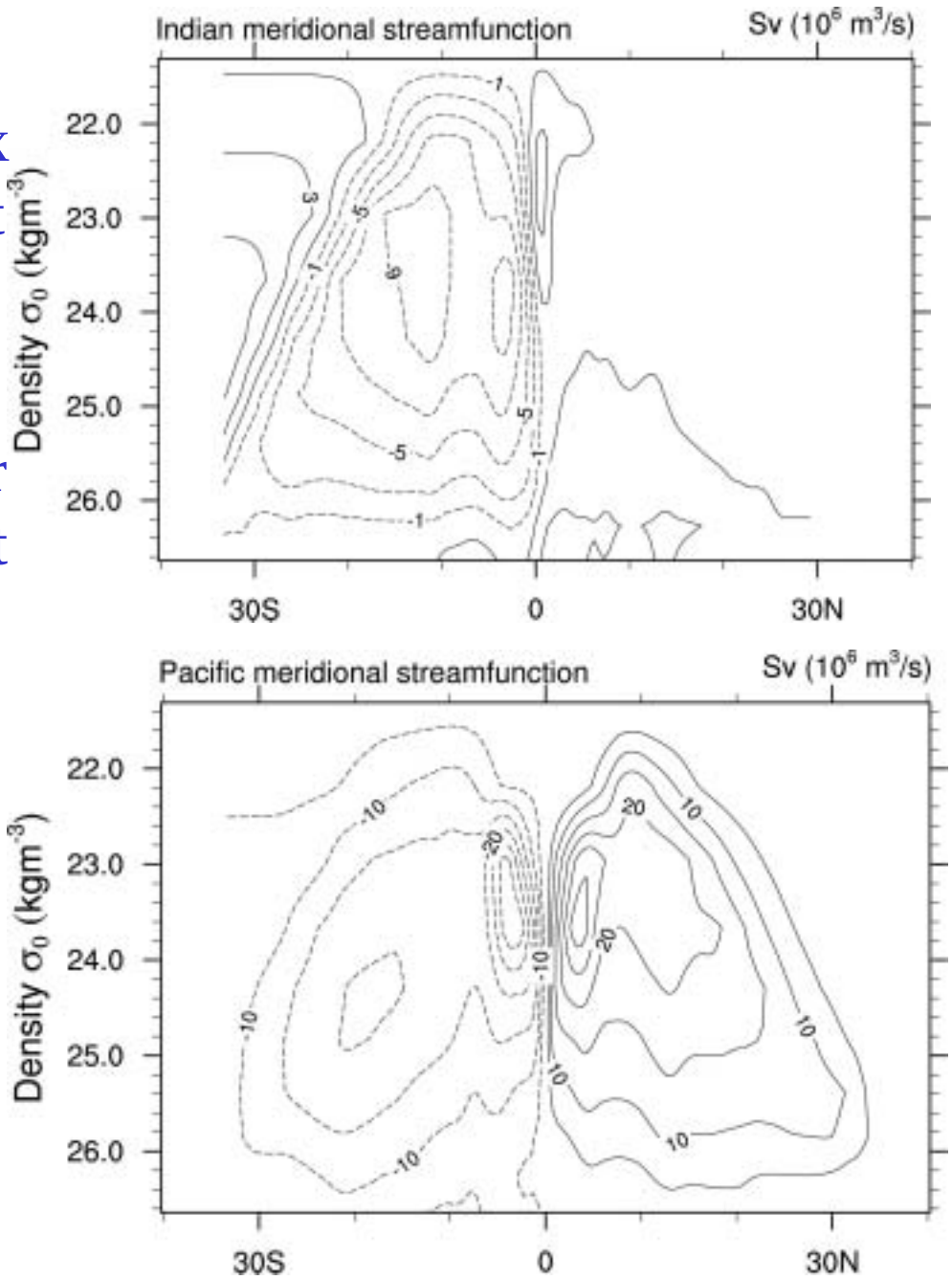
DJF_{+1}


Correlation of WSI1 to Qv: -0.56
sigma
3
2
1
0
-1
-2
-3
20
40
60
80
100
Years
JJAS Monsoon Westerly Shear Index (WSI1)
JJAS Indian Ocean Meridional Oceanic Heat Transport across the Equator (Qv)

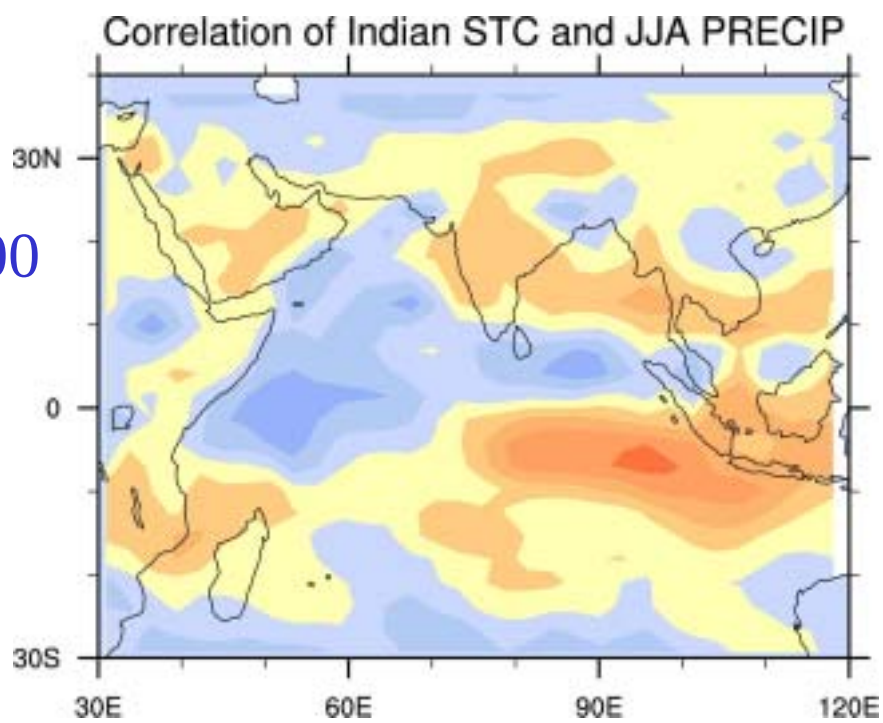
PCM 300 year control run; Correlation of Indian Ocean STC index (9N minus 9S) with heat transport index (9N minus 9S) = +0.74

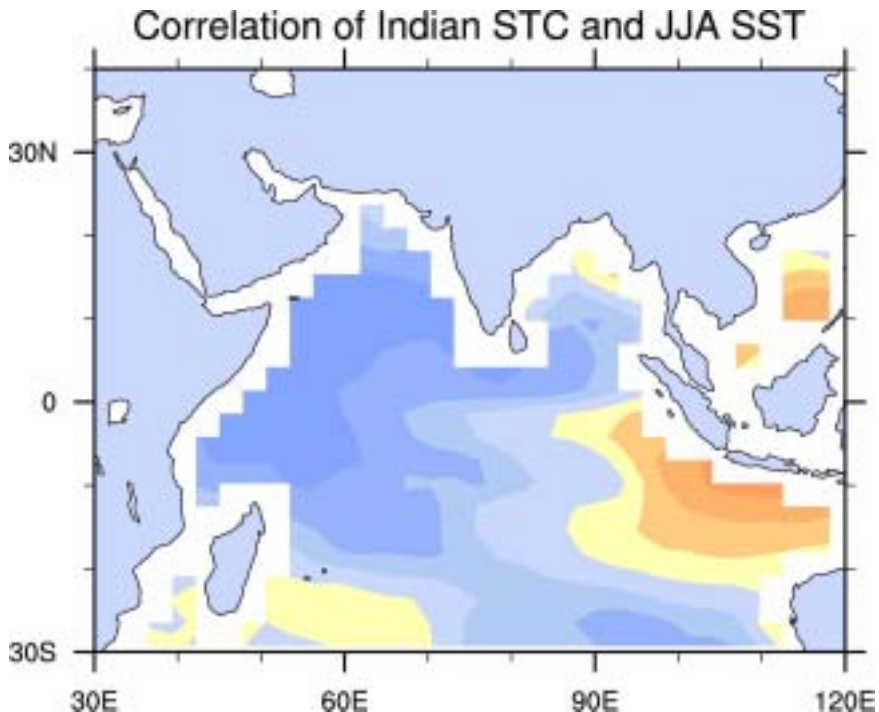
Stronger STC = stronger southward heat transport

Pacific correlation = +0.75



PCM 300 years



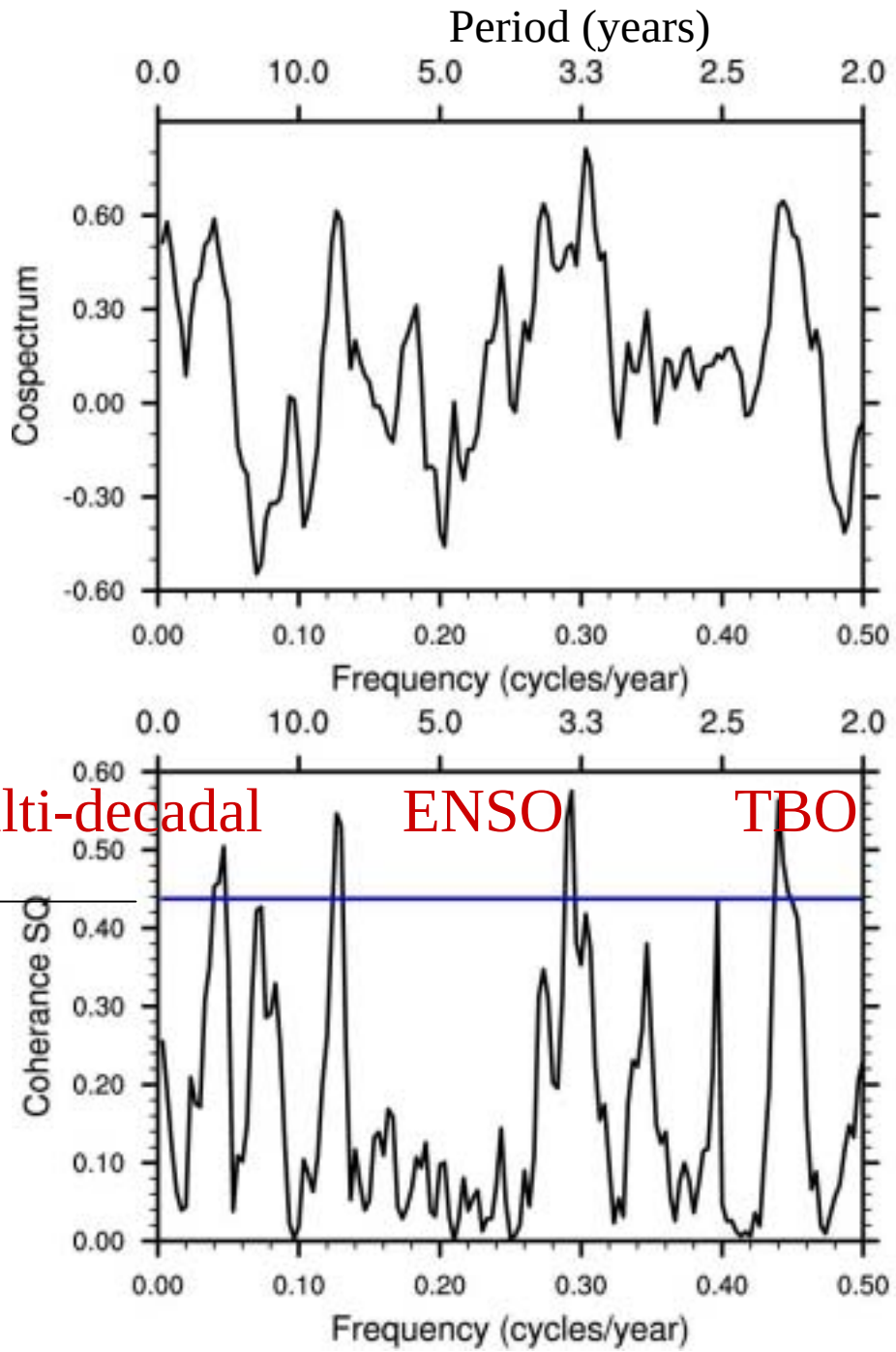


Cospectrum of JJA Indian monsoon rainfall and Indian Ocean STC index

(PCM, 300 years)

Coherence squared

95%



Conclusions

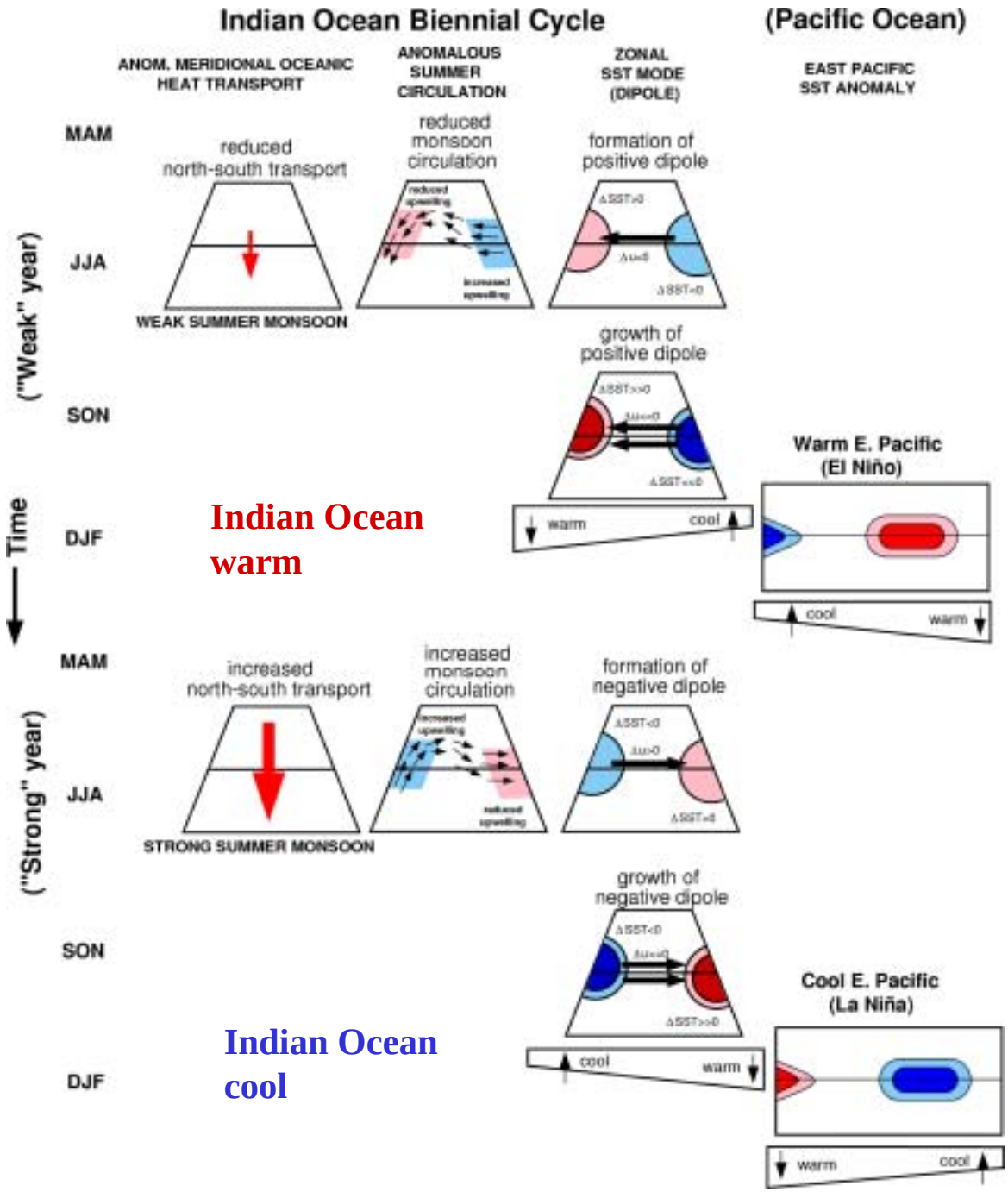
- Observations and model results show the Indian Ocean zonal mode (or IOD) and ENSO are inherent features of the TBO; the TBO is fundamental to the system and provides dynamical framework for ENSO and IOD
- “biennial tendency” of IOD and ENSO = TBO
- Ocean heat transport associated with wind-forced STC strength contributes to heat content changes and thus persistent SST anomalies in the Indian Ocean over multiple seasons, a key factor for the TBO
- Such heat content changes are also likely important for introducing low frequency variability into the system so it is not perfectly biennial

Scale interaction: lower frequency processes set the base state for progressively higher frequency "triggers" to make a transition, and that new base state then affects the higher frequency phenomena

Multi-decadal processes set base state, and an El Nino can then trigger an apparent decadal change (1976-77 El Nino going into a "warm" decadal state; 1998-99 La Nina going into a "cold" decadal state), and then that base state affects subsequent El Nino events

TBO timescale processes set the base state such that an MJO can trigger an onset of IOD or El Nino (MJOs and 1997-98 El Nino), and then the El Nino or IOD conditions affect the manifestation of subsequent MJO's.

Meehl, G.A., R. Lukas, G.N. Kiladis, M. Wheeler, A. Matthews, and K.M. Weickmann, 2001: A conceptual framework for time and space scale interactions in the climate system. *Clim. Dyn.*, **17**, 753--775.



Loschnigg et al., 2003: *J. Climate*, **16**, 1617-1642

Conclusions

- TBO transitions in northern spring affected most by tropical SST anomalies in the Indian and Pacific, and less from land-sea meridional temperature contrasts
- Observations and model results show the Indian Ocean zonal mode (or IOD) and ENSO are inherent features of the TBO; the TBO is fundamental to the system and provides dynamical framework for ENSO and IOD
- “biennial tendency” of IOD and ENSO = TBO
- Ocean heat transport contributes to heat content and persistent SST anomalies in the Indian Ocean over multiple seasons, a key factor for the TBO

Observations and models

- NCEP/NCAR reanalyses, SODA ocean data, CMAP precipitation data
- CSM1 coupled model (100 year period from control run), CCM3 atmosphere T42 18L (5 member ensembles, Jan. to Oct.), 2 degree ocean, dynamic sea ice, LSM land surface model

Indian region TBO monsoon transition conditions:

- 500 hPa height anomalies and associated Asian land temperature anomalies
- Tropical Indian Ocean SST anomalies

Large scale TBO monsoon transition condition:

Tropical Pacific Ocean SST anomalies

Dark shading=+precip

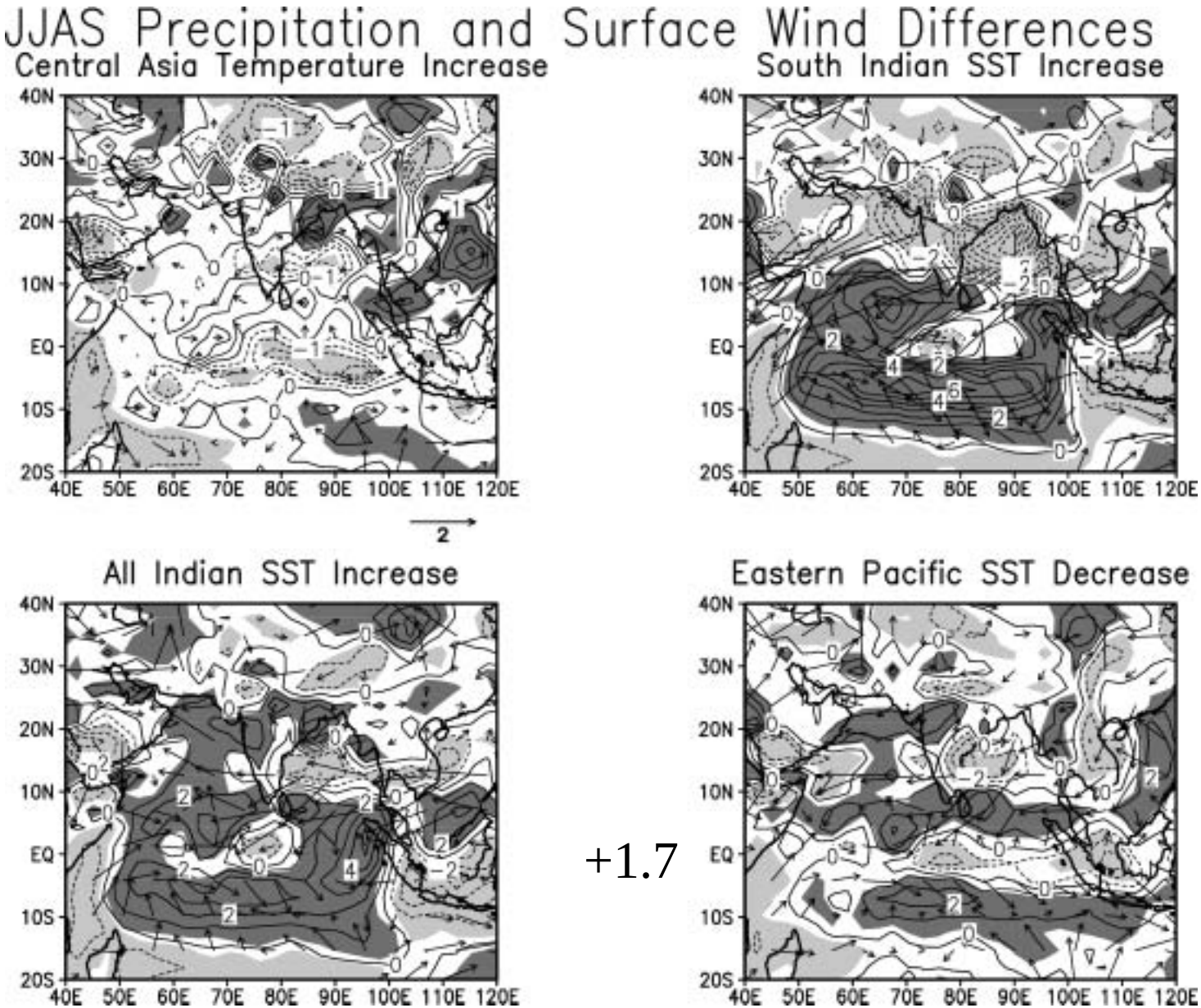
+0.8

AGCM sensitivity experiments

5 member ensemble means; 5% significance shaded

+3.5

+1.7



Meehl and Arblaster, 2002, J. Climate, 15, 923--944

The Indian Ocean, the tropospheric biennial oscillation (TBO), and the Asian-Australian monsoon

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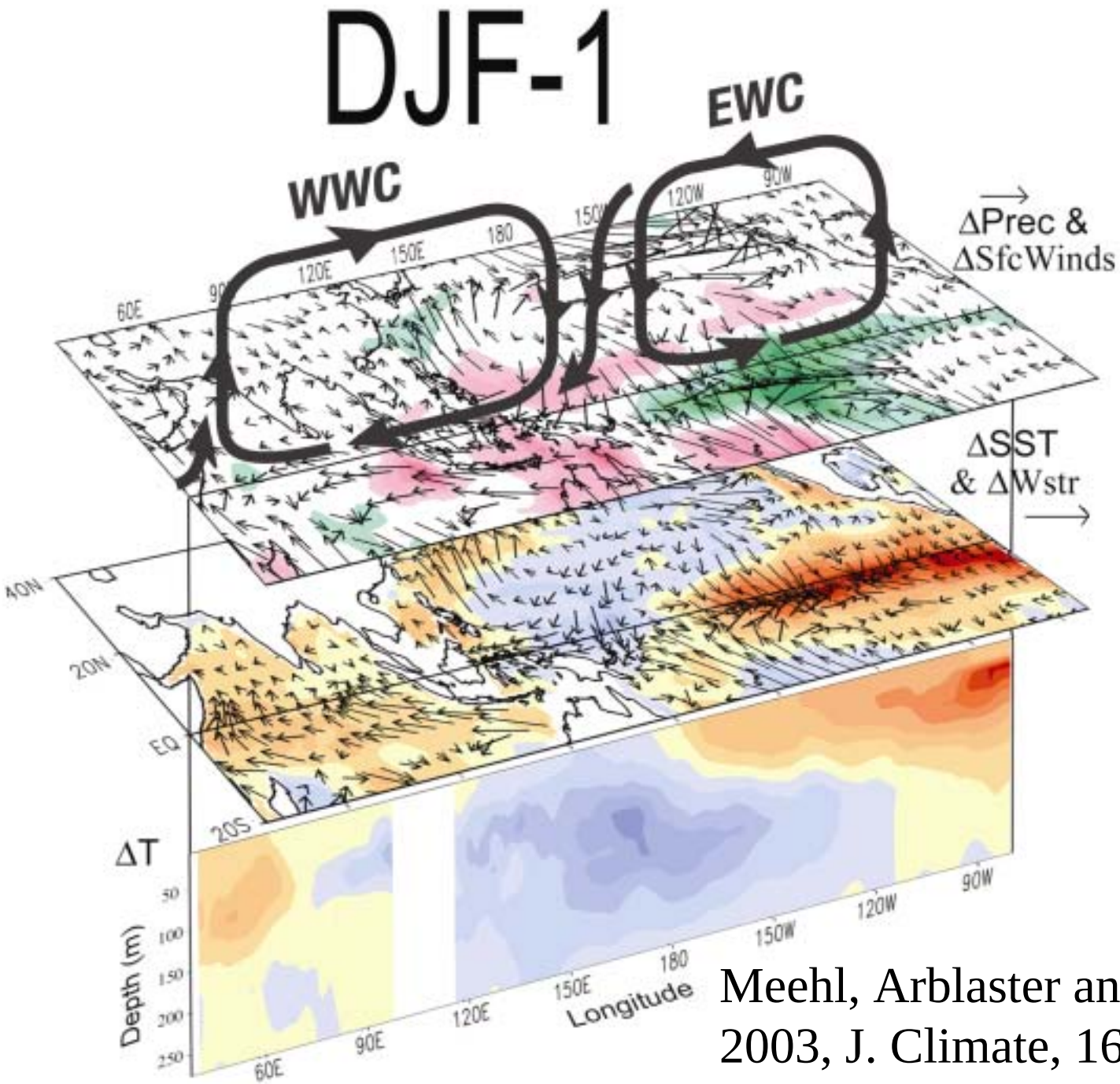
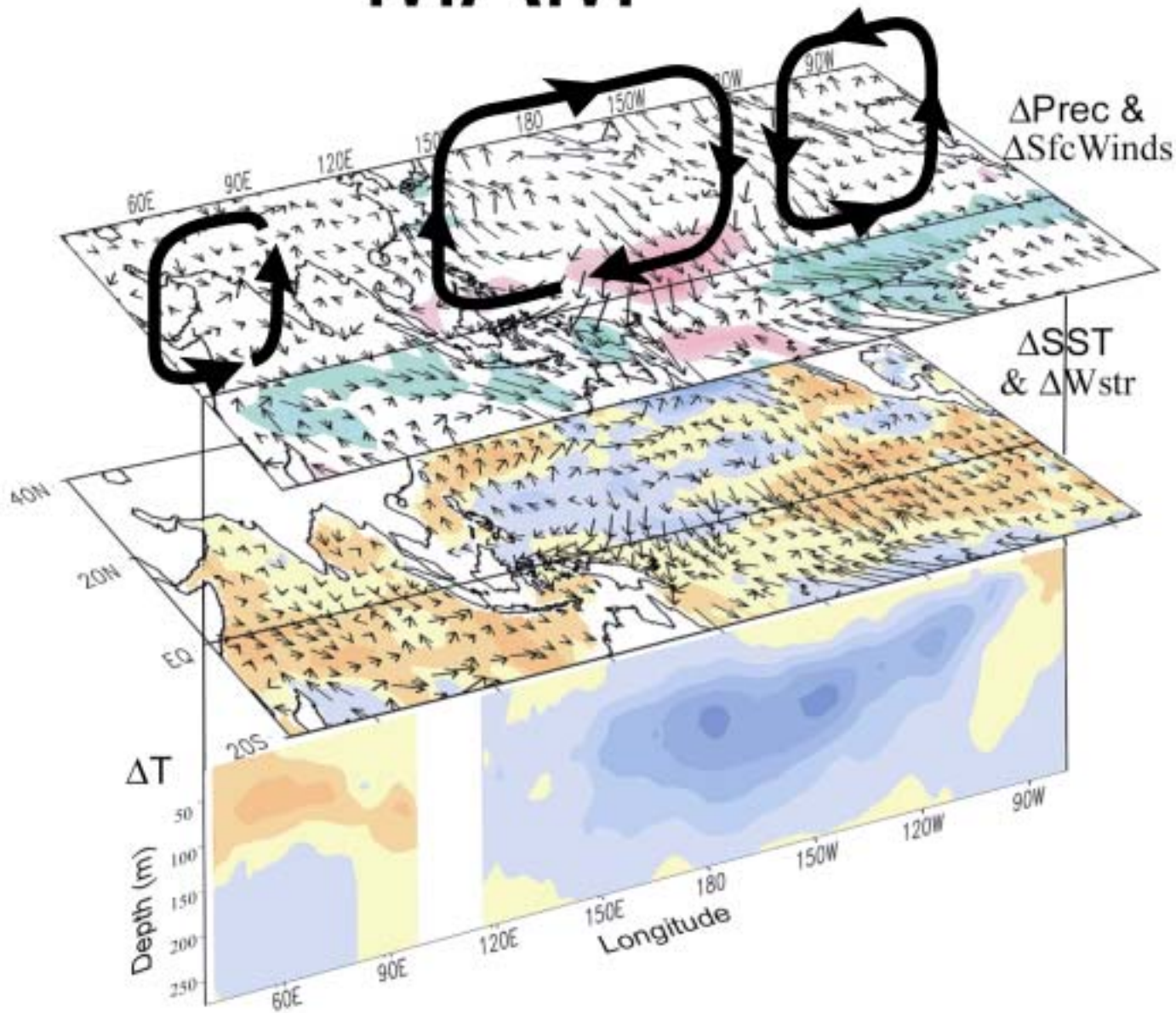
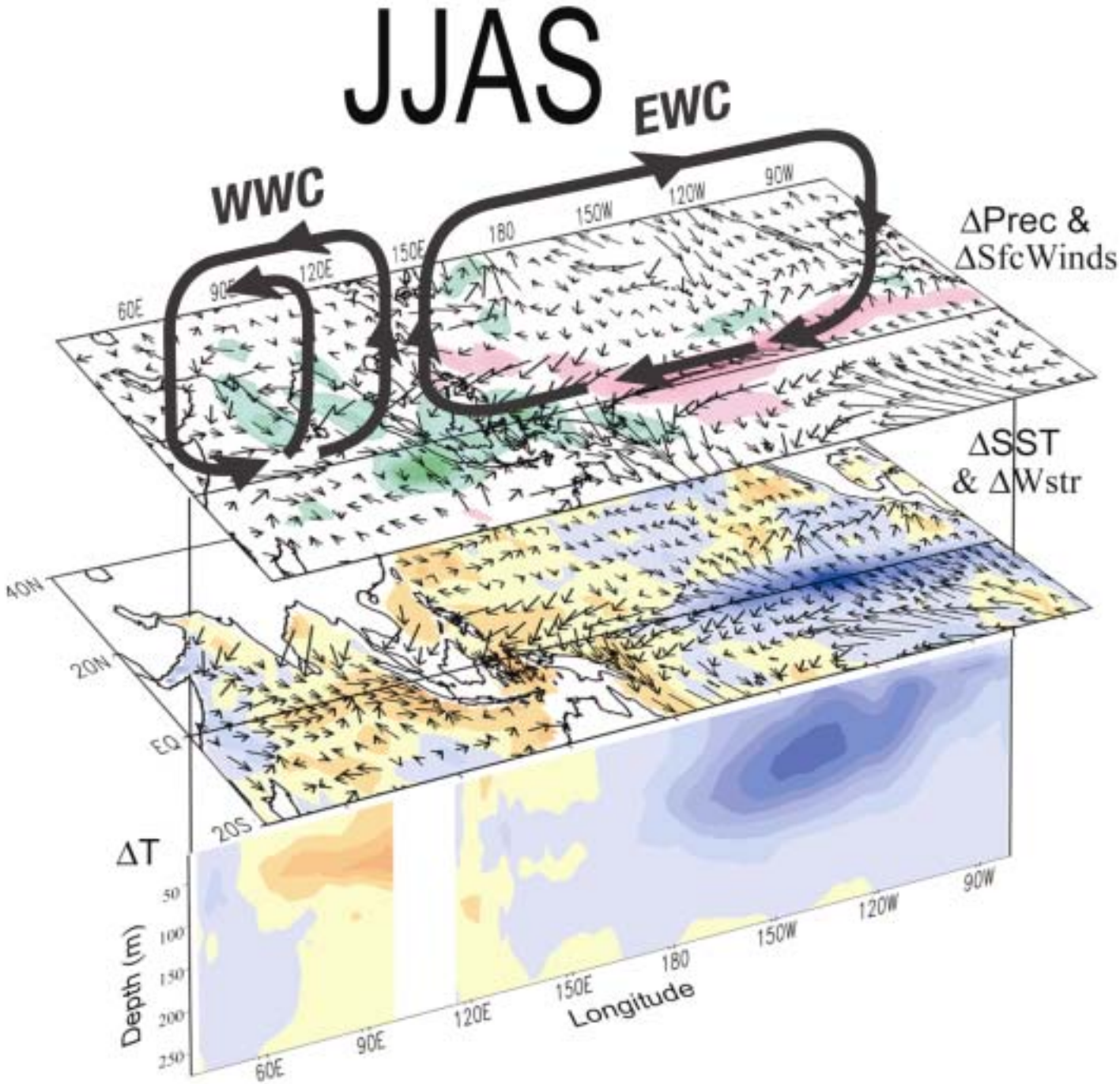
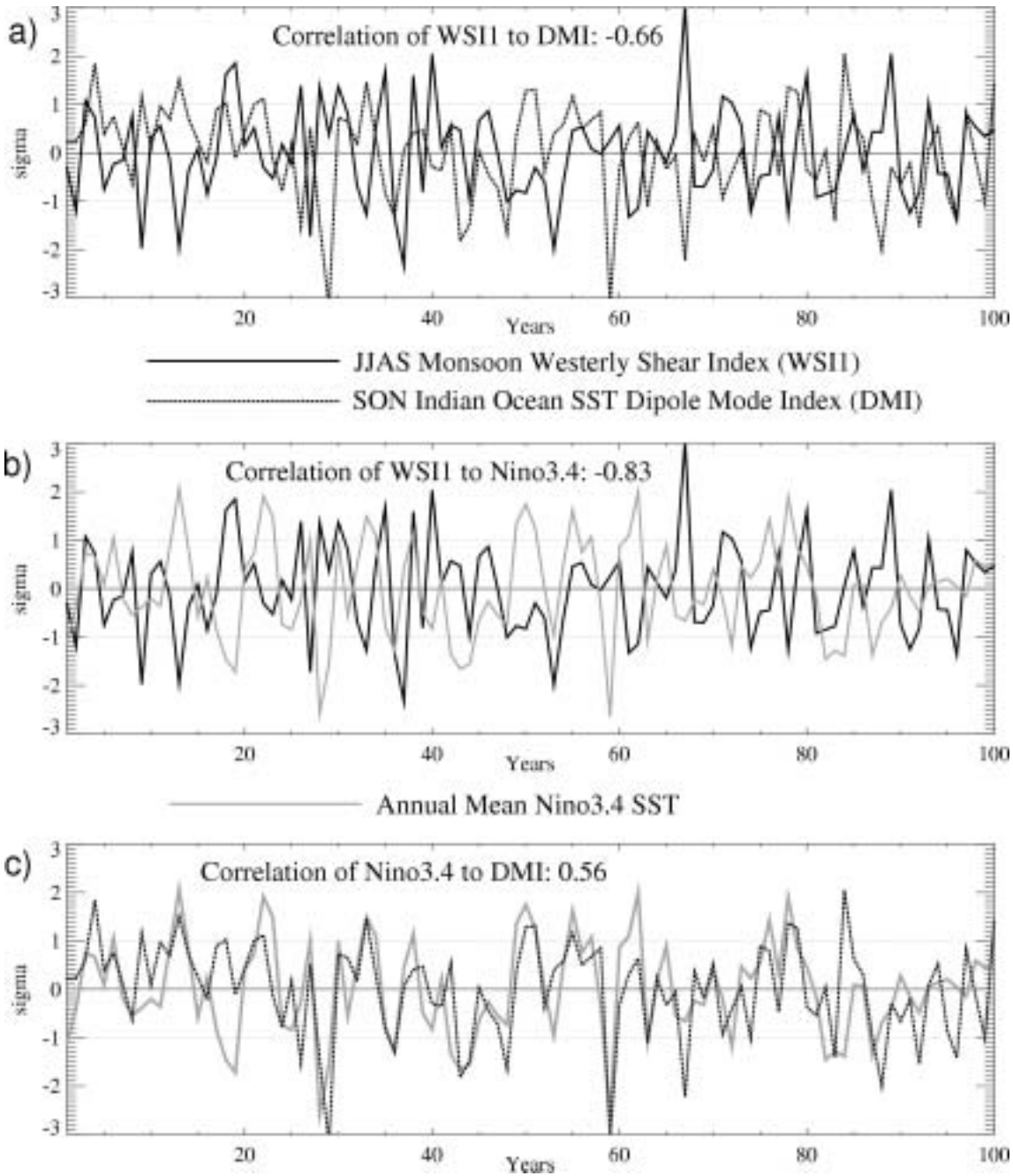


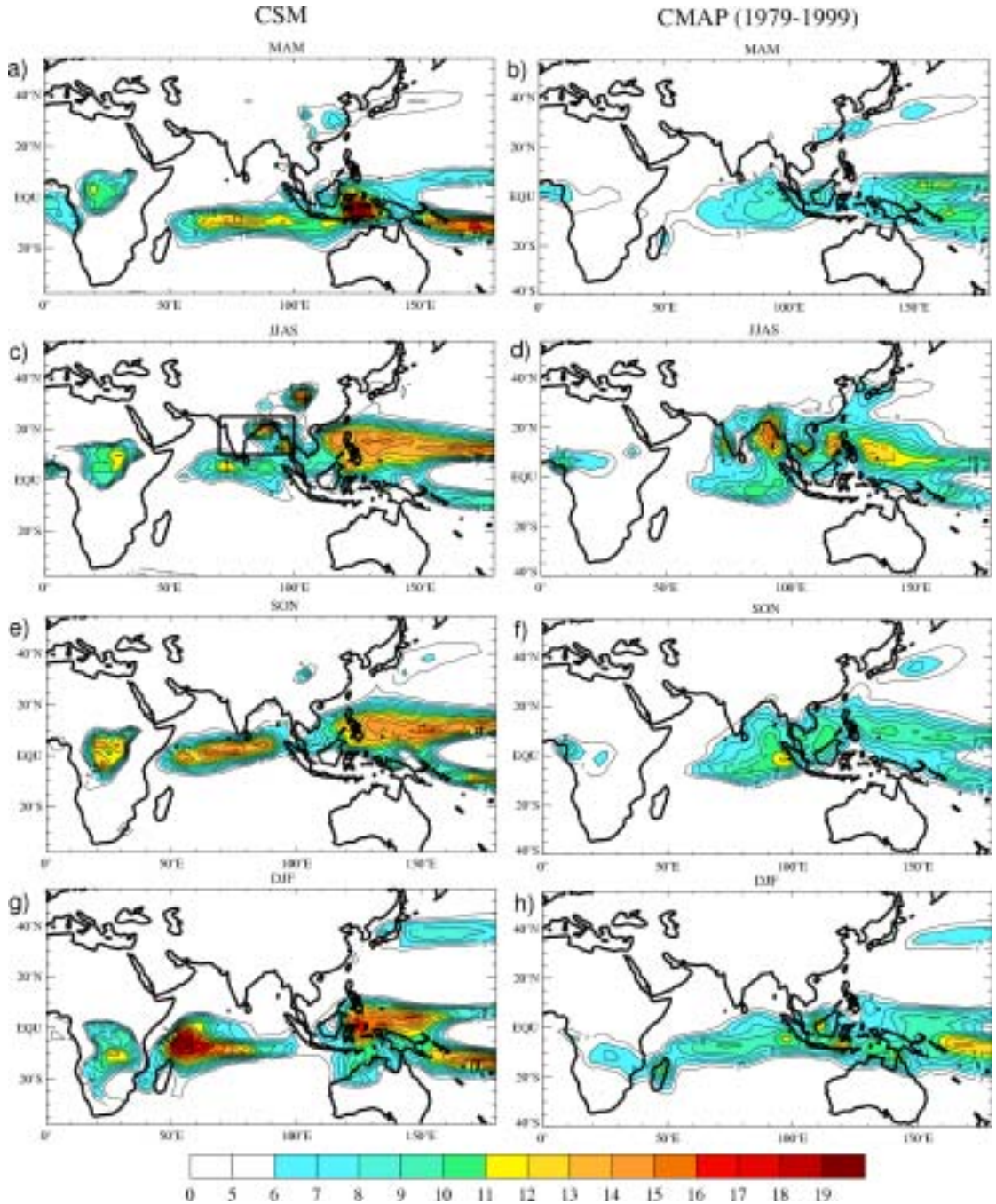
Meehl, Arblaster and Loschnigg, 2003, J. Climate, 16, 2138--2158

MAM

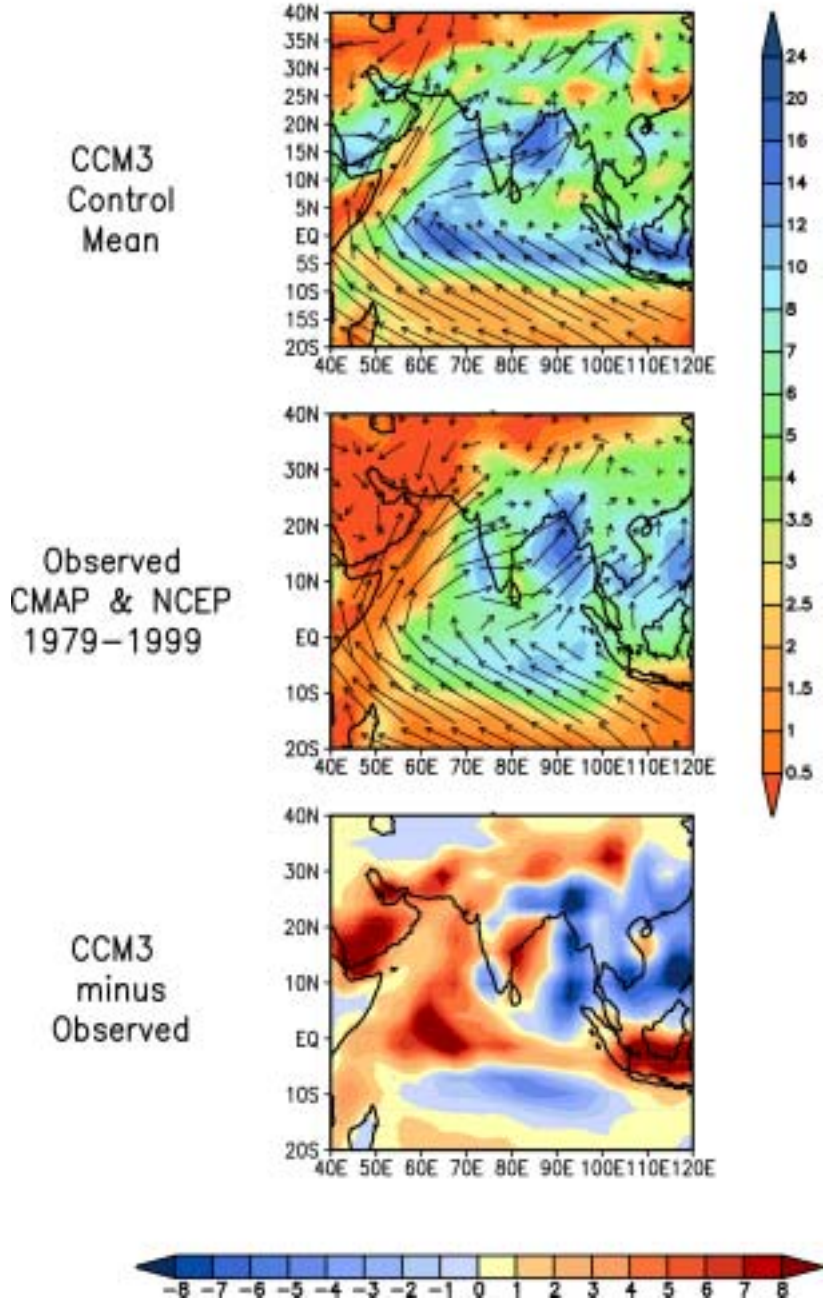

ΔPrec &
ΔSfcWinds
ΔSST
& ΔWstr
ΔT
60E
90E
120E
150E
180
150W
120W
90W
40N
20N
EQ
20S
Depth (m)
50
100
150
200
250
Longitude


JJAS
EWC
WWC
ΔPrec &
ΔSfcWinds
ΔSST
& ΔWstr
ΔT
Depth (m)
Longitude
60E
90E
120E
150E
180
150W
120W
90W
40N
20N
EQ
20S
50
100
150
200
250


a)
Correlation of WSI1 to DMI: -0.66
sigma
Years
JJAS Monsoon Westerly Shear Index (WSI1)
SON Indian Ocean SST Dipole Mode Index (DMI)
b)
Correlation of WSI1 to Nino3.4: -0.83
sigma
Years
Annual Mean Nino3.4 SST
c)
Correlation of Nino3.4 to DMI: 0.56
sigma
Years


CSM
CMAP (1979-1999)
a)
b)
c)
d)
e)
f)
g)
h)
MAM
JJAS
SON
DJF
40°N
20°N
EQU
20°S
40°S
0°
50°E
100°E
150°E
0
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

JJAS
Precipitation and Surface Winds



1979-1999

13 out of 21 are TBO years

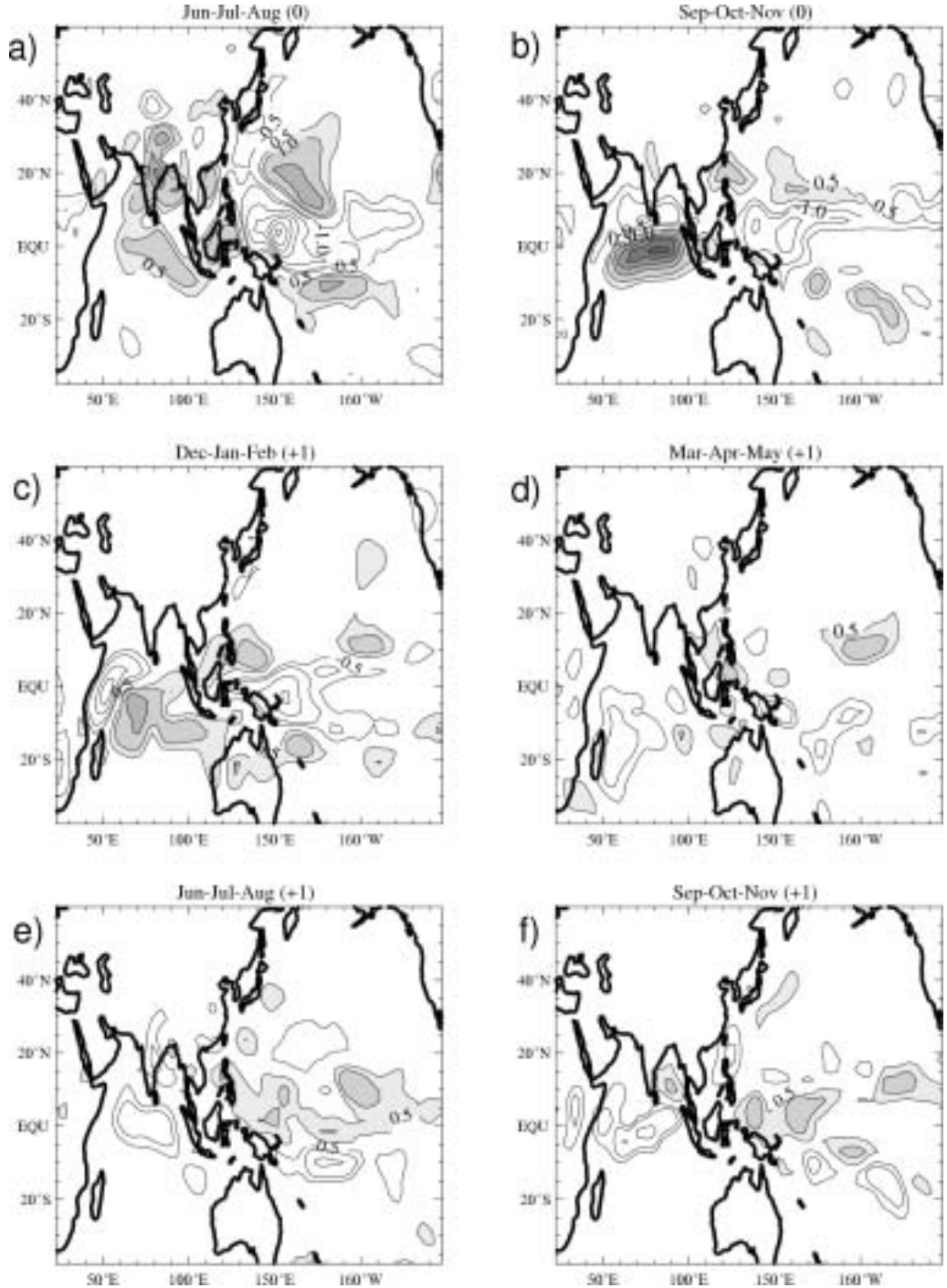
7 relatively strong monsoons

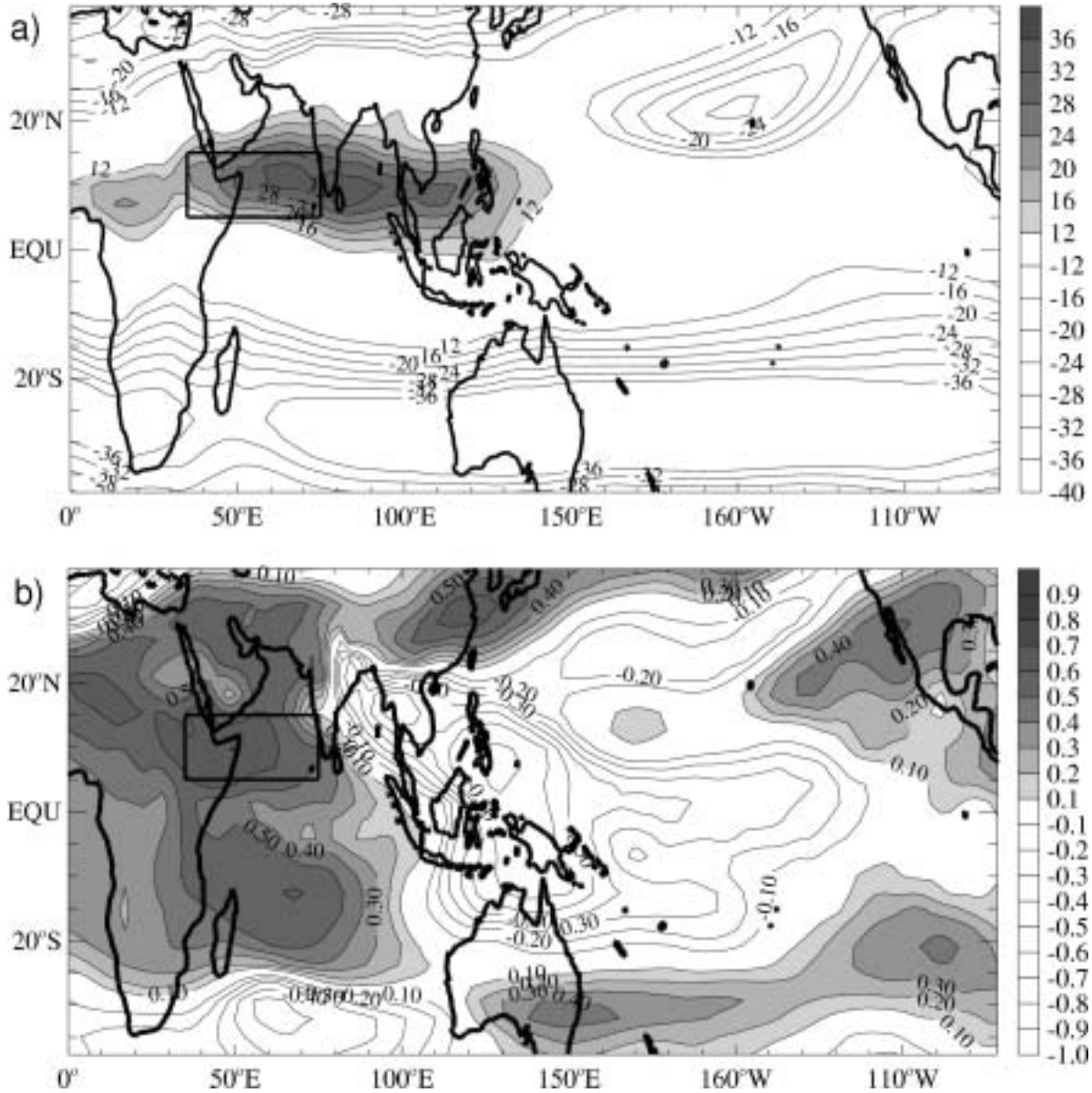
(3 La Nina, 2 negative IOD)

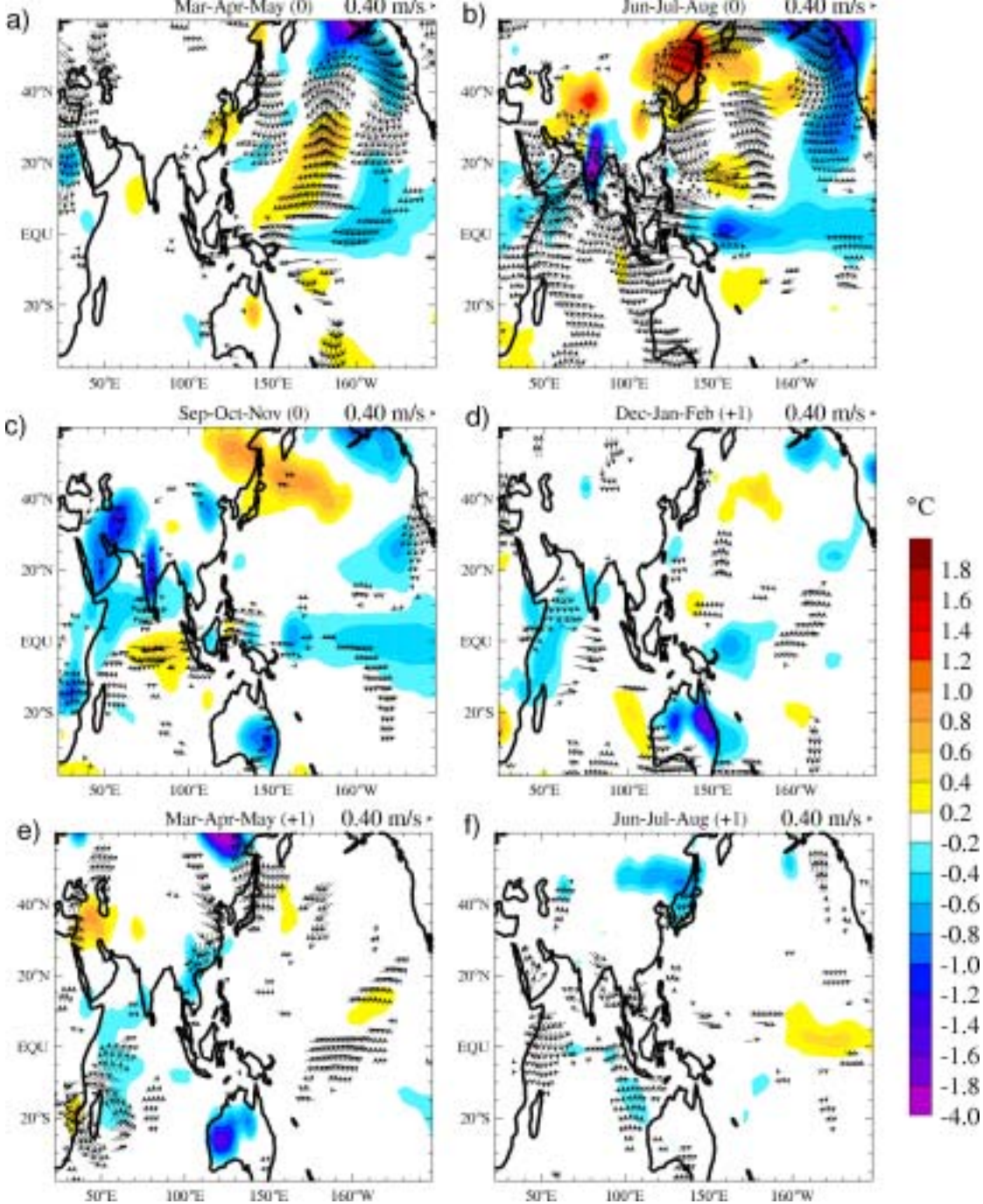
6 relatively weak monsoons

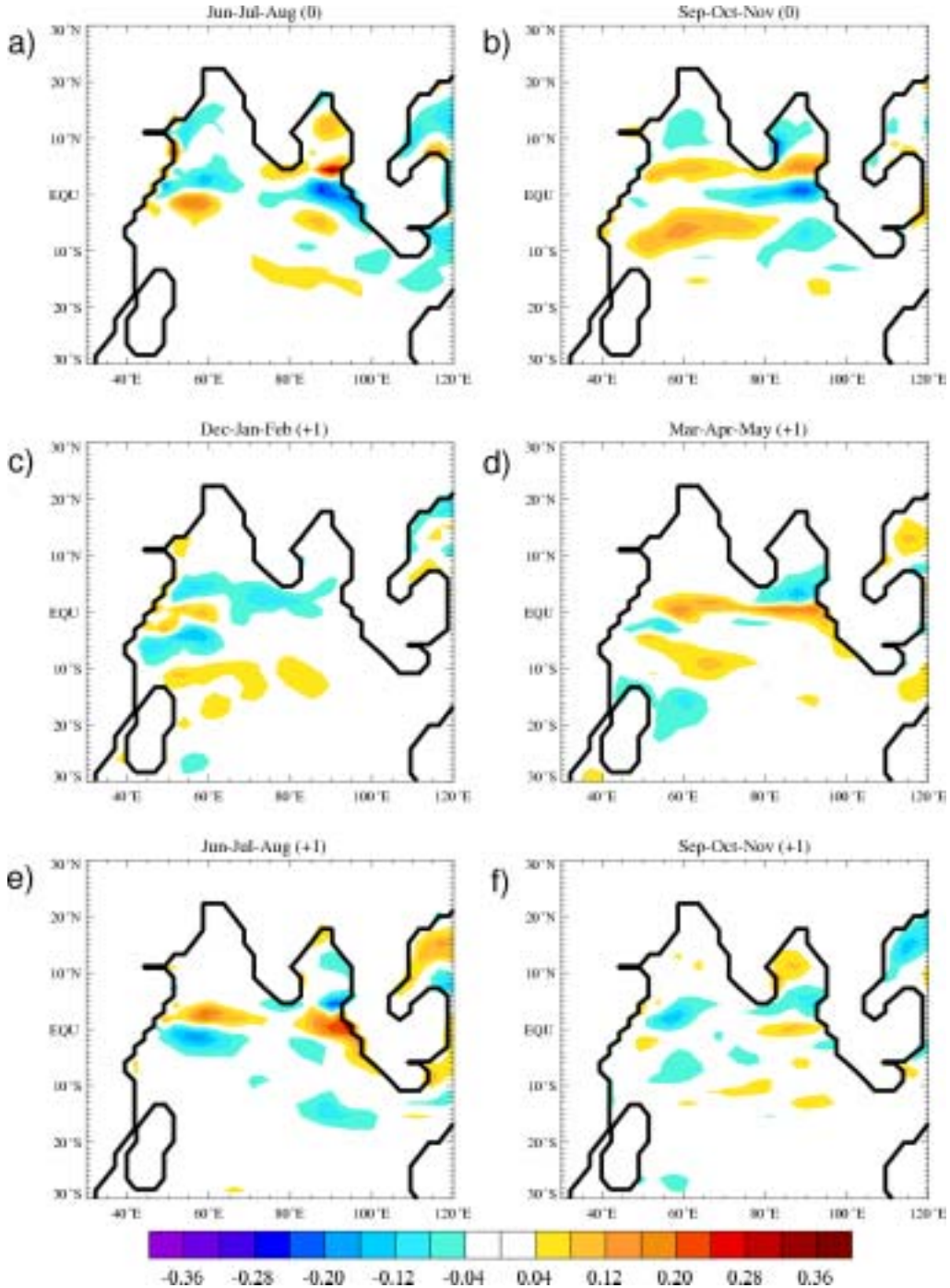
(4 El Nino, 2 El Nino years are positive IOD)

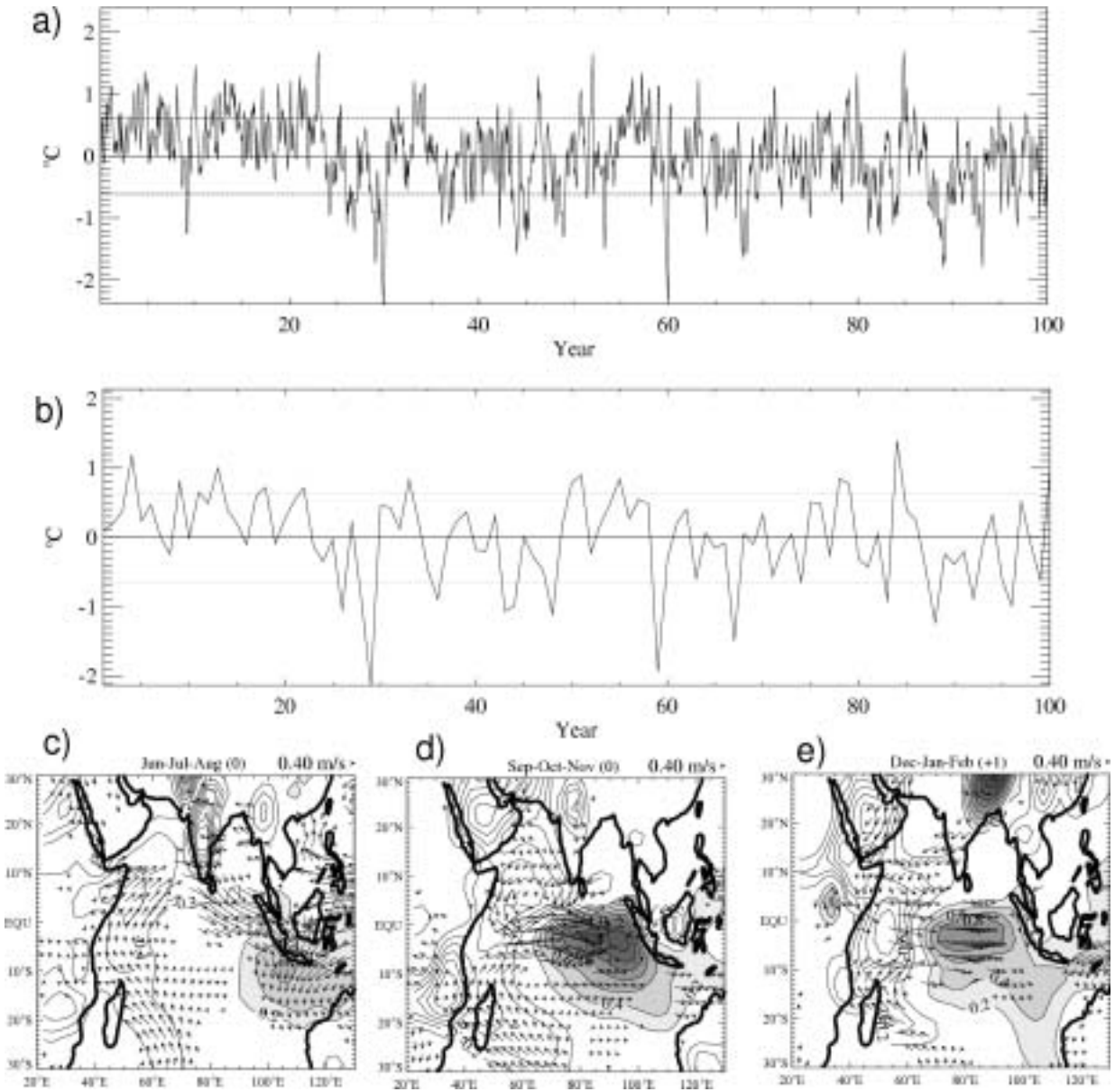
4 years are neither ENSO or IOD and they have similar signals

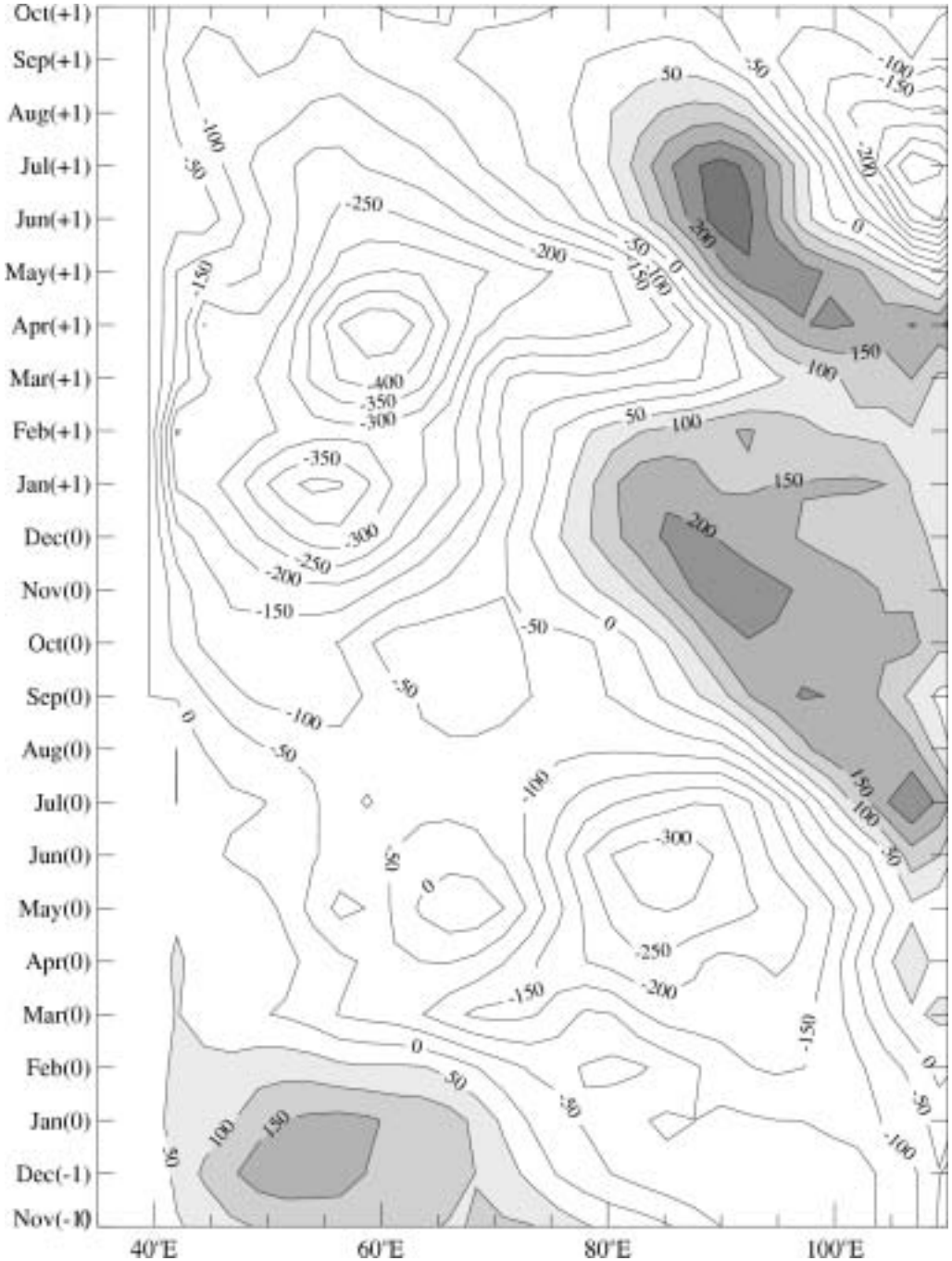

a)
Jun-Jul-Aug (0)
b)
Sep-Oct-Nov (0)
c)
Dec-Jan-Feb (+1)
d)
Mar-Apr-May (+1)
e)
Jun-Jul-Aug (+1)
f)
Sep-Oct-Nov (+1)
40°N
20°N
EQU
20°S
50°E
100°E
150°E
160°W

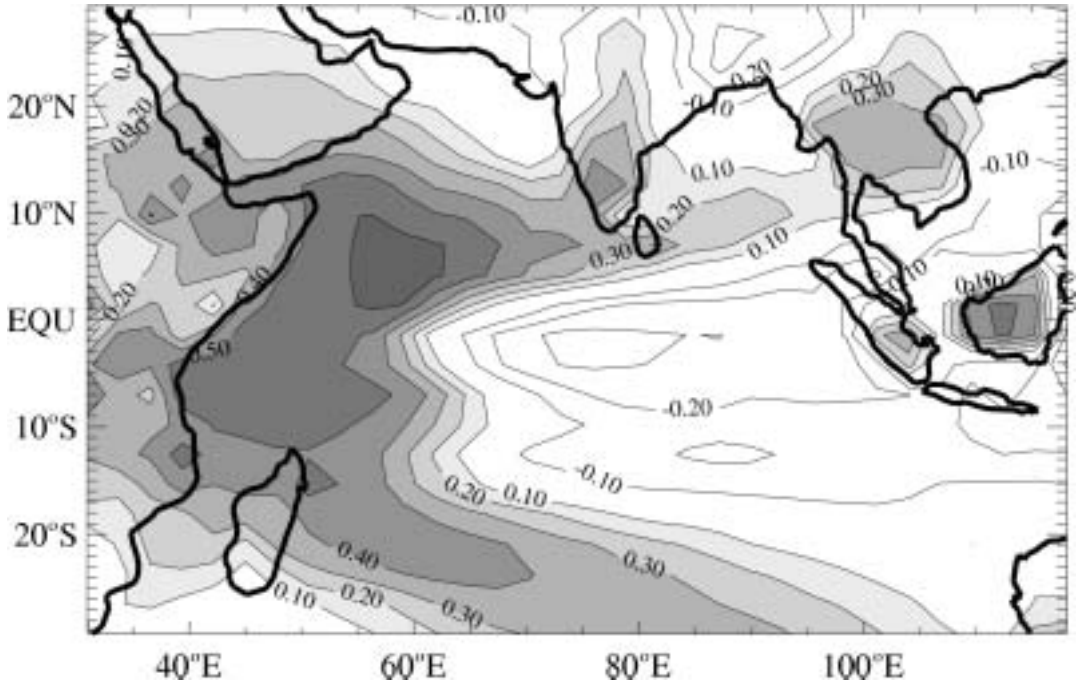

a)
20°N
EQU
20°S
0°
50°E
100°E
150°E
160°W
110°W
36
32
28
24
20
16
12
-12
-16
-20
-24
-28
-32
-36
-40
b)
20°N
EQU
20°S
0°
50°E
100°E
150°E
160°W
110°W
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0

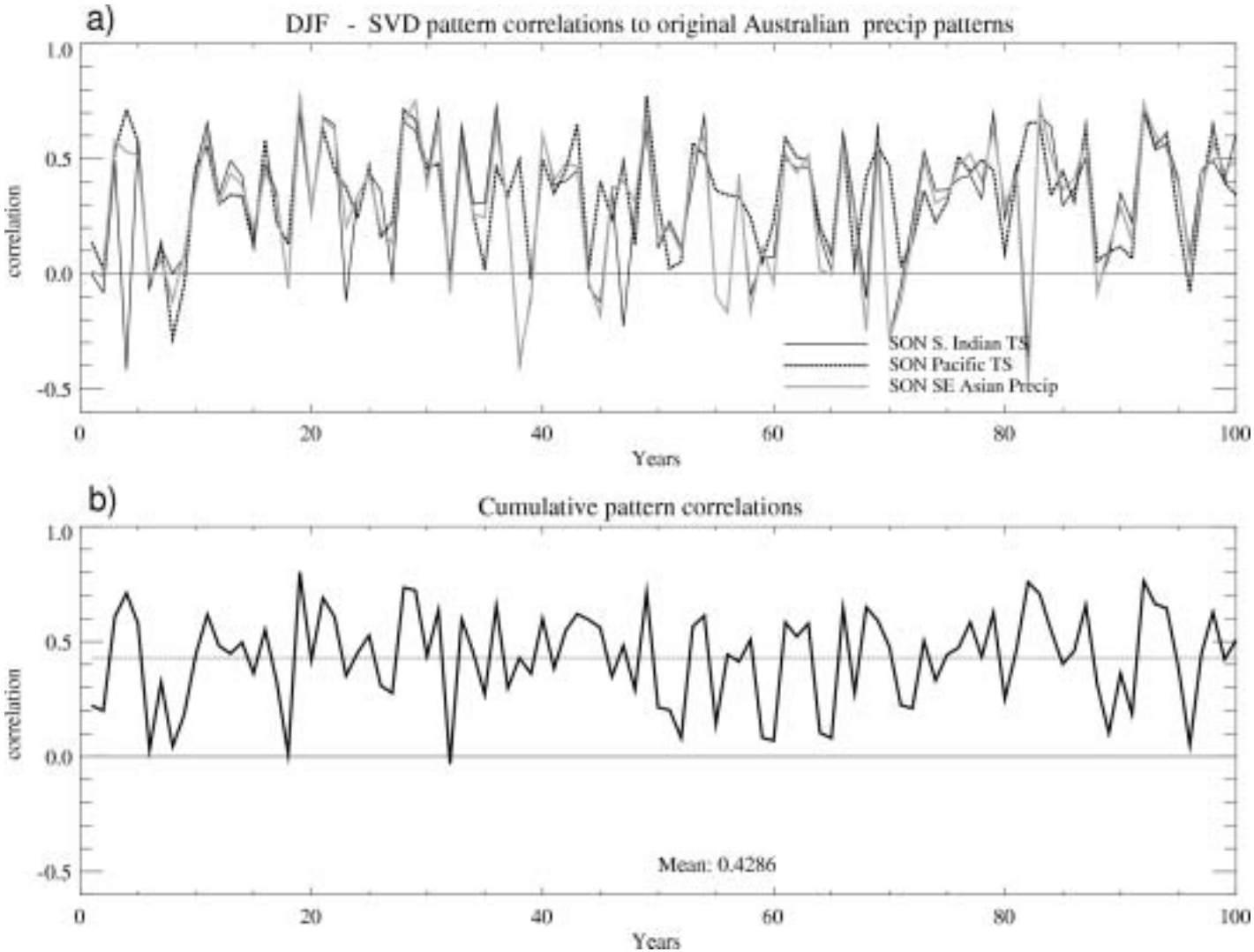

a)
Mar-Apr-May (0)
0.40 m/s
b)
Jun-Jul-Aug (0)
0.40 m/s
c)
Sep-Oct-Nov (0)
0.40 m/s
d)
Dec-Jan-Feb (+1)
0.40 m/s
e)
Mar-Apr-May (+1)
0.40 m/s
f)
Jun-Jul-Aug (+1)
0.40 m/s
40°N
20°N
EQU
20°S
50°E
100°E
150°E
160°W
°C
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-4.0

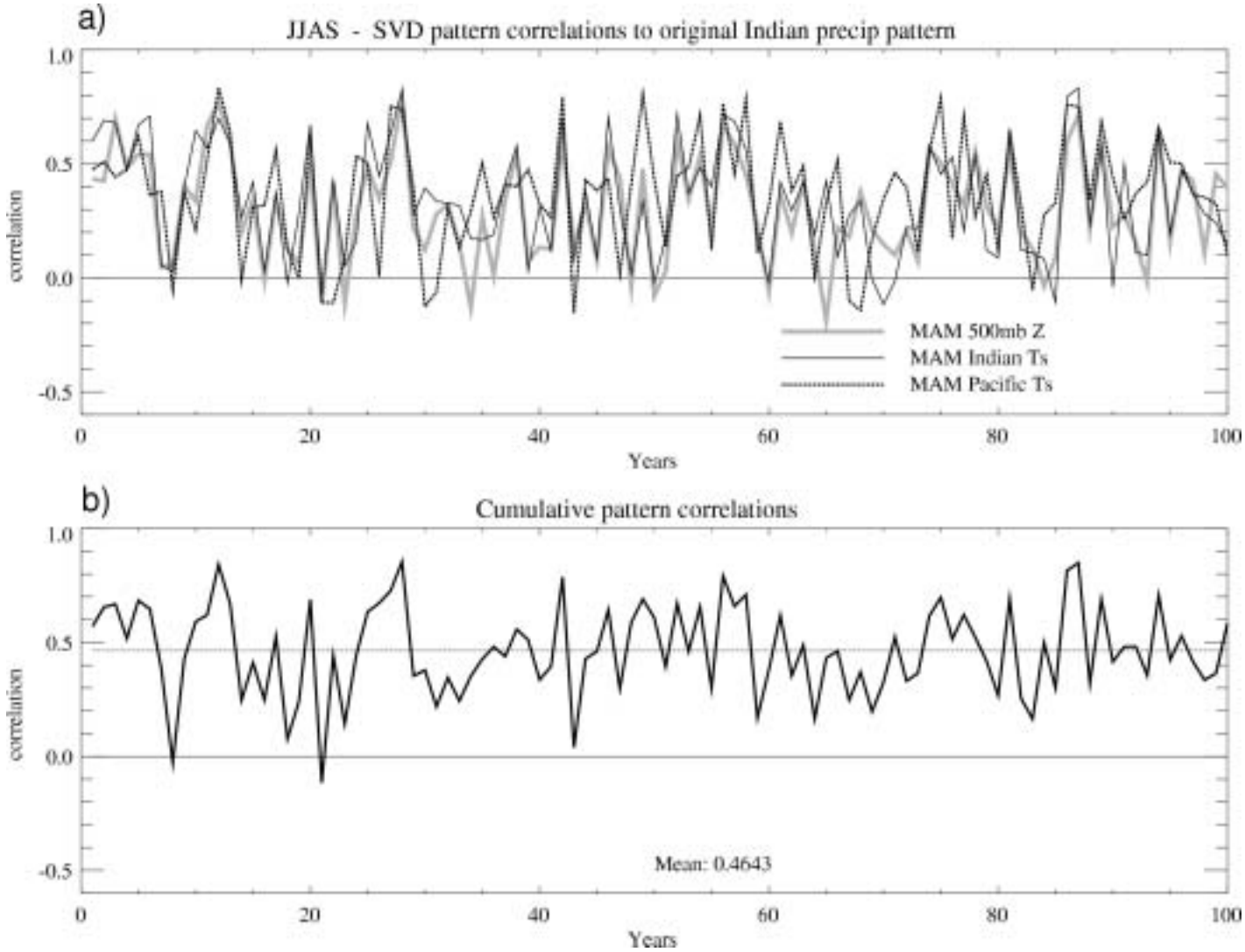

a)
Jun-Jul-Aug (0)
b)
Sep-Oct-Nov (0)
c)
Dec-Jan-Feb (+1)
d)
Mar-Apr-May (+1)
e)
Jun-Jul-Aug (+1)
f)
Sep-Oct-Nov (+1)
30°N
20°N
10°N
EQU
10°S
20°S
30°S
40°E
60°E
80°E
100°E
120°E
-0.36
-0.28
-0.20
-0.12
-0.04
0.04
0.12
0.20
0.28
0.36

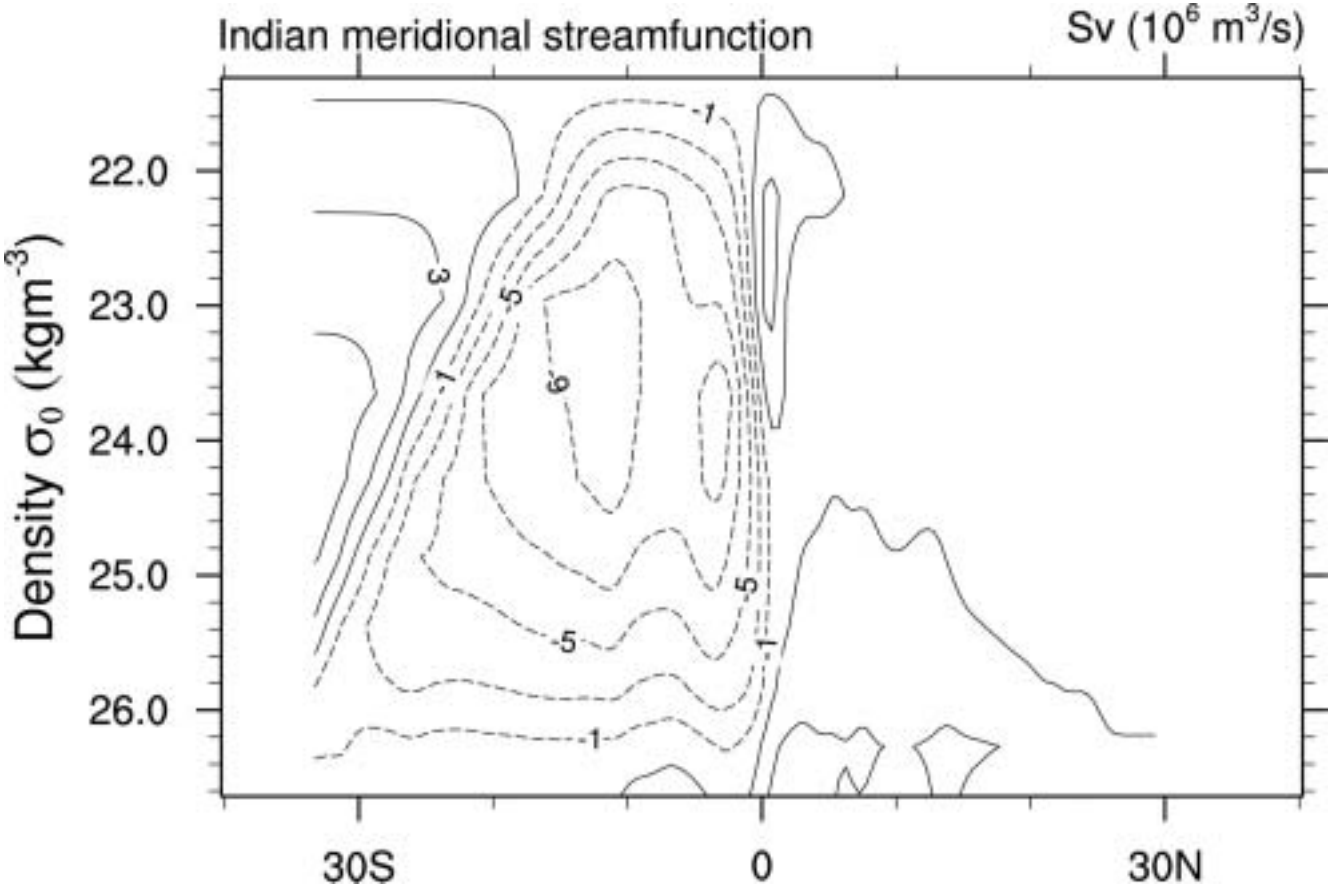

a)
°C
Year
b)
°C
Year
c)
Jun-Jul-Aug (0)
0.40 m/s
d)
Sep-Oct-Nov (0)
0.40 m/s
e)
Dec-Jan-Feb (+1)
0.40 m/s

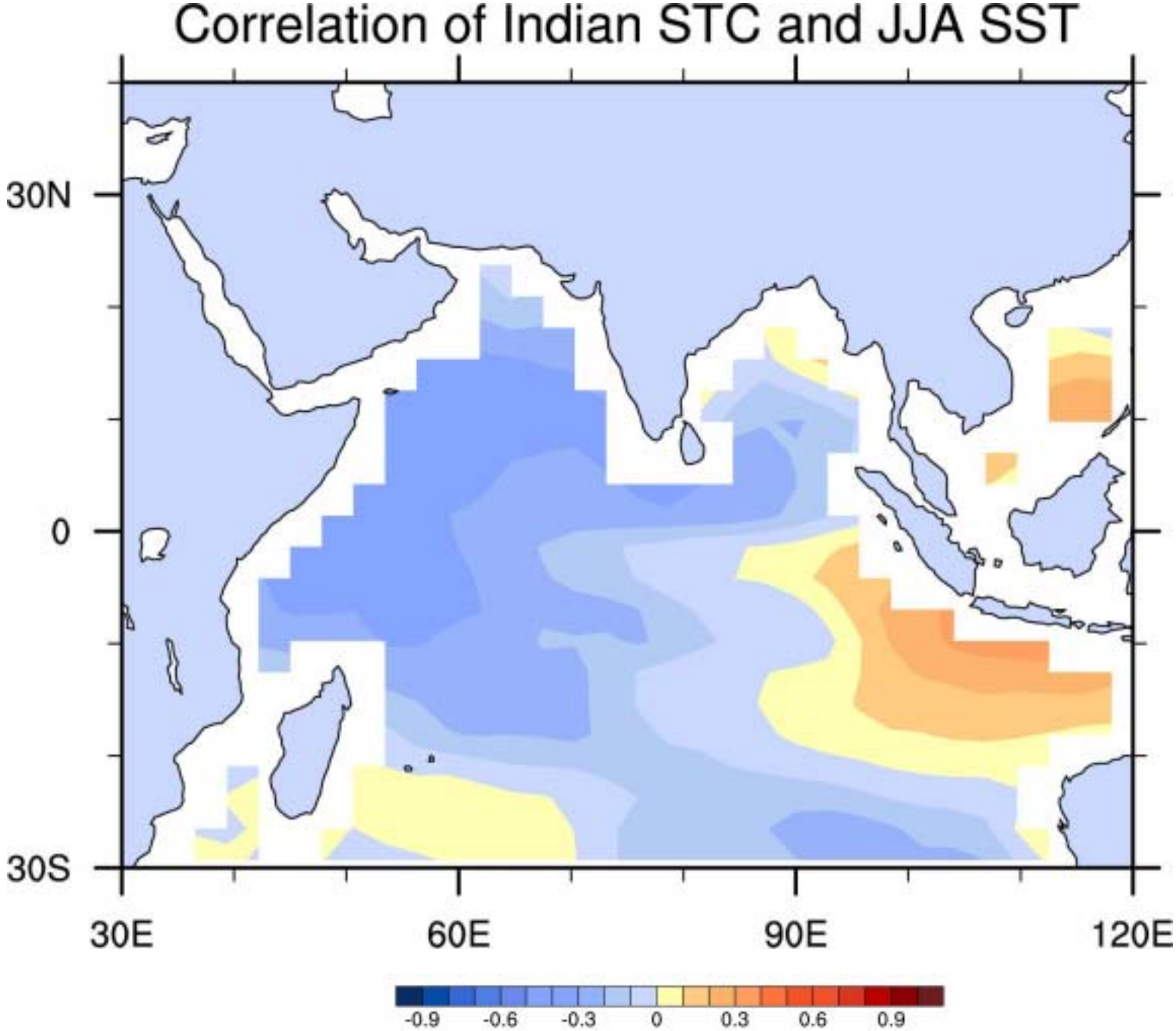

Oct(+1)
Sep(+1)
Aug(+1)
Jul(+1)
Jun(+1)
May(+1)
Apr(+1)
Mar(+1)
Feb(+1)
Jan(+1)
Dec(0)
Nov(0)
Oct(0)
Sep(0)
Aug(0)
Jul(0)
Jun(0)
May(0)
Apr(0)
Mar(0)
Feb(0)
Jan(0)
Dec(-1)
Nov(-1)
40°E
60°E
80°E
100°E


20°N
10°N
EQU
10°S
20°S
40°E
60°E
80°E
100°E
-0.10
0.10
0.20
0.30
0.40
-0.20


a)
DJF - SVD pattern correlations to original Australian precip patterns
correlation
1.0
0.5
0.0
-0.5
0
20
40
60
80
100
Years
SON S. Indian TS
SON Pacific TS
SON SE Asian Precip
b)
Cumulative pattern correlations
correlation
1.0
0.5
0.0
-0.5
Mean: 0.4286
0
20
40
60
80
100
Years


a)
JJAS - SVD pattern correlations to original Indian precip pattern
correlation
1.0
0.5
0.0
-0.5
0
20
40
60
80
100
Years
MAM 500mb Z
MAM Indian Ts
MAM Pacific Ts
b)
Cumulative pattern correlations
correlation
1.0
0.5
0.0
-0.5
Mean: 0.4643
0
20
40
60
80
100
Years


Indian meridional streamfunction
Sv (10^6 m^3/s)
Density σ_0 (kgm^{-3})
22.0
23.0
24.0
25.0
26.0
30S
0
30N
-1
-3
-5
-9
-5
-1
-5
-1
-1


Correlation of Indian STC and JJA SST
30N
0
30S
30E
60E
90E
120E
-0.9
-0.6
-0.3
0
0.3
0.6
0.9