Low Frequency variations of the Indian Ocean in a 10,000 year GFDL CGCM simulation*

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Climate impacts of IOD

- *The IOD (Saji et al., 1999; Webster et al,1999.) - Its impact on climate of different regions)*

  Saji et al. (1999); Behera et al., 1999; Ashok et al., 2001, Lareef et al., 2002; Ashok et al., 2003a; Guan & Yamagata, 2003; Saji et al., 2003; Black et al., 2003; Gadgil et al., 2003 & 2004; Ashok et al., 2004; Bhaskar Rao et al., 2004; Rao et al., 2004 etc).
- Frequent occurrence of the strong IOD events in 1960s and then in 1990s – slower variability ~*decadal ?*

Motivation

- IODMI has a significant (at 90% confidence level from red noise spectrum) peak at 125-months (Ashok et al. 2003a; from GISST 1871-1998).
- Recently, Kripalani & Kumar (2004) found decadal epochs (positive/negative) in seasonally stratified IODMI time series.
- Rao et al. (2004)- Decadal changes in subsurface influence on SST .
- Abram et al. (2003; science) – Decadal and centennial modulations of the IOD
- *Presence of decadal IOD similar to decadal ENSO?*

Slower frequency impacts/modulations

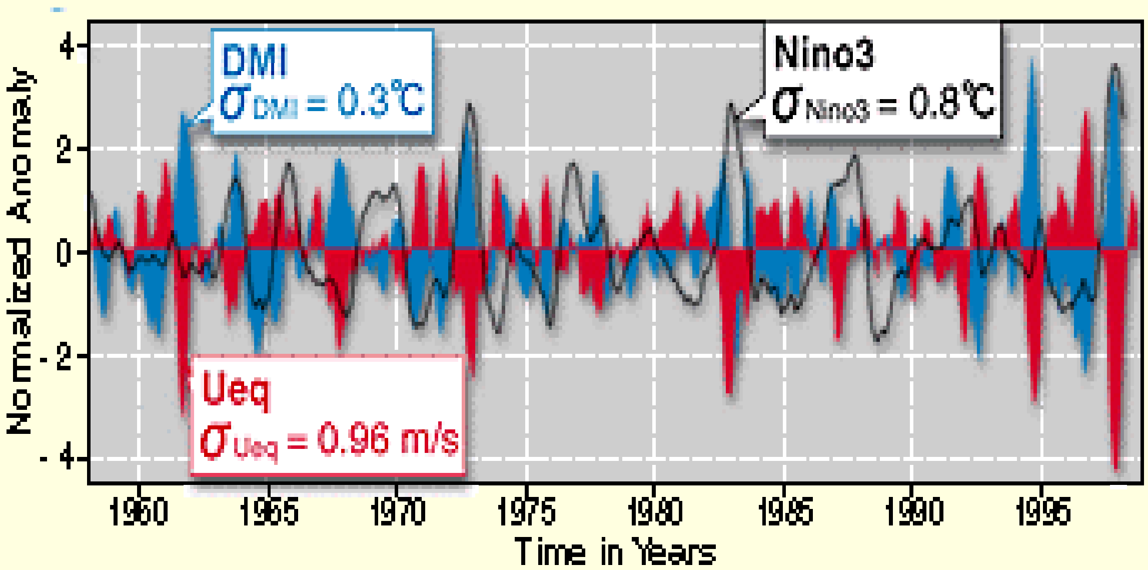
- Decadal modulation of the IOD frequency, and its apparent role in weakening of ENSO-Indian monsoon relationship (Ashok et al., 2001, 2004).
- Weakening of the El Nino-Southern Oscillation period in recent decade (Behera et al., 2003).
- Decadal and centennial modulation of the IOD SST (Abram et al., 2003).

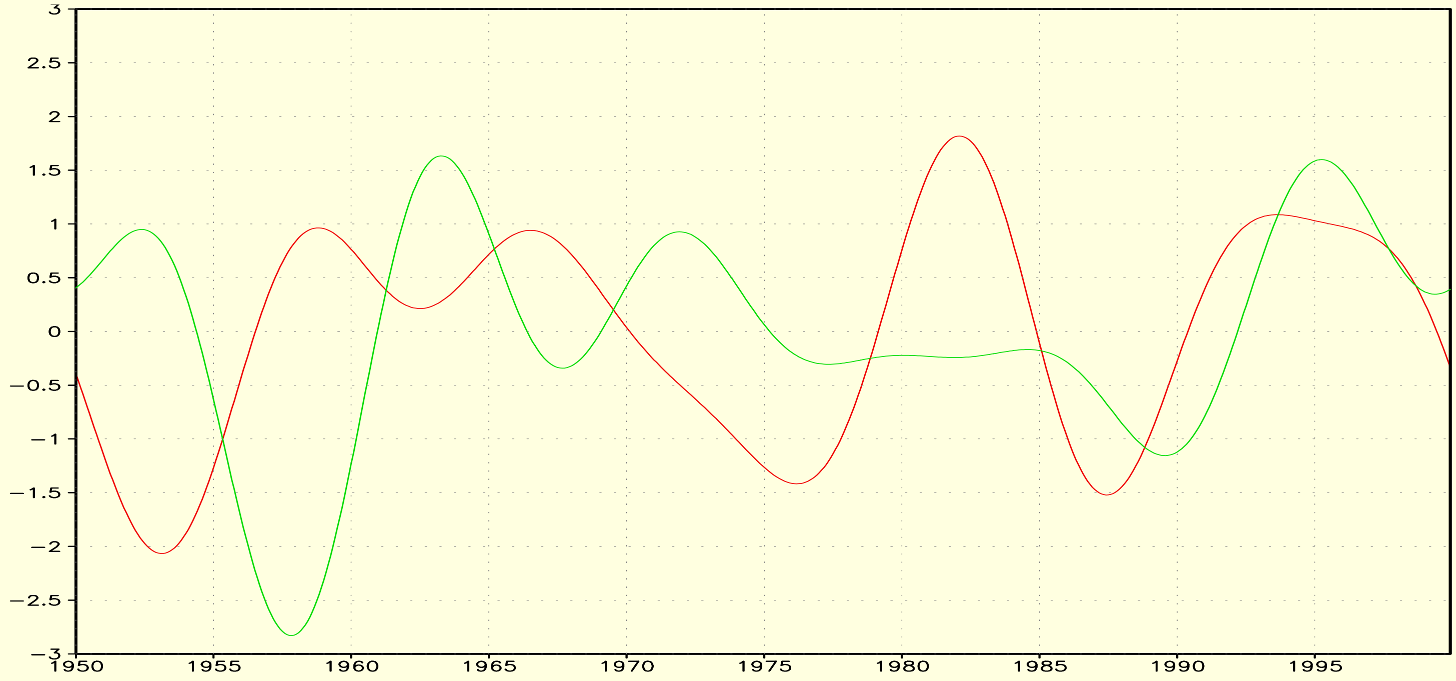
Datasets

- GISST (Rayner et al., 1996)
- SODA D20 depth (Carton et al., 2000)

from 1950-1999

- NCEP/NCAR Winds (Kalnay et al., 1996)

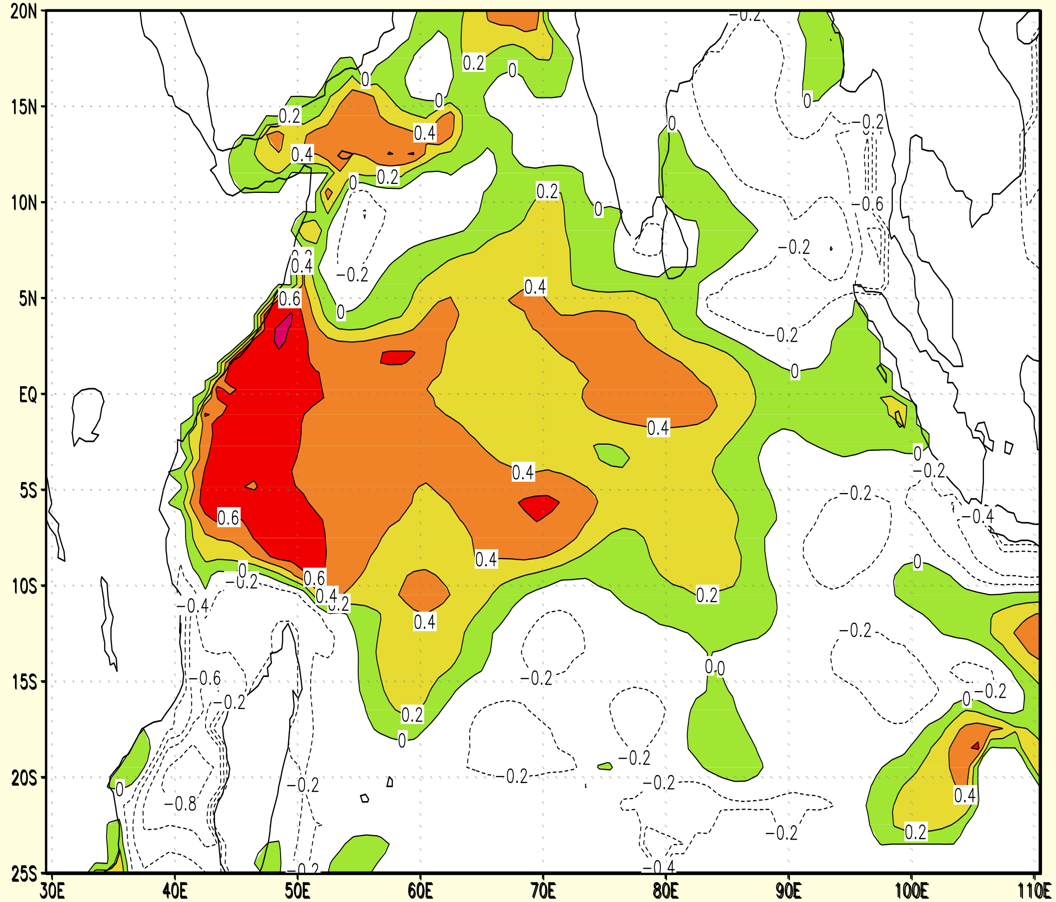

DMI
σ_{DMI} = 0.3℃
Nino3
σ_{Nino3} = 0.8℃
Ueq
σ_{Ueq} = 0.96 m/s
Normalized Anomaly
4
2
0
- 2
- 4
1960
1965
1970
1975
1980
1985
1990
1995
Time in Years



Decadal signals (8-25 years) of IODMI (green) and NINO3 index from GISST

Decadal IODMI standard deviation ~ 0.12°C as compared to 0.33°*C* of the interannual IODMI signal

Observed decadal (8–25 years) partial correlations
between IODMI and anomalies of Z20



Brief description of GFDL coupled model:

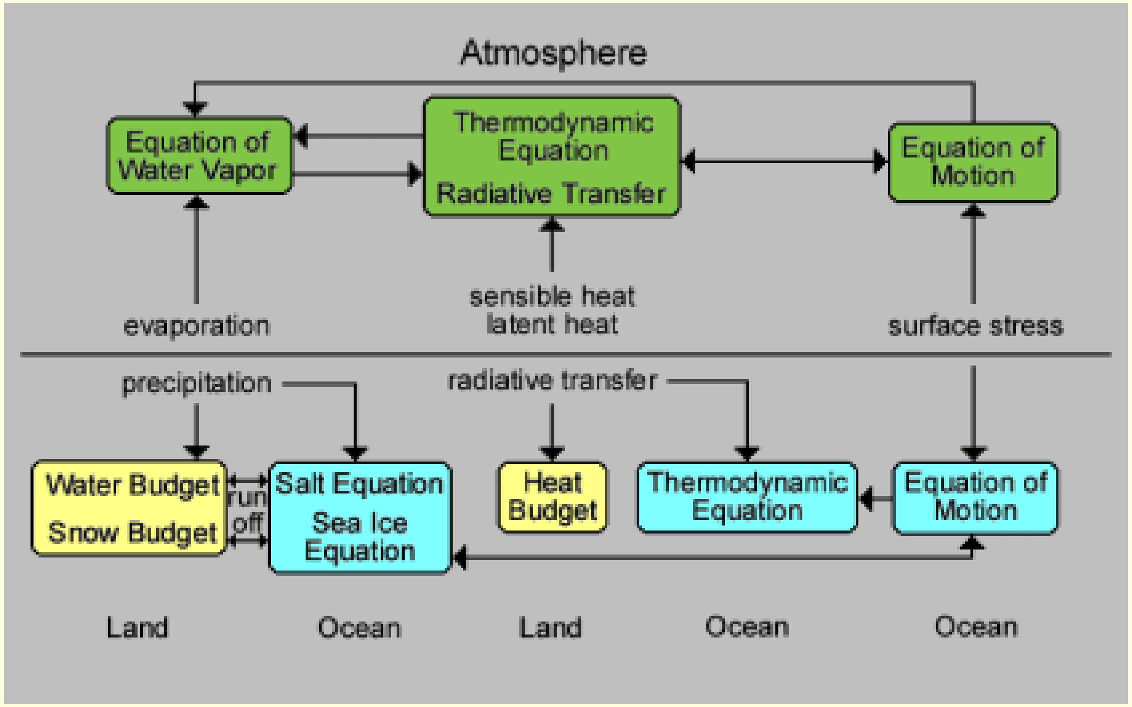
AGCM: 9 vertical levels, horizontal resolution R15. Seasonally-varying insolation.

OGCM: 12 vertical levels, horizontal grid of approx 4.5°(lat) by 3.75°(lon).

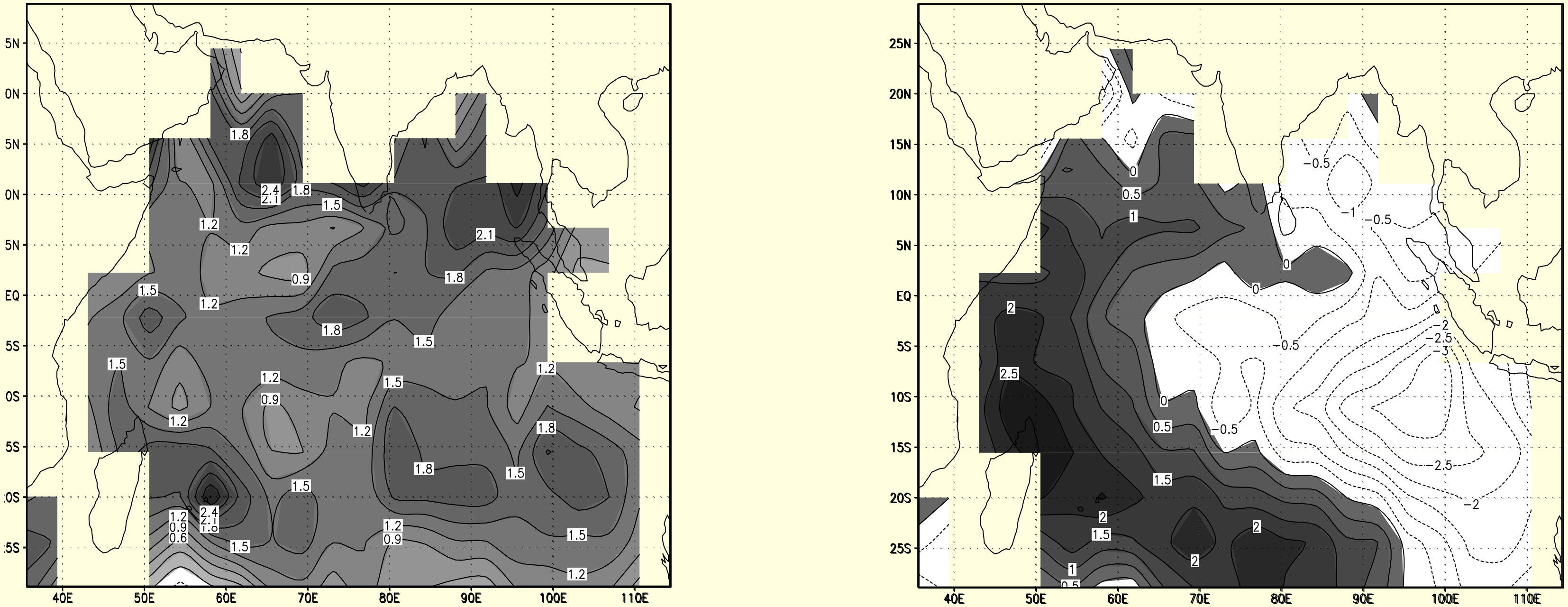
Atmosphere-ocean interaction once a day (heat, water and momentum flux exchanges).

Simple sea-ice model also included. Land component: uses bucket model.

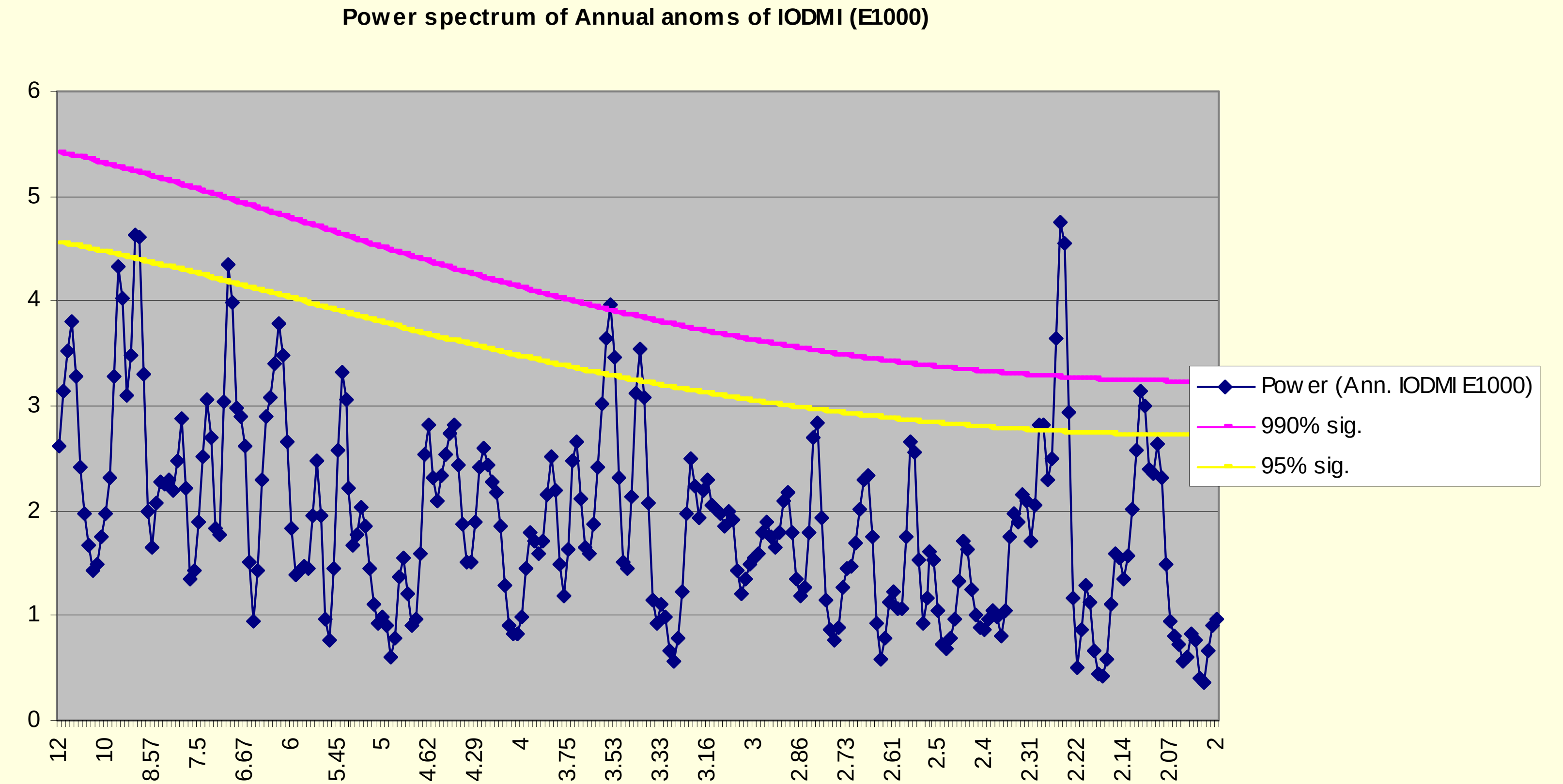
Flux corrections incorporated. Time integrations (10,000 yrs); most of the work shown here is based on the analysis of outputs between years 4001-5000.

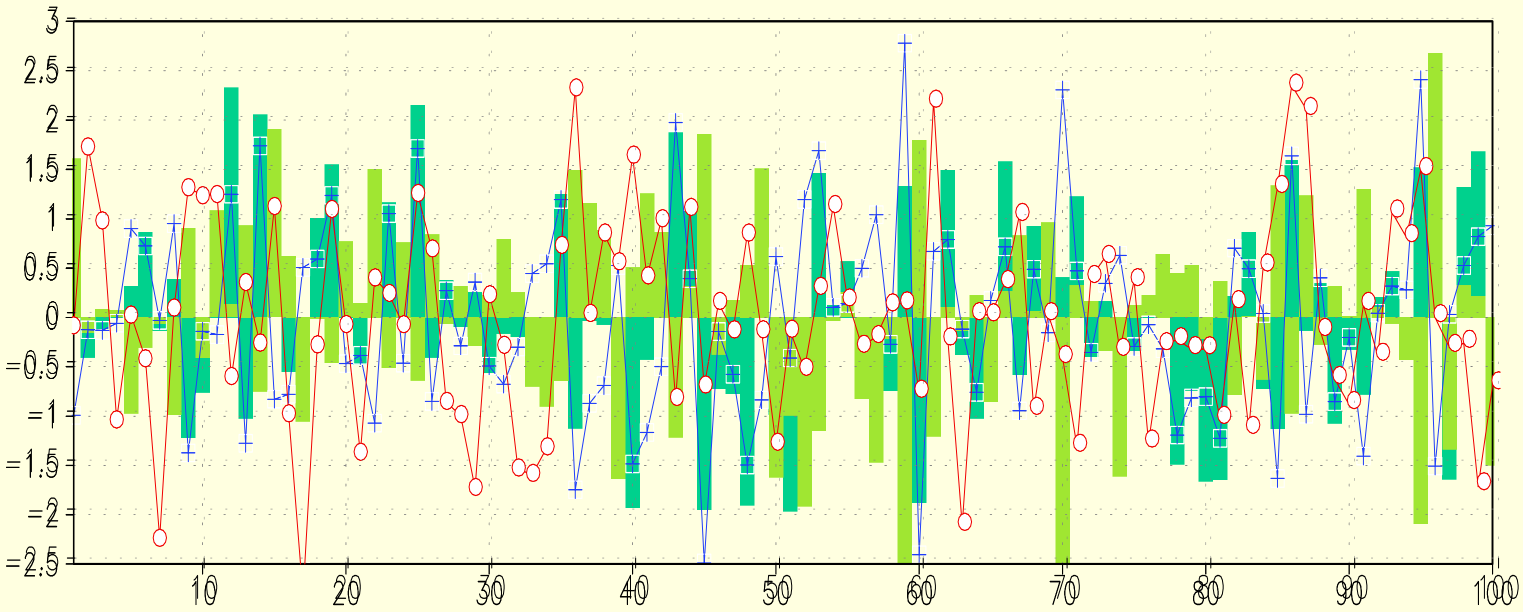


from Manabe and Stouffer (1999)



The simulated EOF2 pattern (of SON SSTA) shows a dipolar structure with both poles centered in the equatorial Indian Ocean, similar to the EOF2 of the observed SST; the variance explained by this simulated mode is 9%, close to the observed value of 12% [Saji et al., 1999]. Based on this distribution, we define an index for model IOD variations as the difference between the area-averaged SST anomalies over the tropical west Indian Ocean bounded by 40ºE-60ºE, 15ºS-10ºN, and the tropical southeastern Indian Ocean bounded by 90ºE-110ºE, 15ºS-equator. The standard deviation of the simulated IODMI is 0.44ºC, which is close to observations.

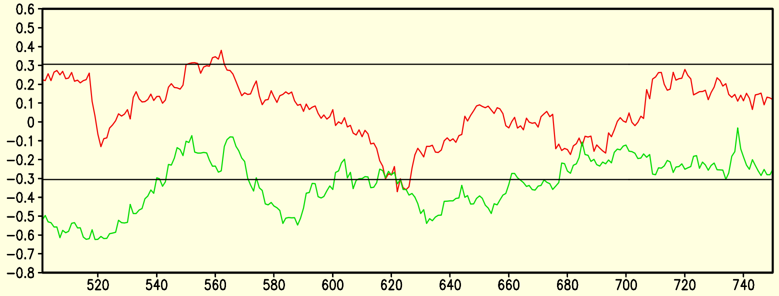

Power spectrum of Annual anoms of IODMI (E1000)
6
5
4
3
2
1
0
12
10
8.57
7.5
6.67
6
5.45
5
4.62
4.29
4
3.75
3.53
3.33
3.16
3
2.86
2.73
2.61
2.5
2.4
2.31
2.22
2.14
2.07
2
Power (Ann. IODMI E1000)
990% sig.
95% sig.

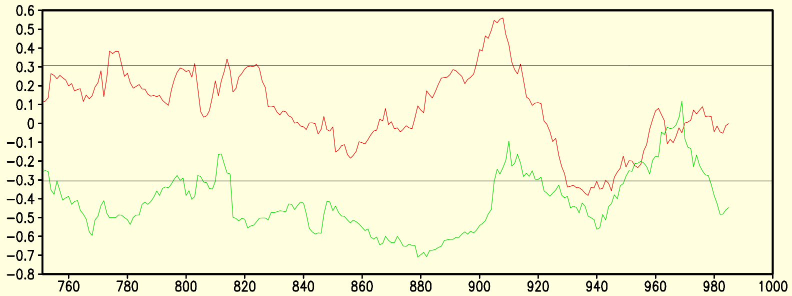


Time series of SON anomalies during J100: IODMI (Blue line), NINO index (Red line),

Western Box (Aqua Bar), and Eastern Box (Yellow Bar)

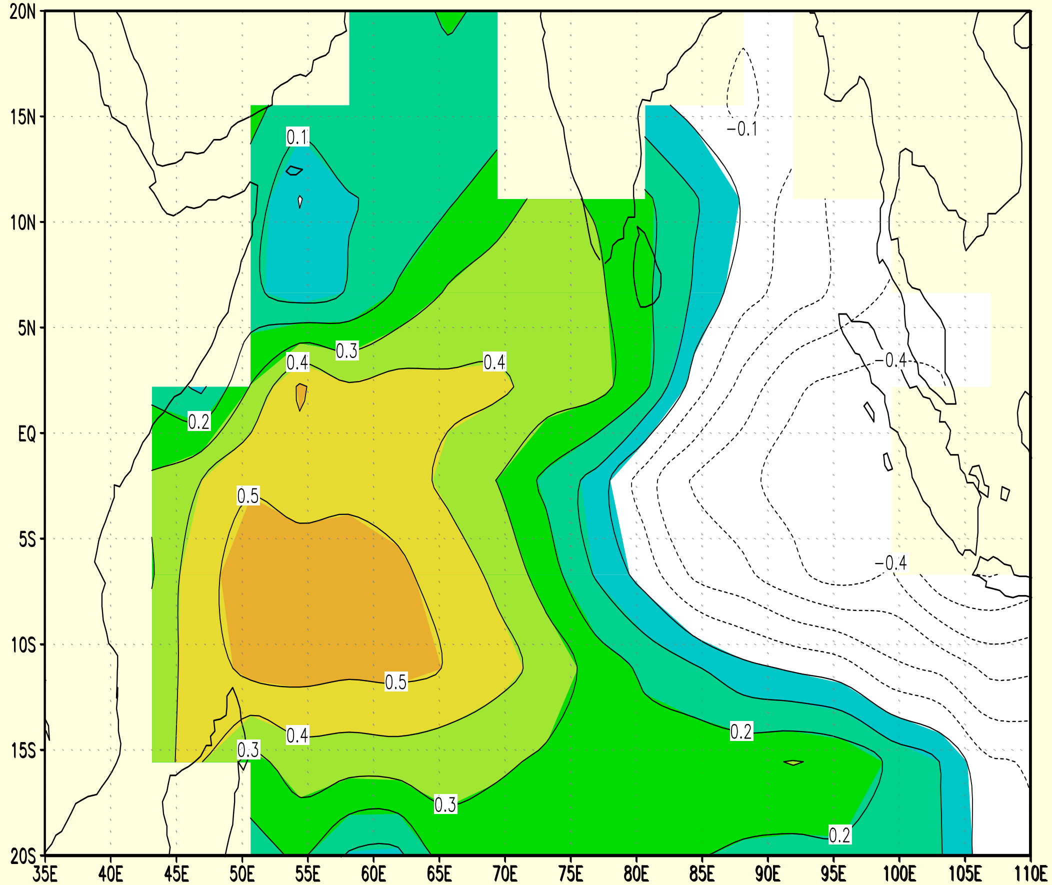
Western Box (15S-10N,40E-60E), and Eastern Box (15S-Equator,90E-110E), NINO index (7S-7N, 173E-120W)

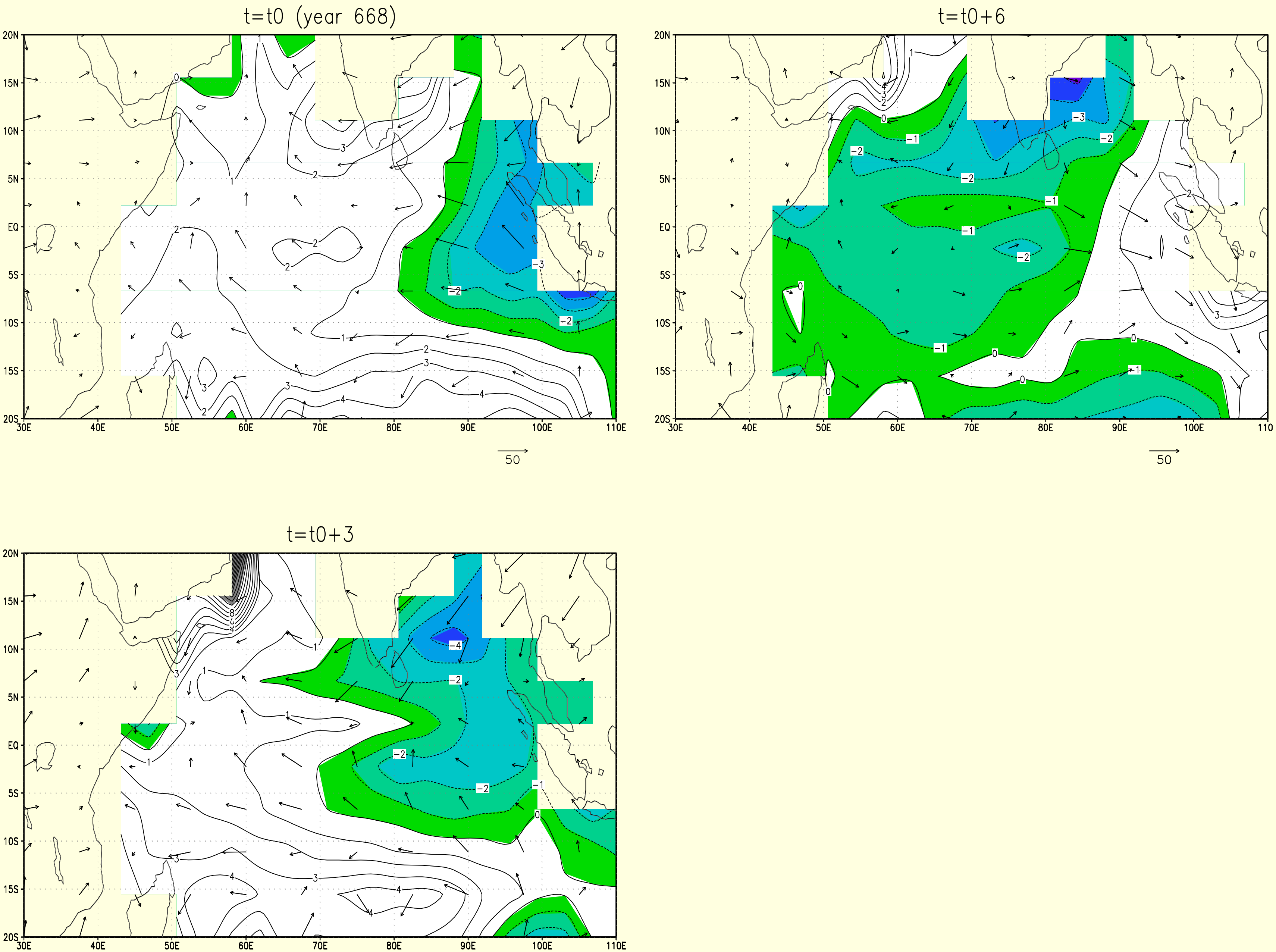


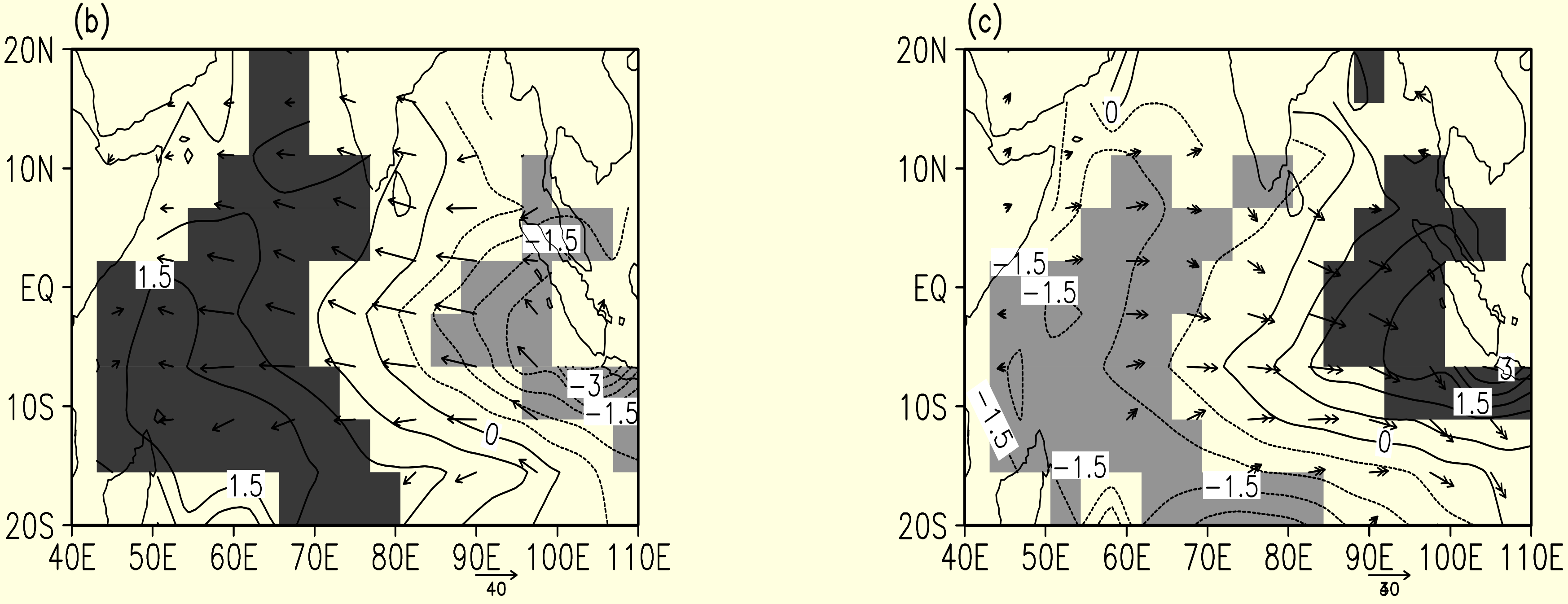


E1000 SON correlations between IODMI & NINO3.4 SSTA (red) and those between IODMI and EIOZW (green)

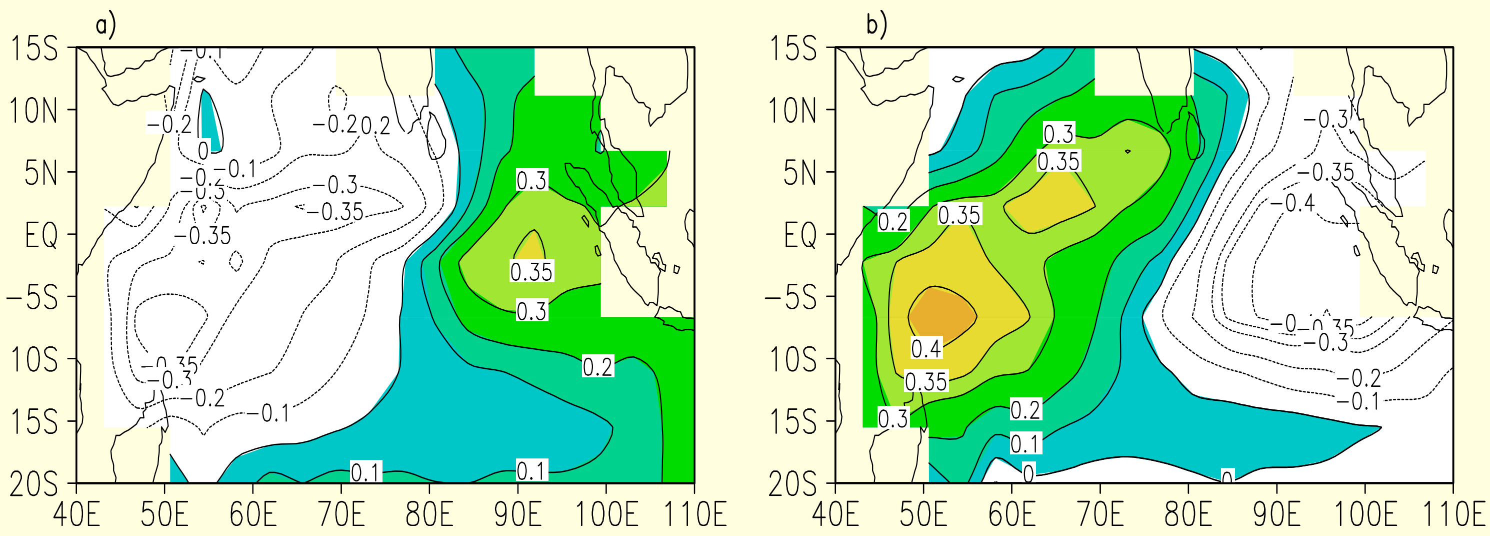
Simulated decadal (9–31 years) partial correlations
between IODMI & Z20 anomalies



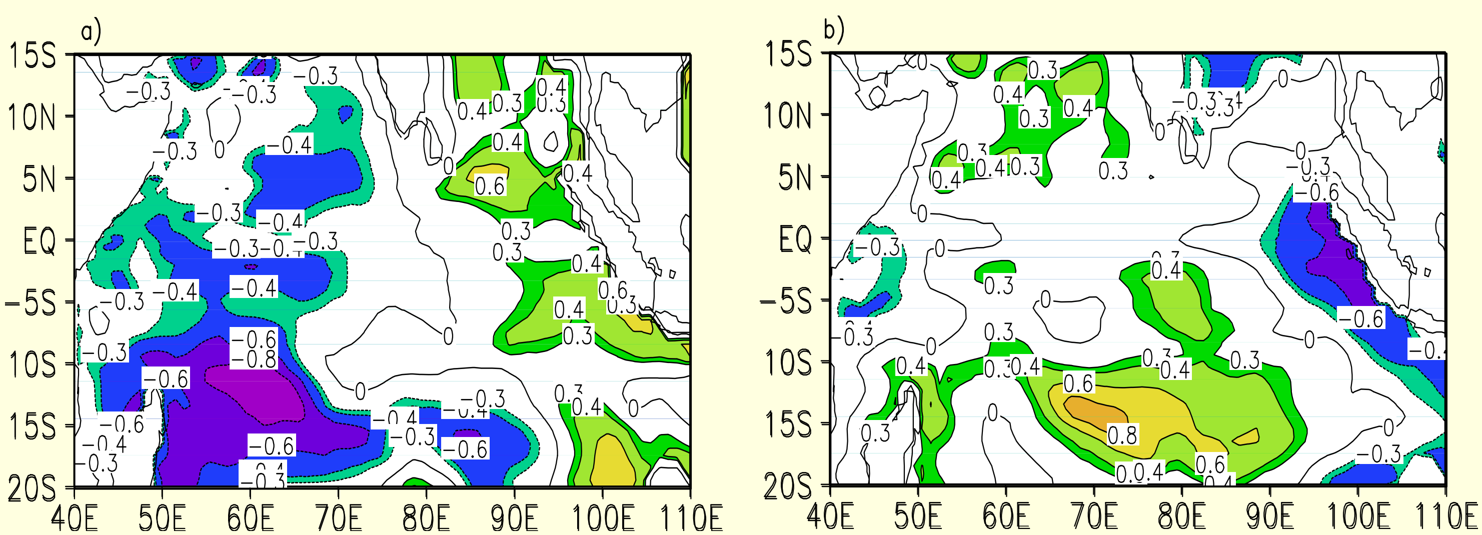

t=t0 (year 668)
t=t0+6
t=t0+3
20N
15N
10N
5N
EQ
5S
10S
15S
20S
30E
40E
50E
60E
70E
80E
90E
100E
110E
50



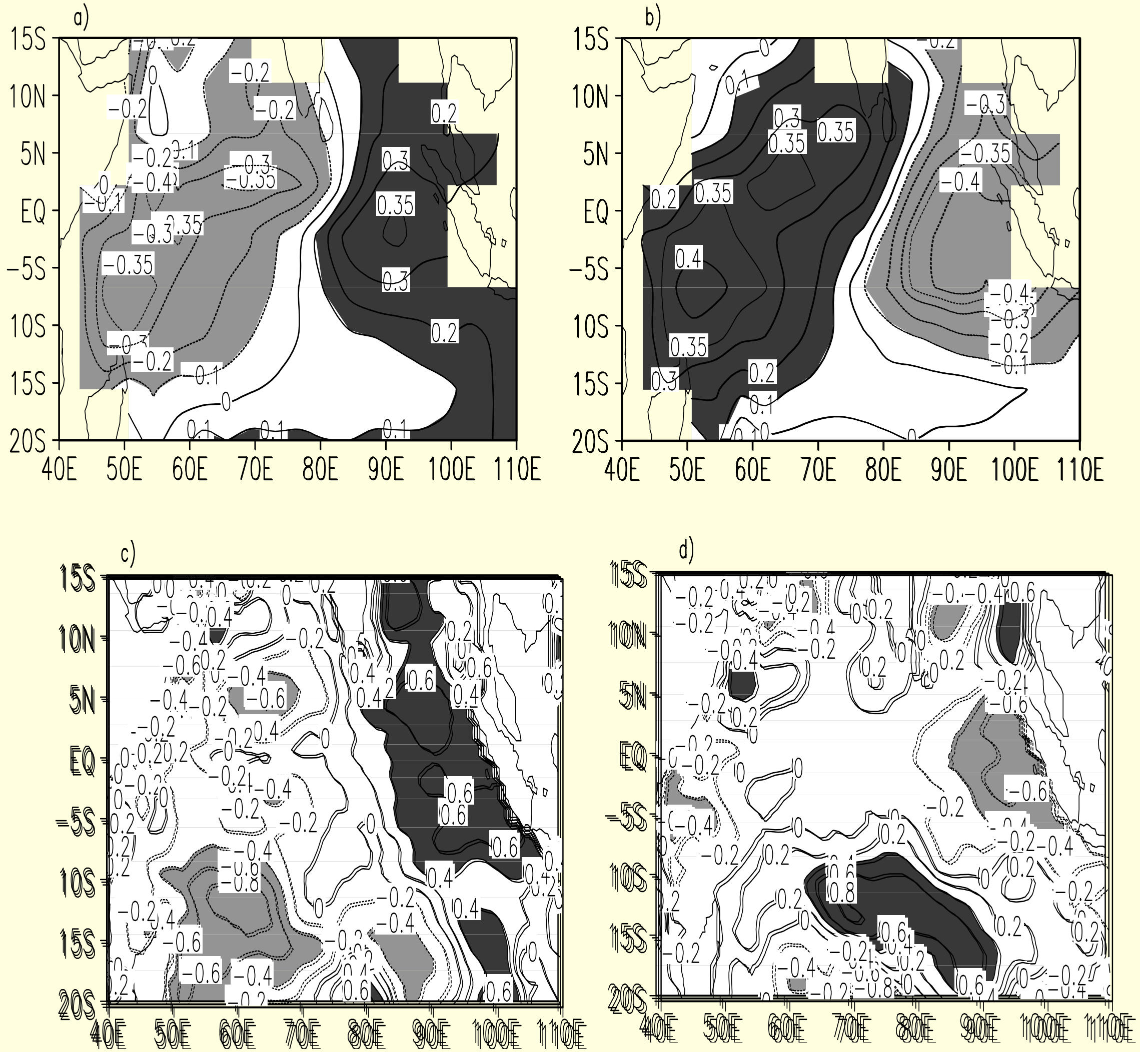
Simulated decadal (8-31 year signals) (b) composite D20 anomalies (cm) during 1st year of the cycle; in contours, and surface winds (cm.s-1) (c) same as b, but in 6th year. Shaded values are significant at 90% confidence level from 2-tailed t-test. The whole process similar to that of the interannual IOD [Saji et al., 1999; Rao et al., 2002] except for the much longer timescale. This situation reminds us of such similarity between delayed oscillator theory for the interannual ENSO [Schopf and Suarez, 1988] and that for the decadal ENSO [Knutson and Manabe, 1998]. However, the phase speed (of about 0.08 m/sat 10ºS) of simulated decadal Rossby waves is smaller than the theoretical prediction of 0.18 m/s. This may be due to their coupling with the overlying atmosphere, as suggested by White et al [2003] in the context of slower tropical Pacific decadal waves.



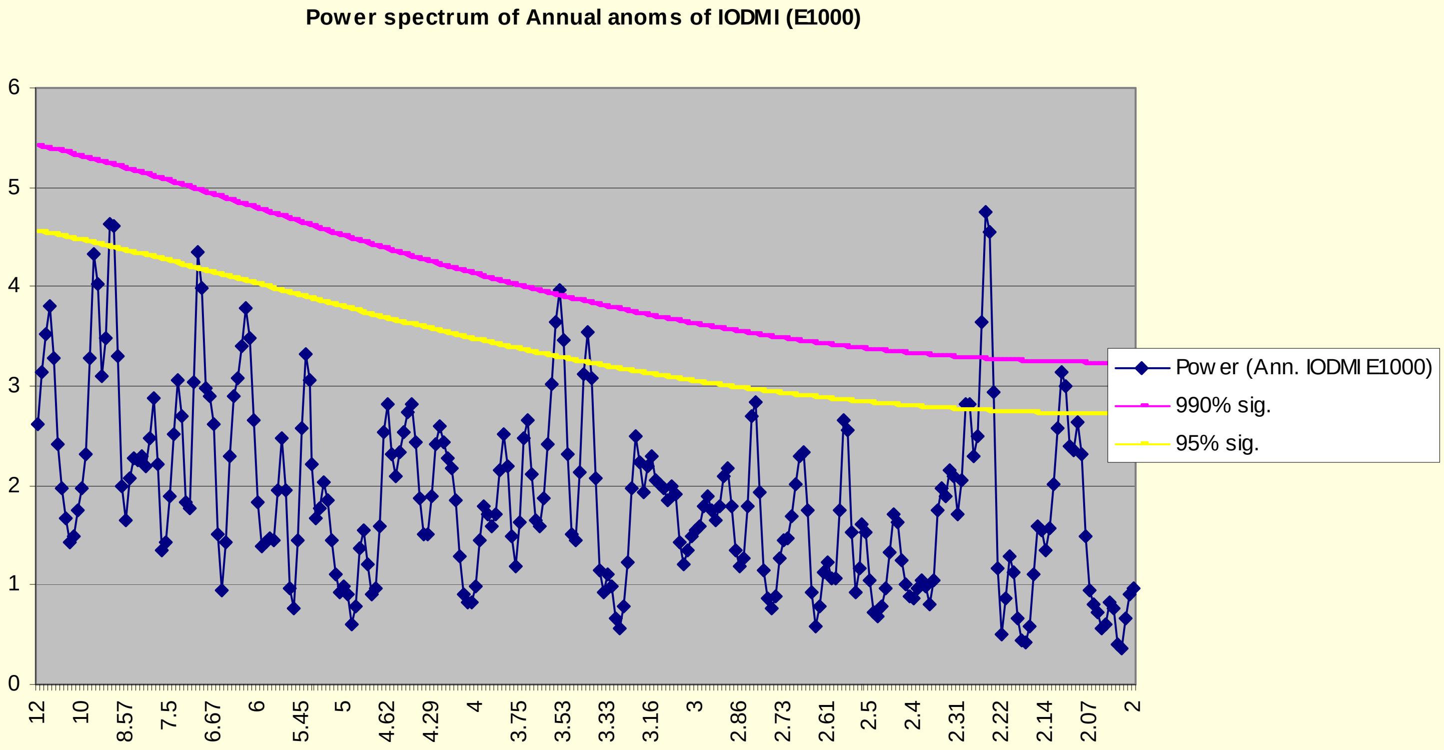
Correlations between simulated decadal (8-31 year signals) SON D20 anomalies with JJA Webster-Yang index with the latter leading by 5 years (a) and for the same year (b).

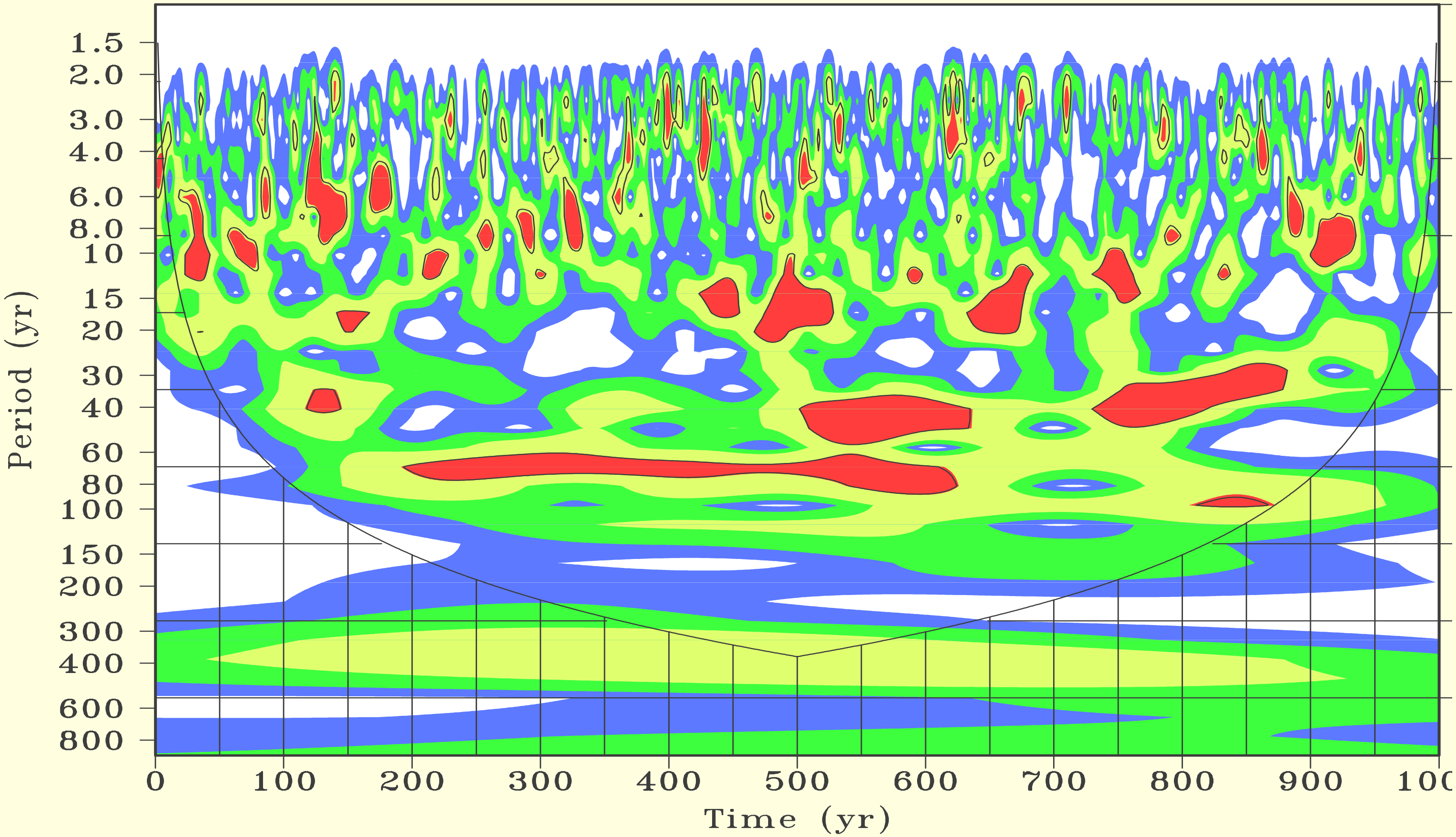


Same as above, but for decadal (8-25 year signals) correlations between SON SODA-derived D20 anomalies and NCEP derived decadal JJA W-Y index.



Partial correlations between simulated decadal SON D20 anomalies with JJA Webster-Yang index (a) with the latter leading by 5 years (b) both during the same year (c-d) same as Figs. a & b but for decadal correlations between SON SODA-derived D20 anomalies and NCEP derived decadal JJA W-Y index. Significant values are shaded.

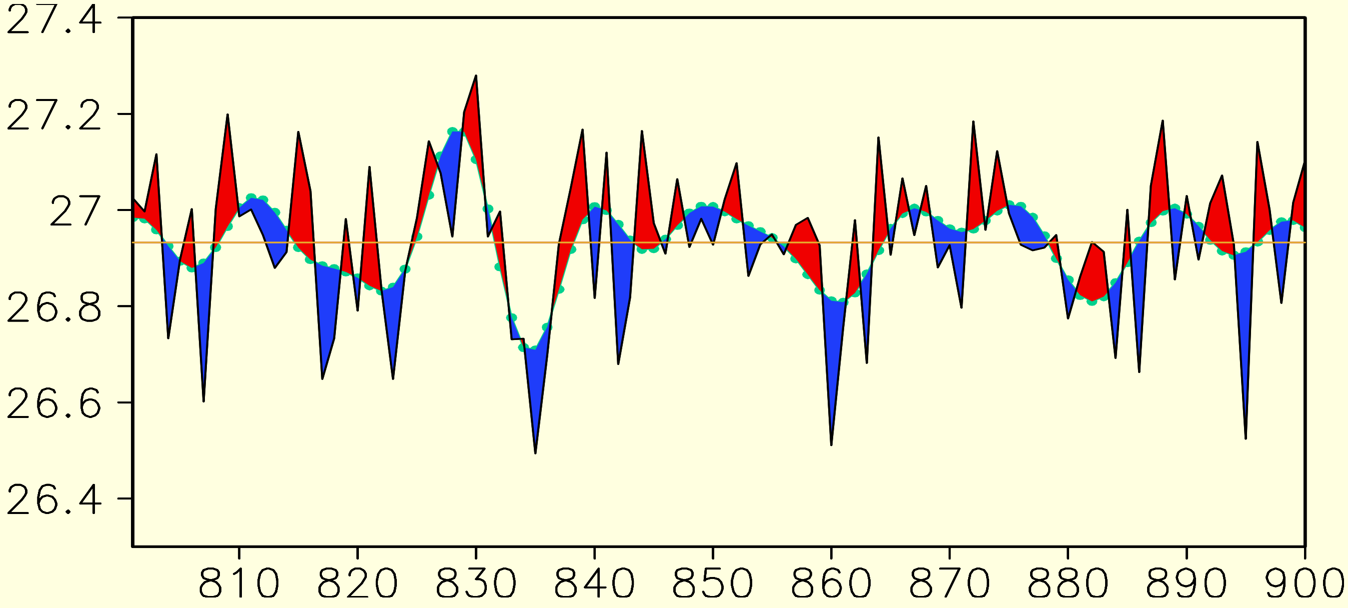

Power spectrum of Annual anoms of IODMI (E1000)
0
1
2
3
4
5
6
12
10
8.57
7.5
6.67
6
5.45
5
4.62
4.29
4
3.75
3.53
3.33
3.16
3
2.86
2.73
2.61
2.5
2.4
2.31
2.22
2.14
2.07
2
Power (Ann. IODMI E1000)
990% sig.
95% sig.



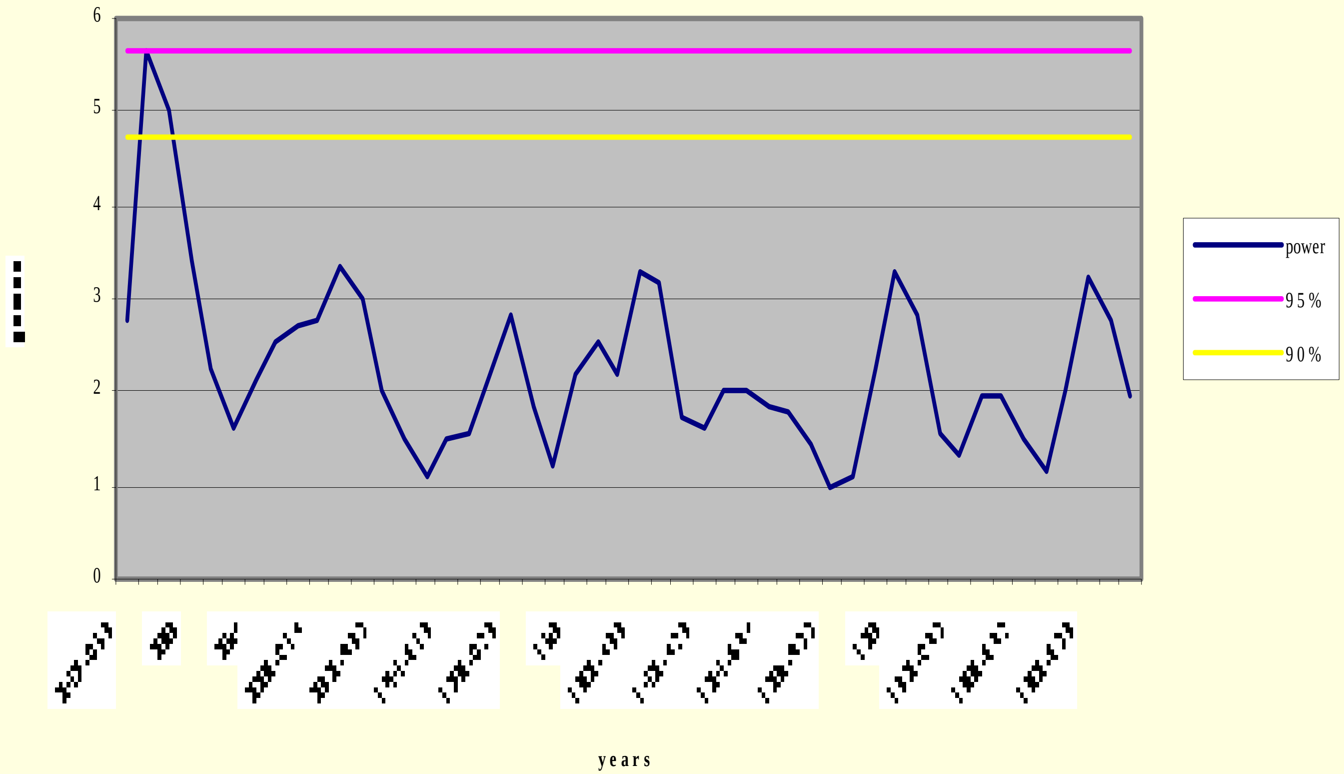
Wavelet spectrum of the simulated annual IODMI. Significant values (at 95% confidence level from red noise spectrum) are circumscribed by a thick line. Hatched lines indicate regions with variance reduced due to padding. The correlation between the scale-averaged variance of 2-8 (5-8) year band with that of 8-32 years is 0.23 (0.34), which is significant at 99.9% confidence level.

However, we cannot exclude involvement of other factors such as tropical and extratropical interactions associated intrinsically with the interannual events [Lu and McCreary, 1996; Gu and Philander, 1997].

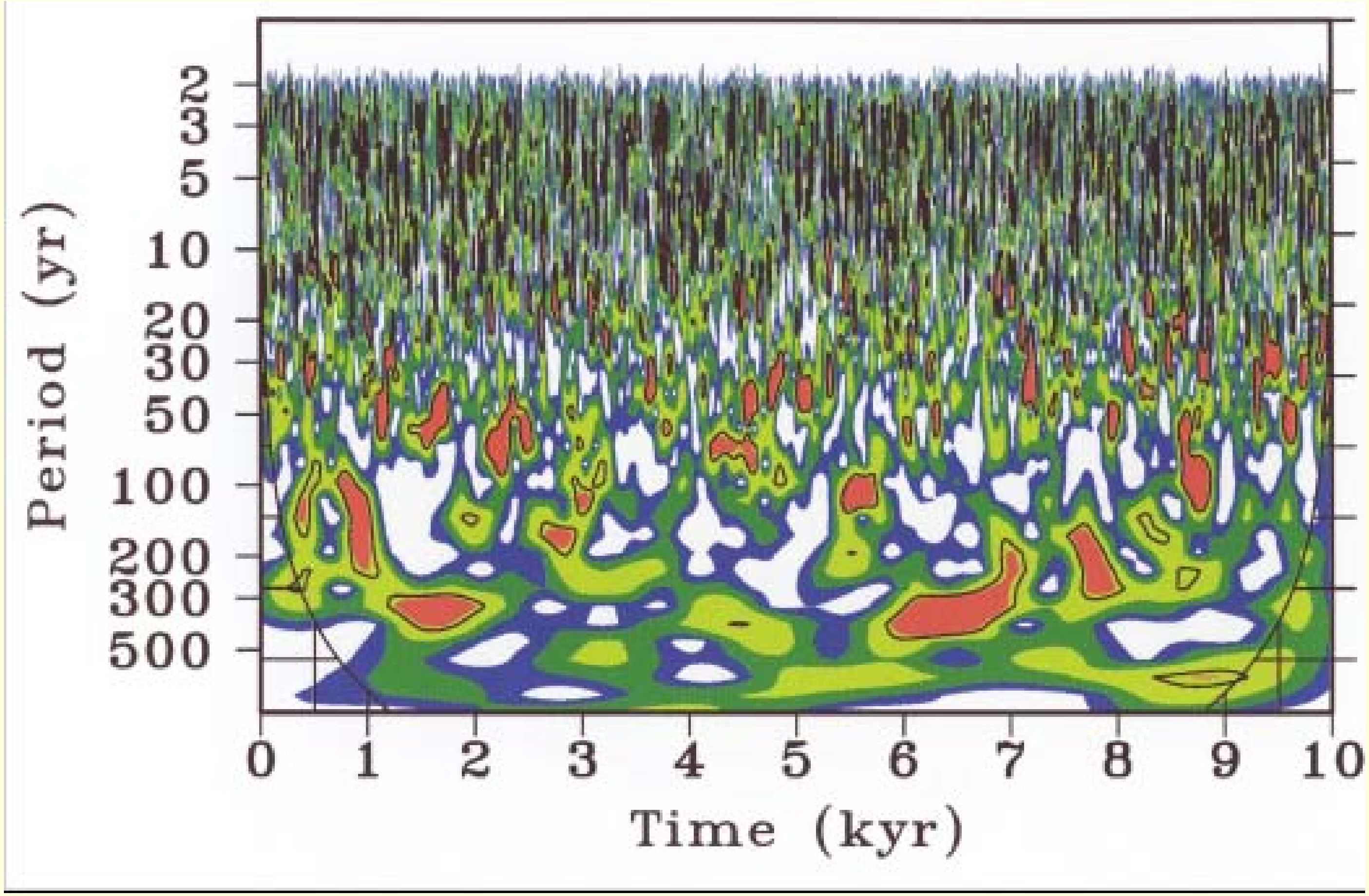
Tozuka et al. [personal communication, 2004] have recently suggested that decadal asymmetric occurrence of positive and negative IOD events may lead us to a decadal IOD-like picture because of linear statistical analysis methods. Such simulated association between the asymmetric interannual fluctuations of SST over the western pole of the IOD, and its decadal component is presented in next slide as an example. The prospective role of the occurrence of asymmetric interannual events in such "*decadal regime shifts*" is a topic that has to be explored further.



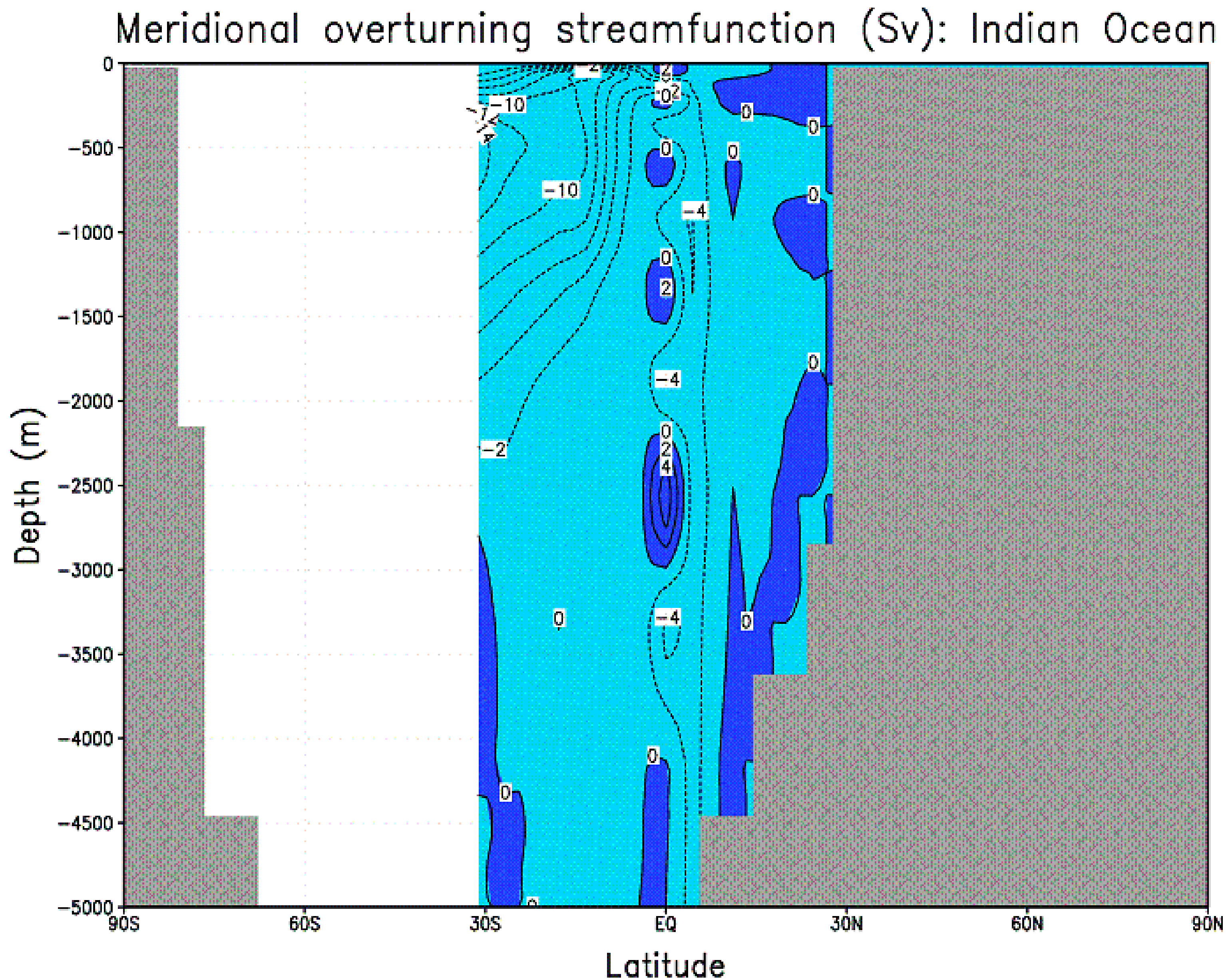
Interannual fluctuations of SST averaged over the western pole of the IOD (black line), and decadal (8-31 years) fluctuations over the same region (circles). Straight line is the time-average over 1000 years. Values from years 801 to 900 are shown as example. Methodology similar to Fig. 1a of Federov and Philander [2000] except that apart from the removal of seasonal cycle and high frequency components, multidecadal and centennial signals also have been removed.



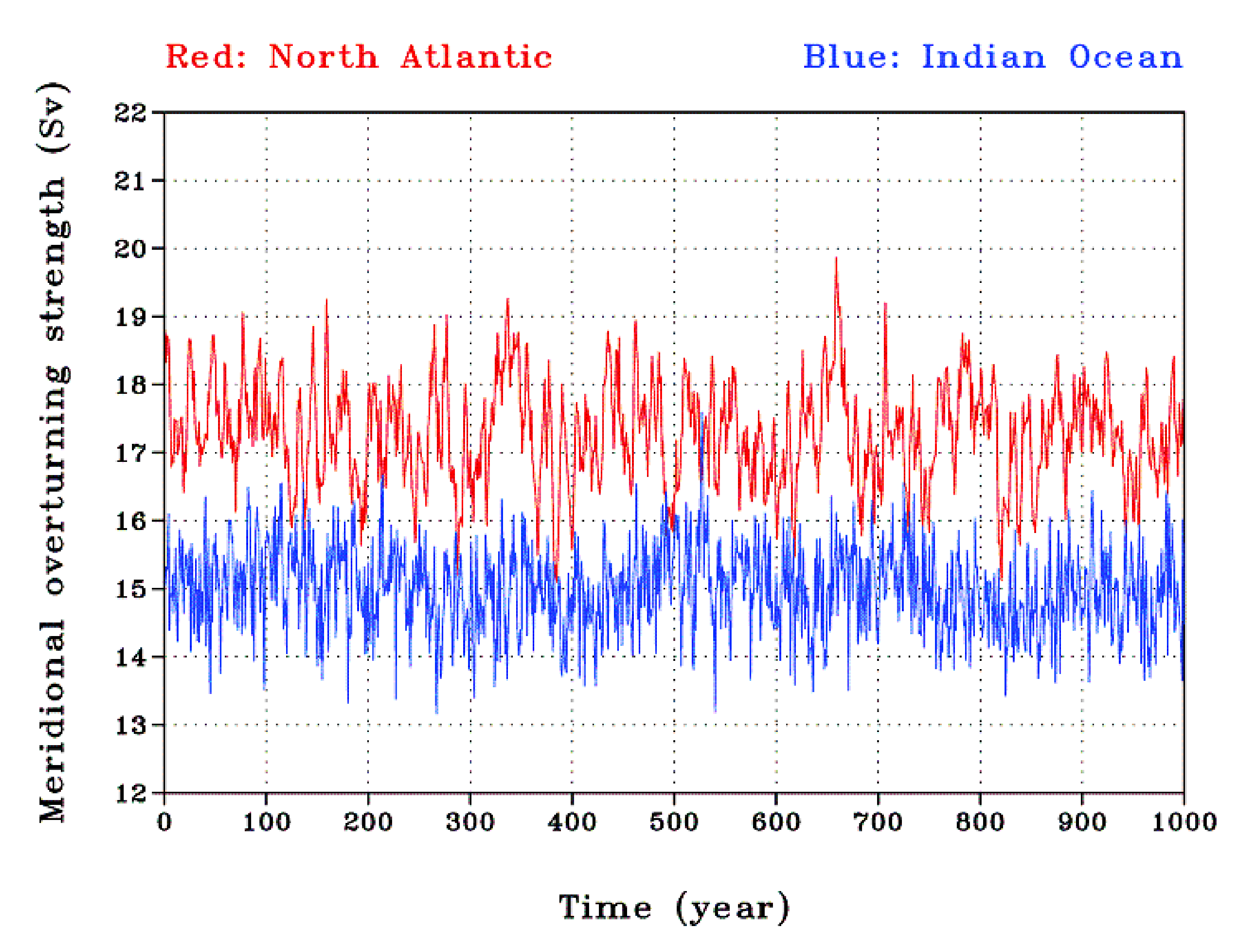
Annual IODMI (10,000 year series) Power spectrum



Wavelet spectrum of simulated annual IODMI (10,000 years)



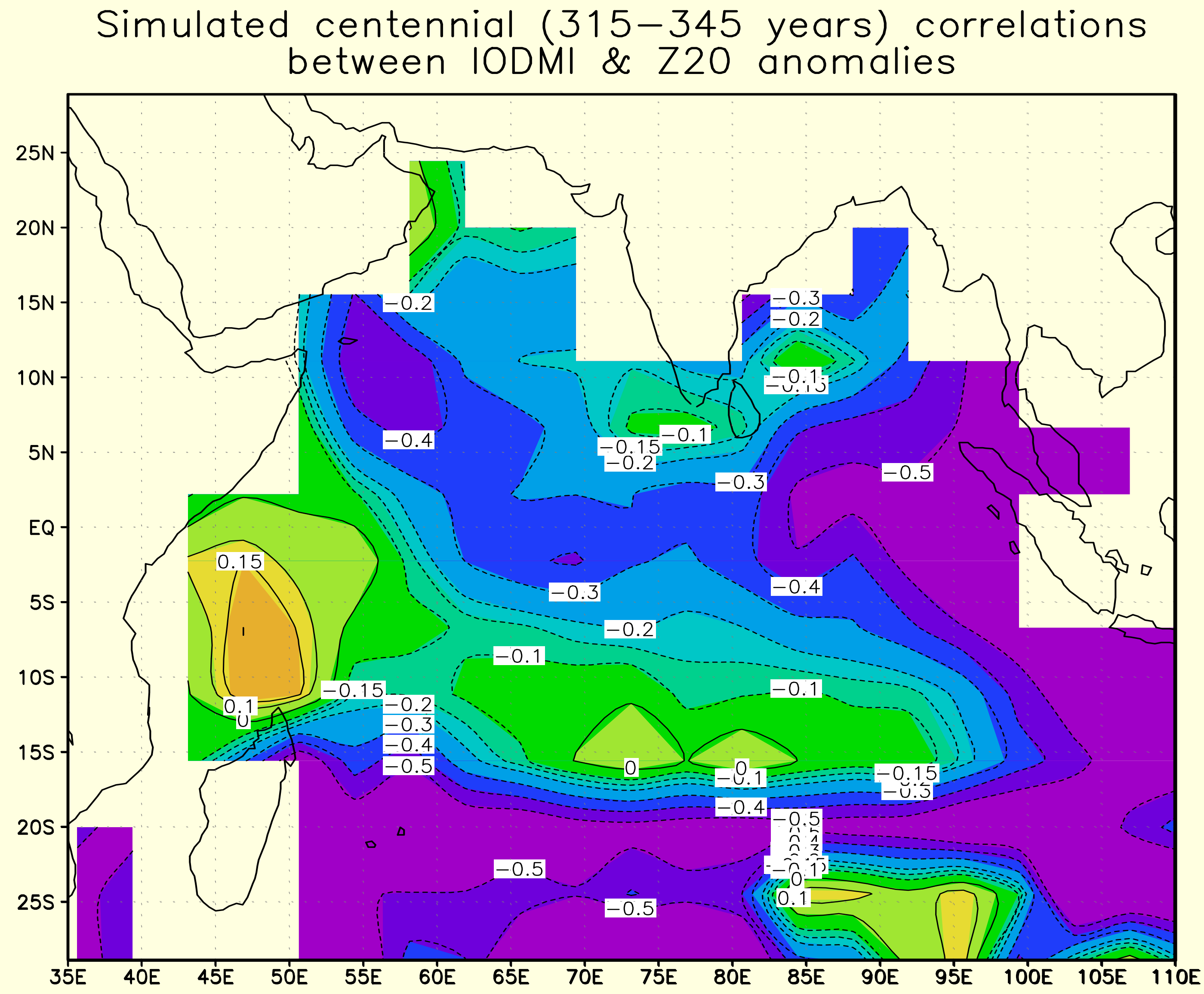
Meridional overturning streamfunction (Sv): Indian Ocean
Depth (m)
Latitude
0
−500
−1000
−1500
−2000
−2500
−3000
−3500
−4000
−4500
−5000
90S
60S
30S
EQ
30N
60N
90N



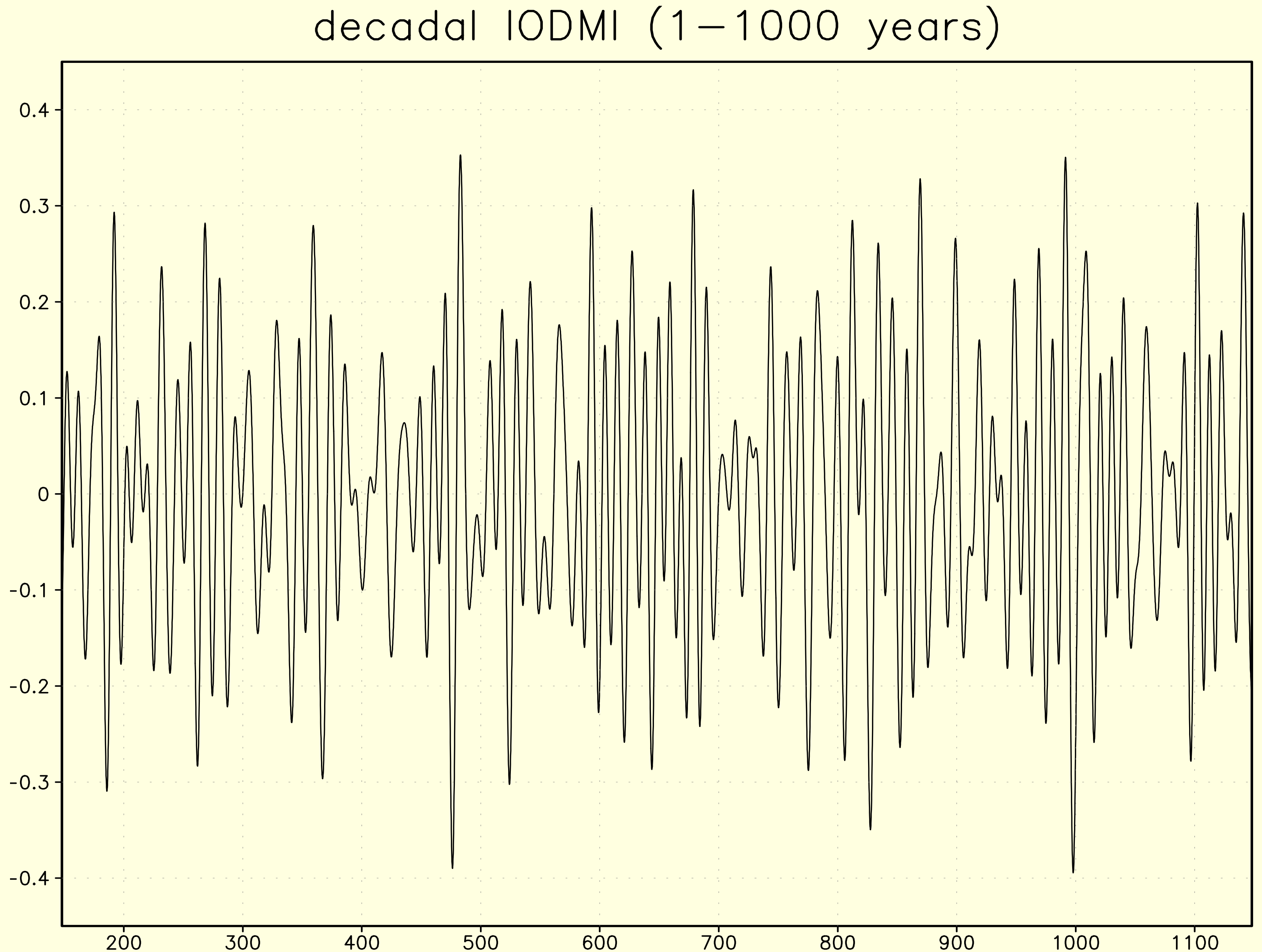
Red: North Atlantic
Blue: Indian Ocean
Meridional overturning strength (Sv)
22
21
20
19
18
17
16
15
14
13
12
0
100
200
300
400
500
600
700
800
900
1000
Time (year)

Summary

- The presence of the decadal IOD from data.
- The coupled model shows the presence of the interannual (to multi-centennial) IOD.
- Diagnosis of the physical mechanism of the model decadal event carried out. Similarity with interannual mechanism but on slower timescale; links to the atmospheric circulation on decadal timescales.
- Possible role of asymmetric interannual IOD events in decadal IOD.
- The results subject to Data quality problems as well as the coarse resolution of the CGCM.
- Centennial IOD



Simulated centennial (315–345 years) correlations
between IODMI & Z20 anomalies
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
35E
40E
45E
50E
55E
60E
65E
70E
75E
80E
85E
90E
95E
100E
105E
110E


decadal IODMI (1–1000 years)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
200
300
400
500
600
700
800
900
1000
1100