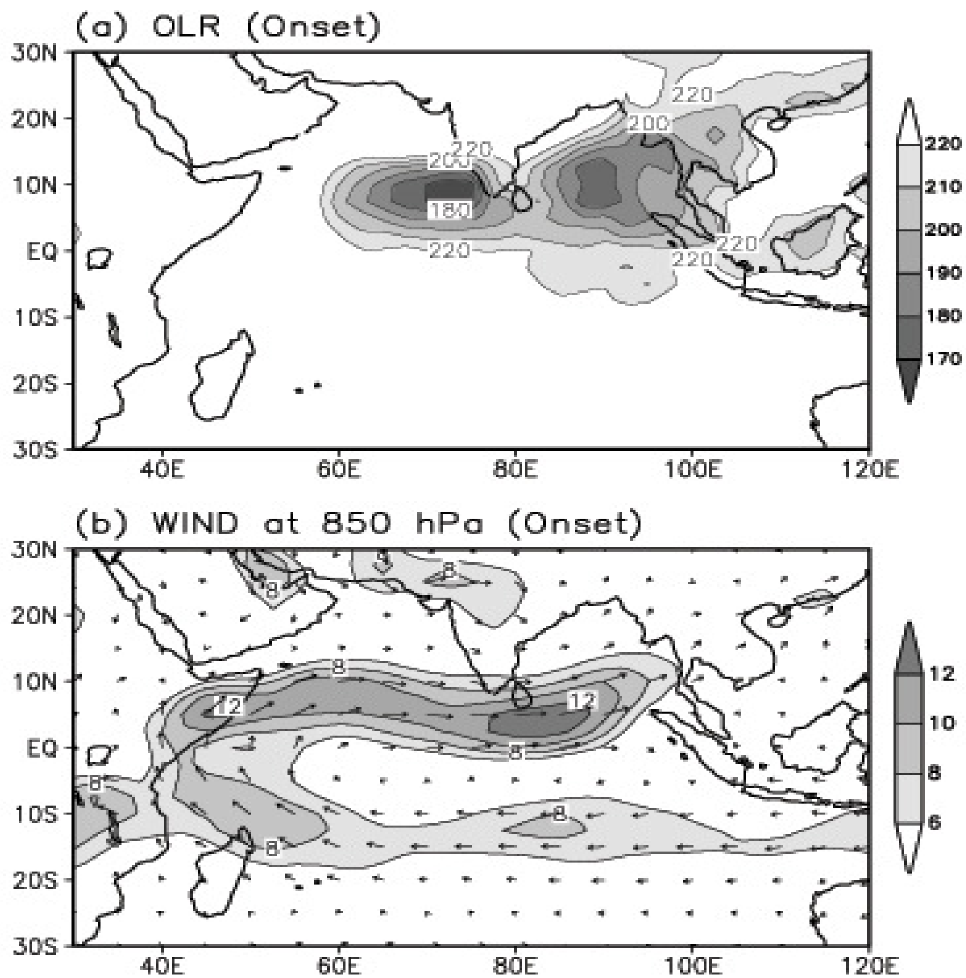
Outstanding issues on extremes in the south Asian monsoon climate

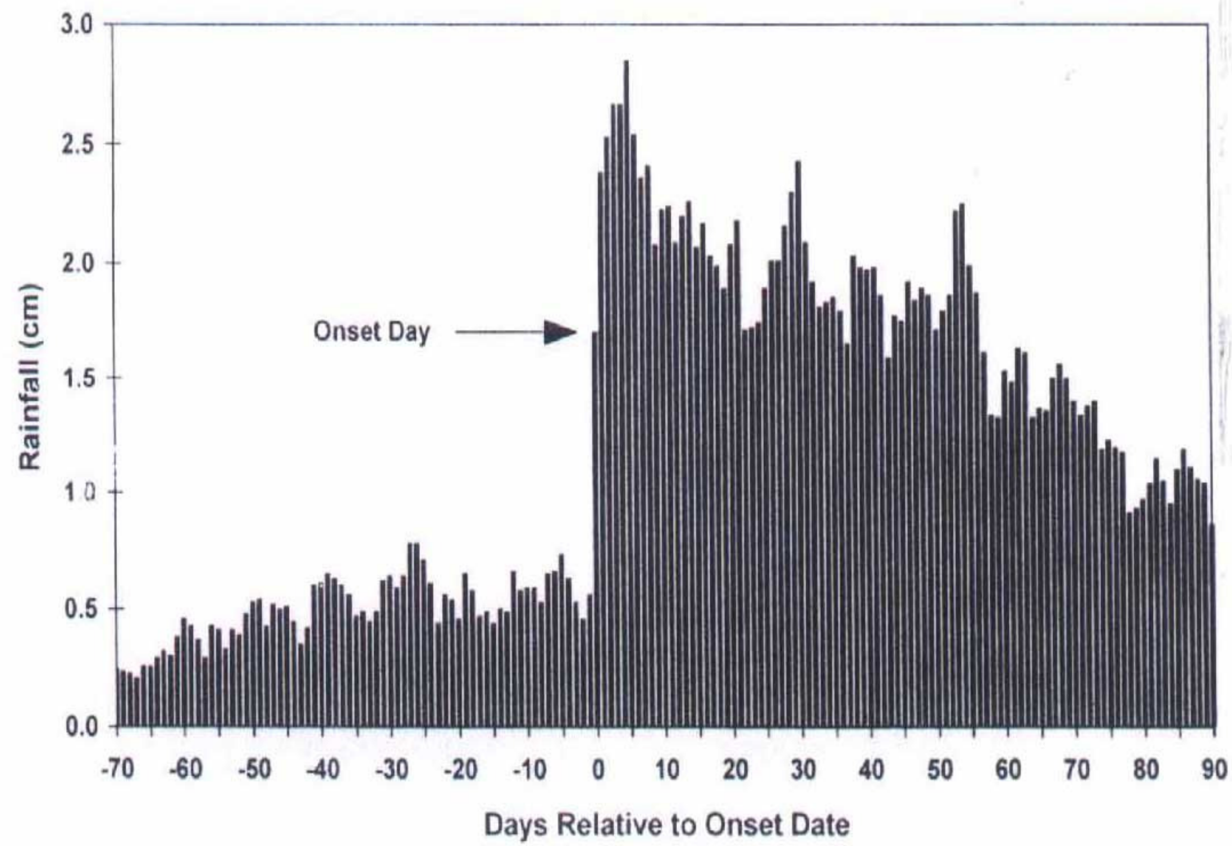
Porathur V. Joseph
Nansen Environmental Research Center India (NERCI), Cochin
and
Cochin University of Science and Technology (CUSAT), Cochin, INDIA
e-mail: joporathur@gmail.com

Topics chosen

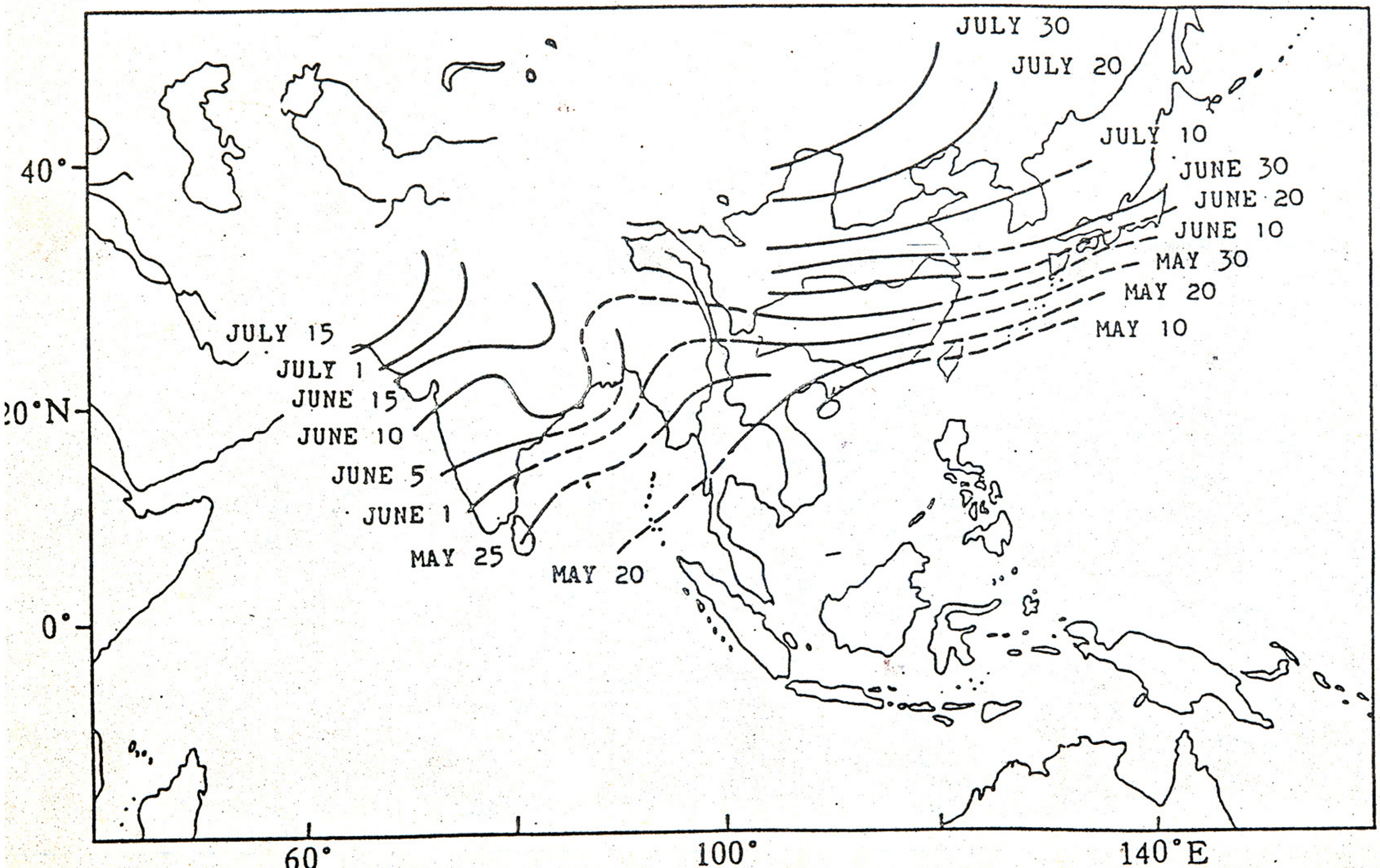
1. Monsoon Onset date variability
2. Long Break Monsoon Spells
3. All India Monsoon Droughts
4. Heavy Rainfall Occurrence frequency
5. Decreasing Monsoon Depressions



Rainfall (OLR) and wind at 1.5km (850hPa) at Monsoon Onset (average of 12 cases) - Joseph and Sijikumar (2004) , Journal of Climate

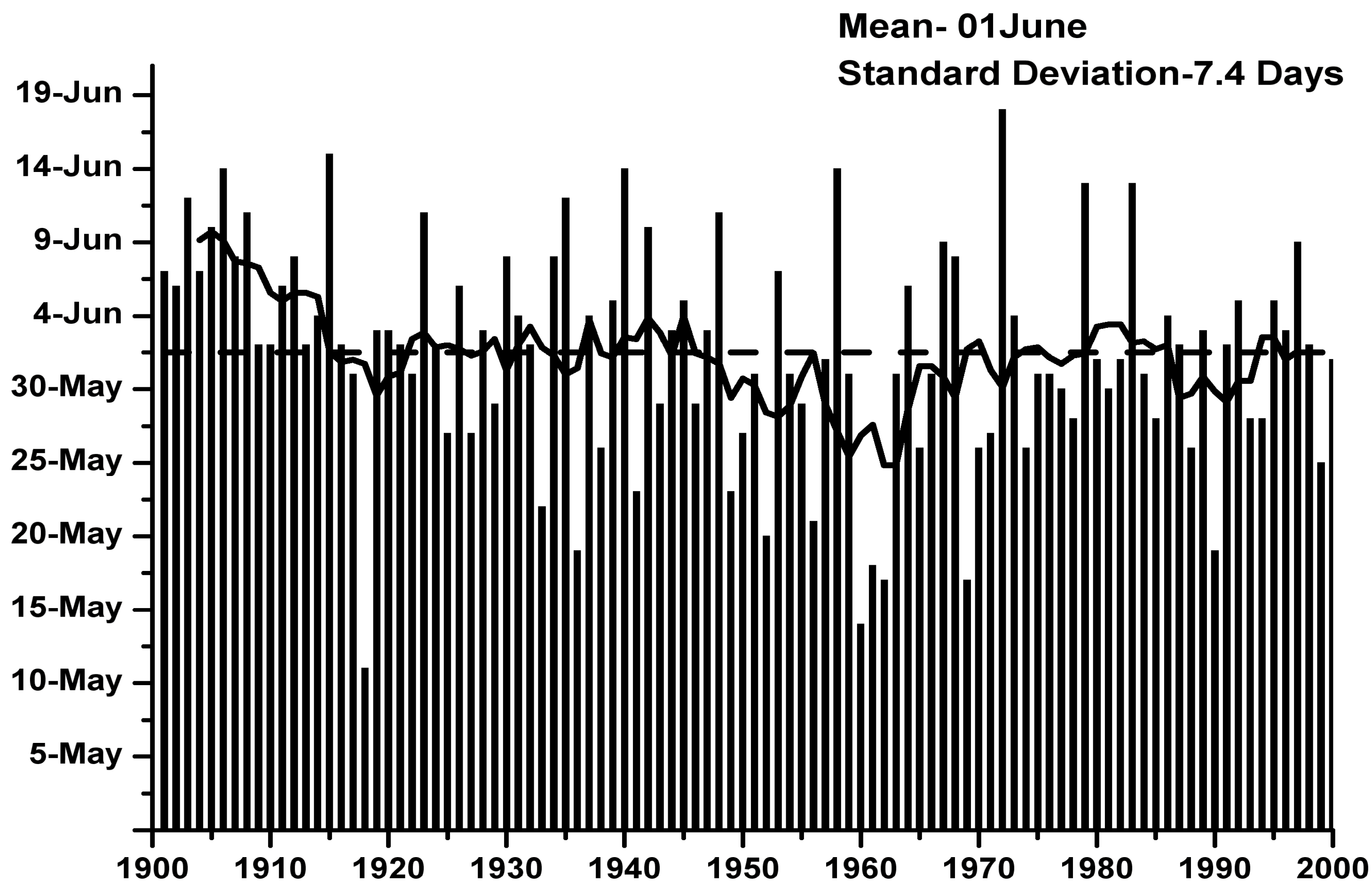


Rainfall of Kerala shows sudden increase at Monsoon Onset (picture shows this as an average of 80 years, 1901-1980) - From Ananthakrishnan and Soman (1988), Journal of Climatology



Isochrones of mean onset dates of Asian summer monsoon similar to fig-1a determined from long term rainfall records (from Tao and Chen, 1987 and IMD publications)

Climate Change in date of Monsoon Onset over Kerala



Subjectively determined IMD dates of onset of monsoon over Kerala 1901 to 2000. 100 year mean is shown by the broken line and the seven year moving average by the continuous line.

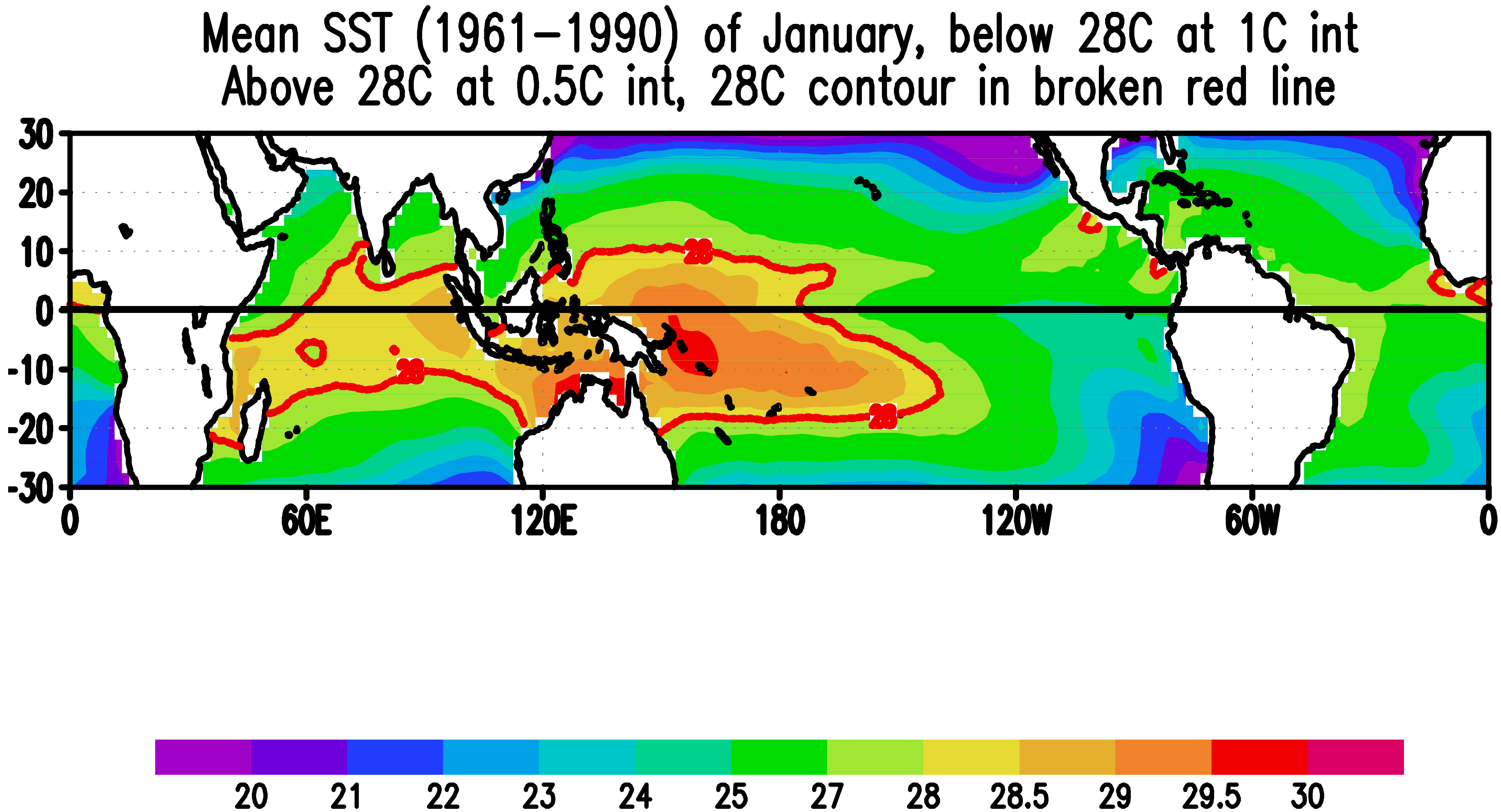
MONSOON ONSET KERALA

Mean Onset Date : 01 June

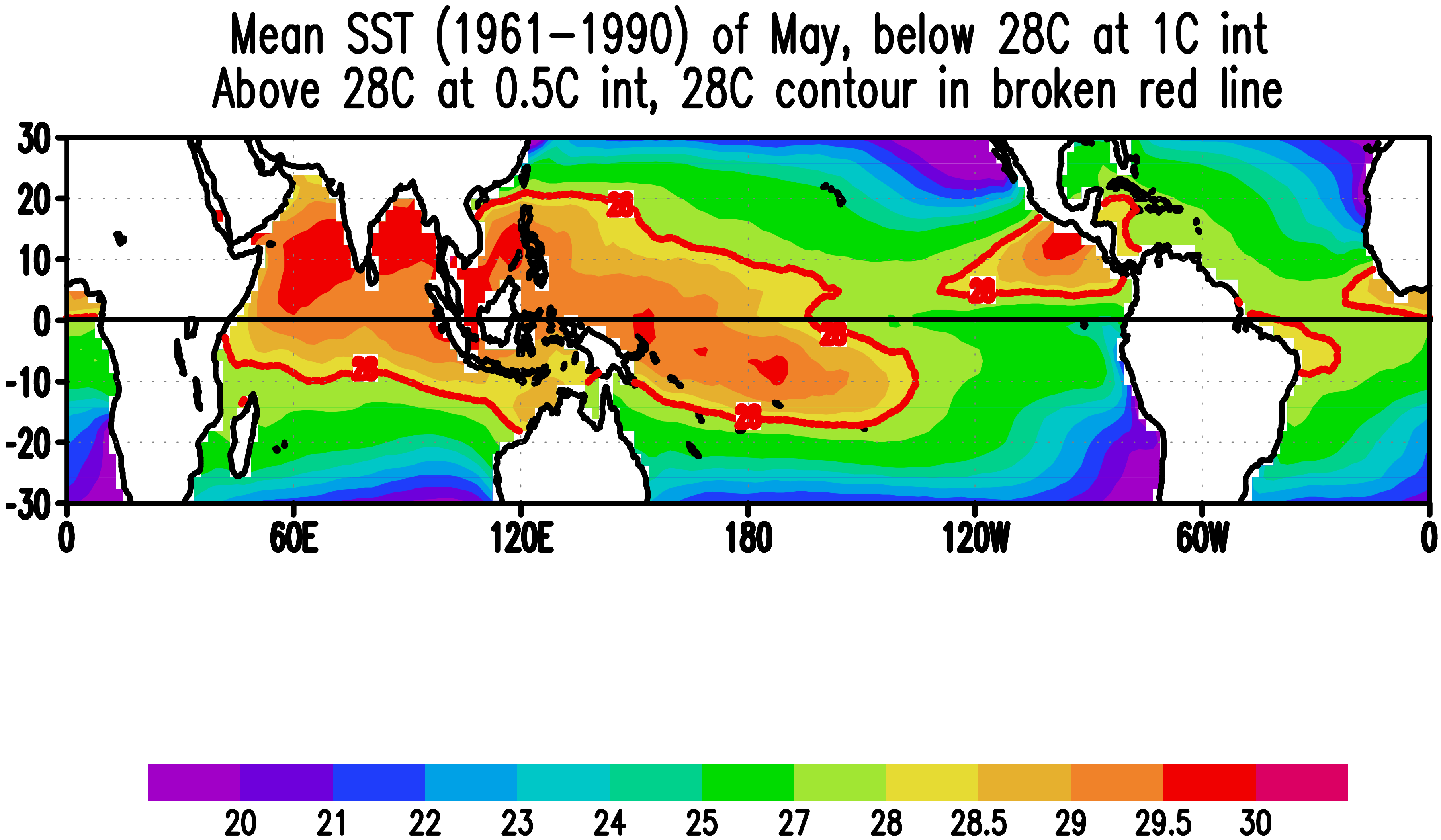
Earliest Onset date : 11 May (1918)

Most delayed Onset: 18 June (1972)

Standard Deviation : 8 days


Mean SST (1961–1990) of January, below 28C at 1C int
Above 28C at 0.5C int, 28C contour in broken red line
30
20
10
0
-10
-20
-30
0
60E
120E
180
120W
60W
0
28
20
21
22
23
24
25
27
28
28.5
29
29.5
30

January

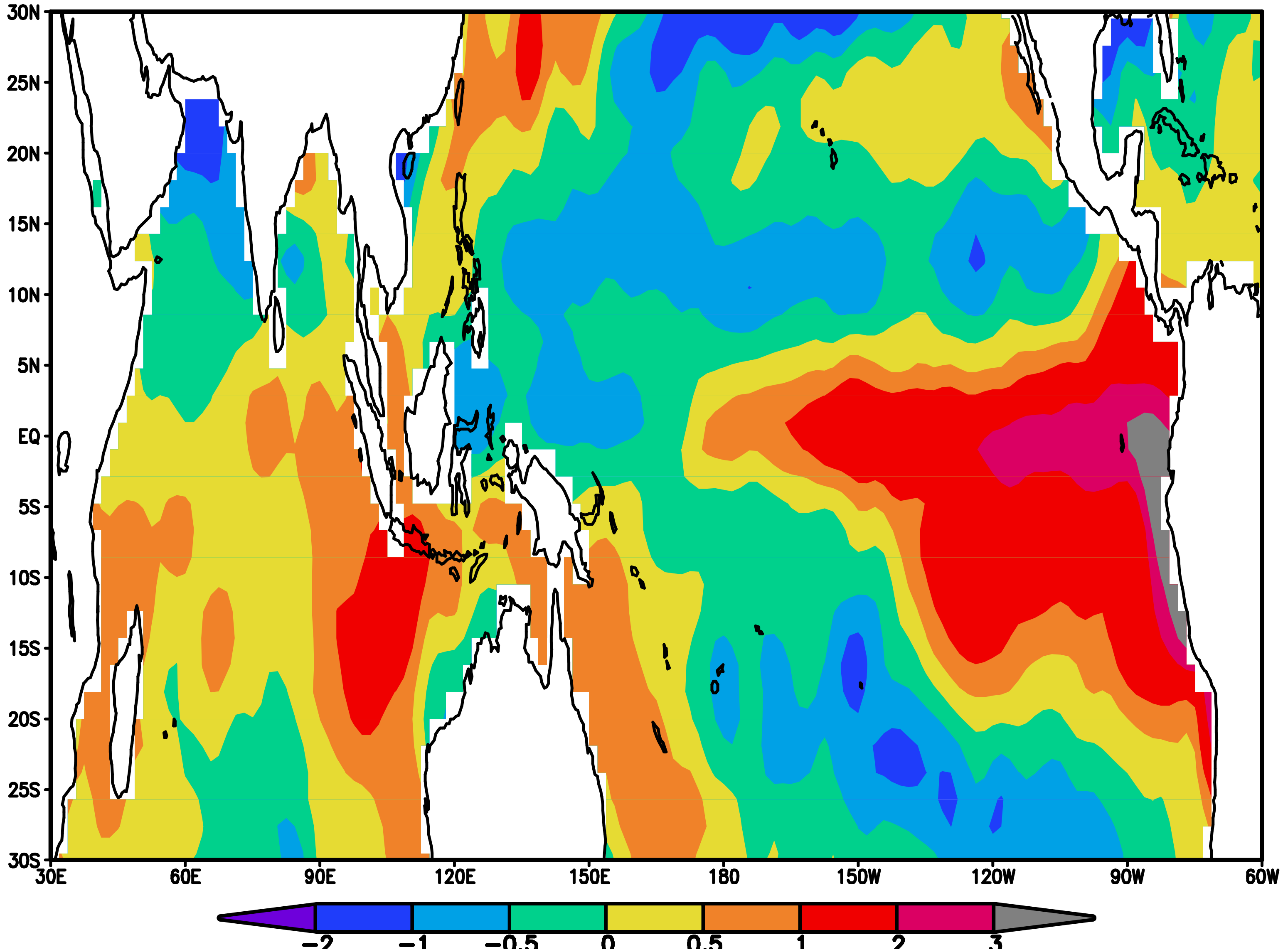

Mean SST (1961–1990) of May, below 28C at 1C int
Above 28C at 0.5C int, 28C contour in broken red line
30
20
10
0
-10
-20
-30
0
60E
120E
180
120W
60W
0
28
20
21
22
23
24
25
27
28
28.5
29
29.5
30

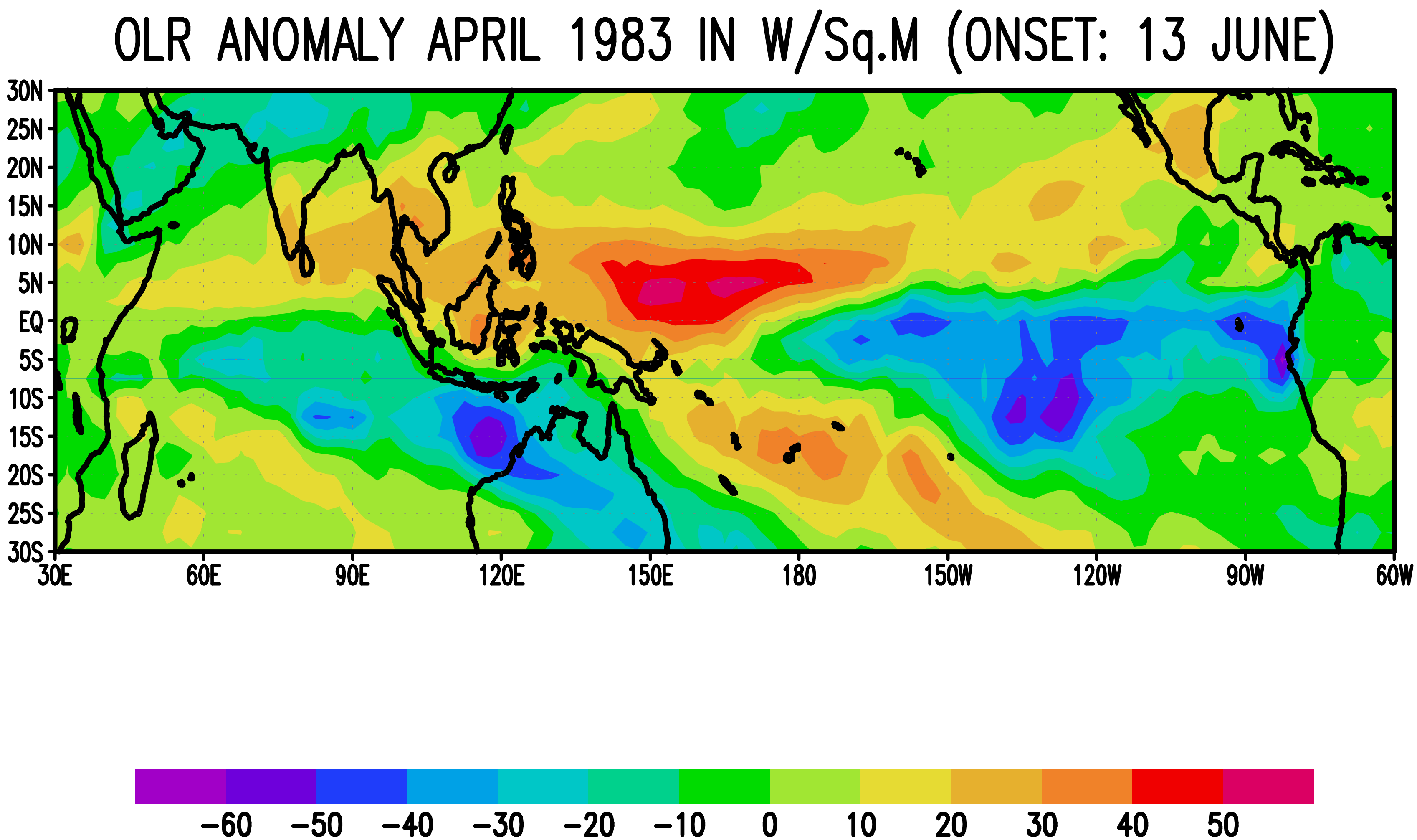
May

Global SST Anomalies are associated with the interannual variability of the dates of Monsoon Onset over Kerala.

(Joseph et al, 1994, Journal of Climate and modeling studies by Ju and Slingo, Soman and Slingo and Annamalai)

SST Anomaly April 1983 – Late Onset 13th June





OLR ANOMALY APRIL 1983 IN W/Sq.M (ONSET: 13 JUNE)
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
30S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50

Fig – 16: Correlation Coefficient between HadISST and IMD's objective dates of MOK (1971- 2002).

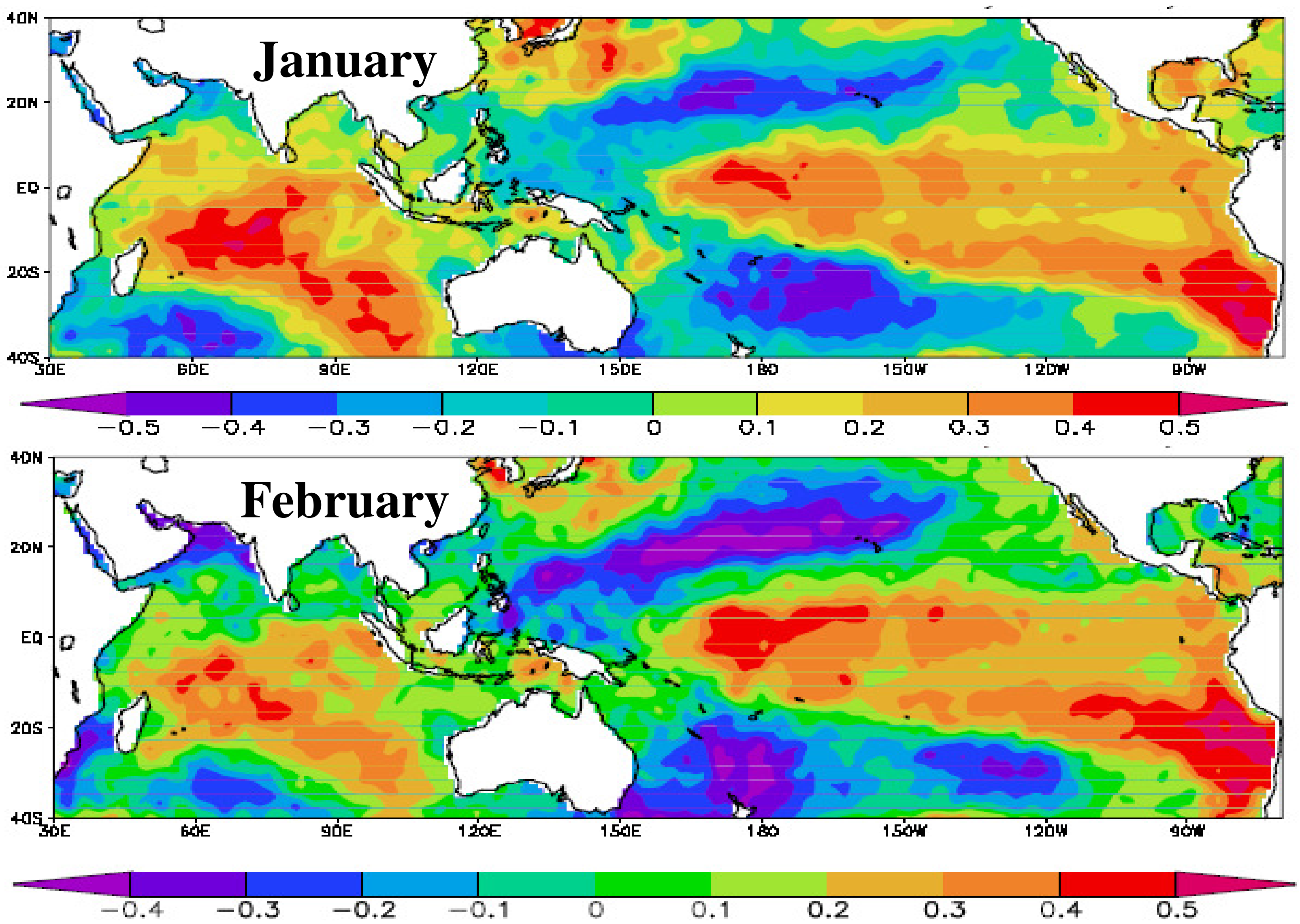
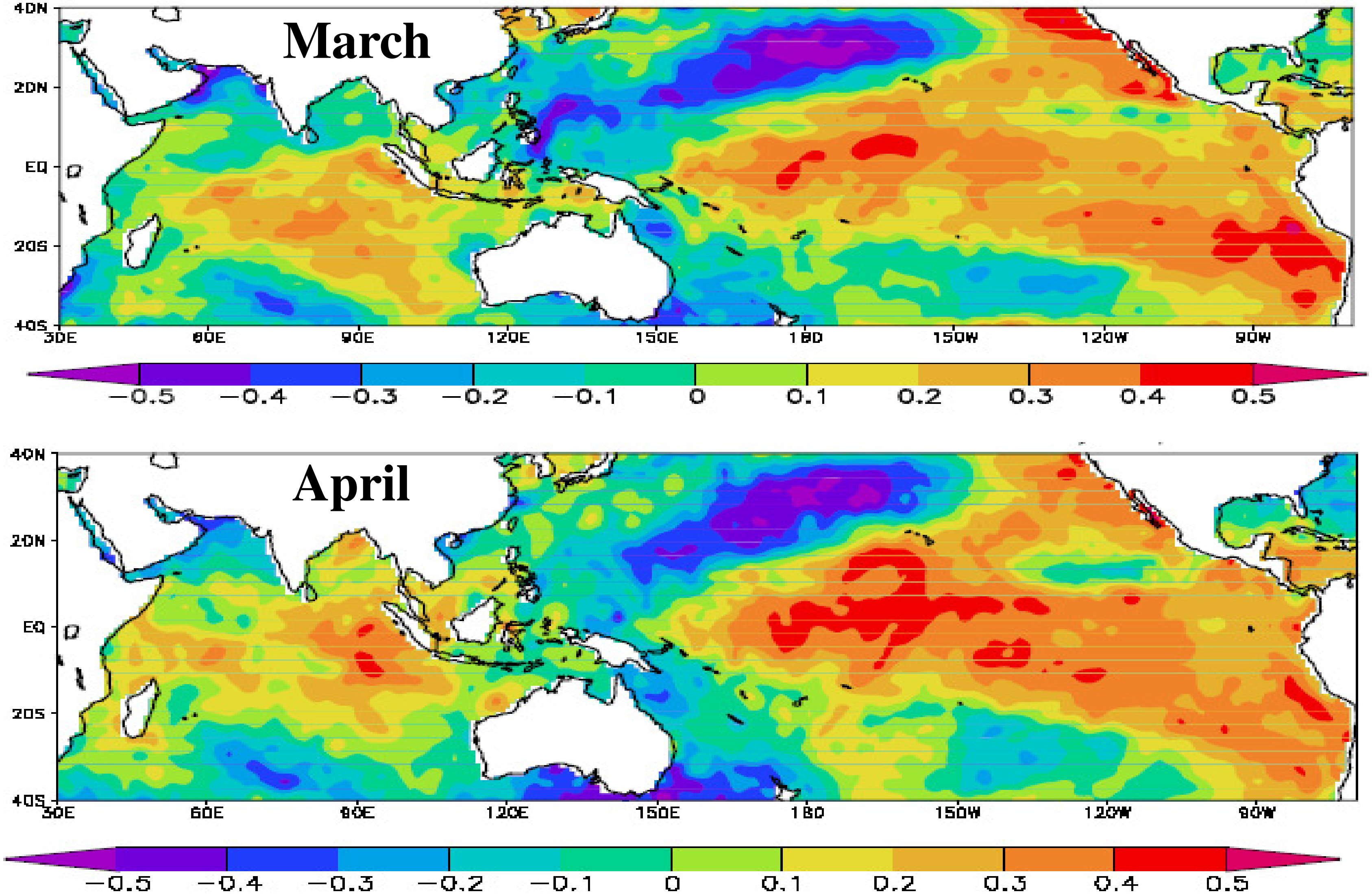


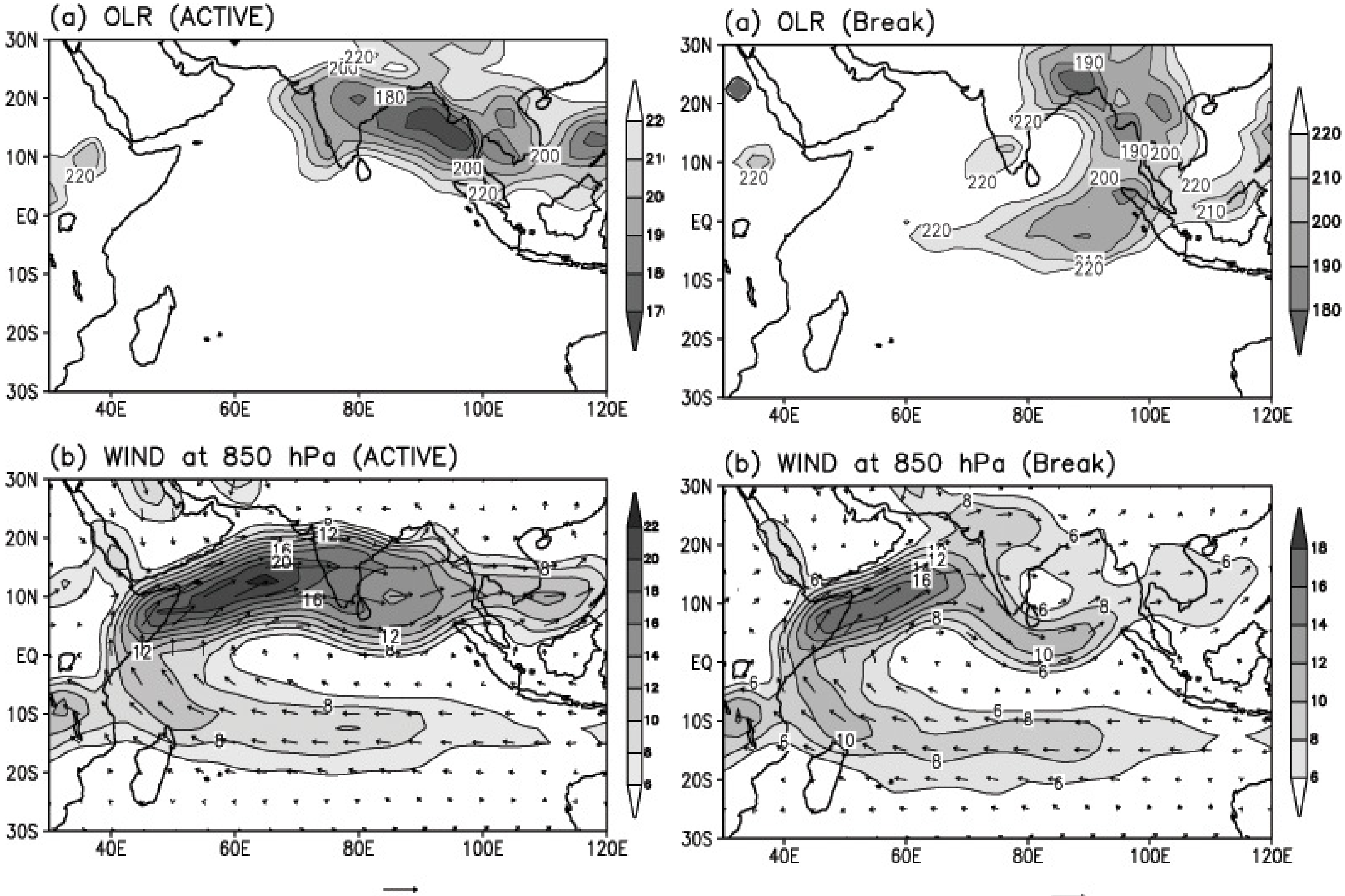
Fig – 16 (contd.): Correlation coefficient between HadISST and IMD's objective dates of MOK (1971- 2002).



ACTIVE BREAK CYCLE

& LONG BREAKS

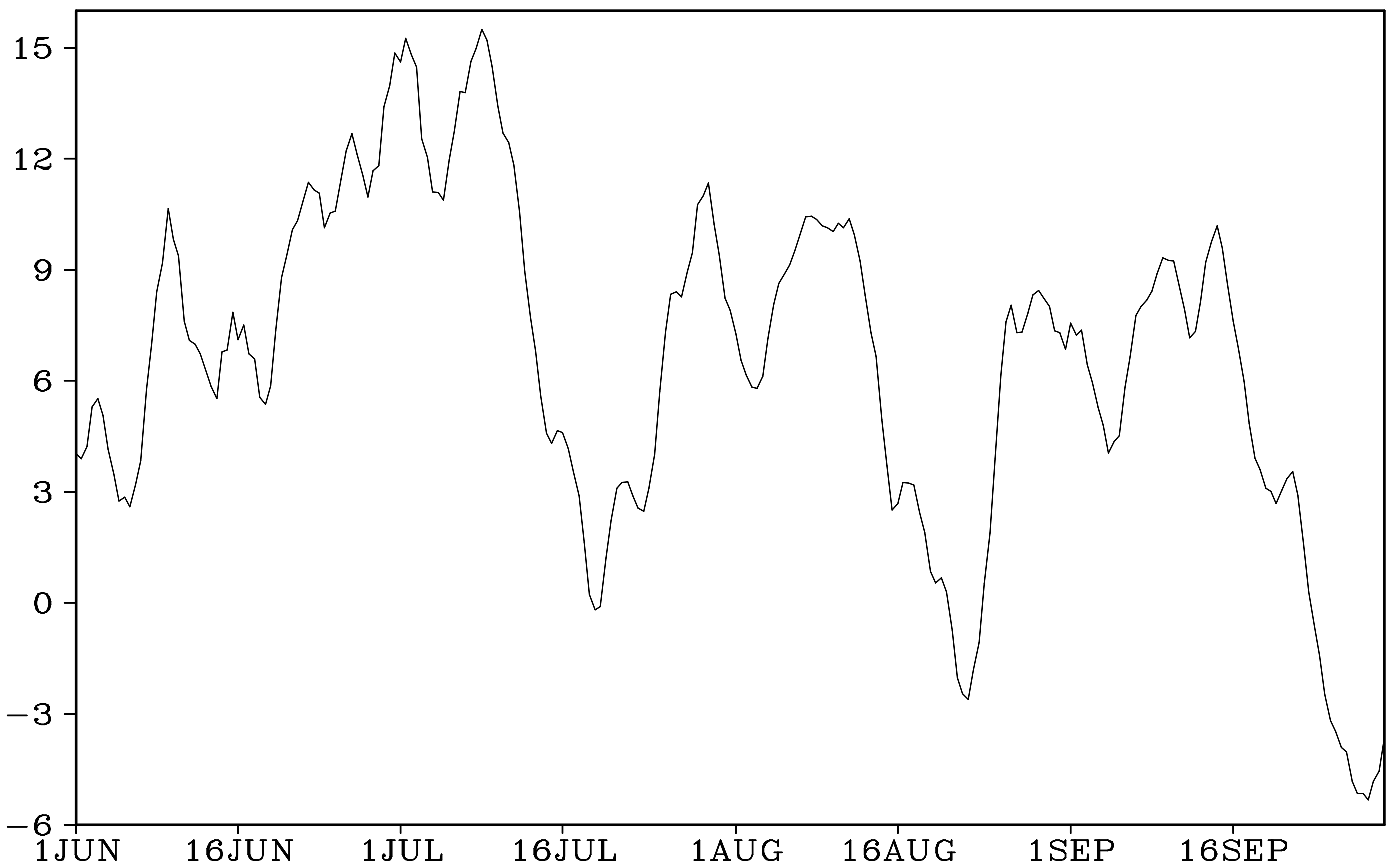
Period of AB cycle varies between 30 and 60 days with the most frequent period around 40 days

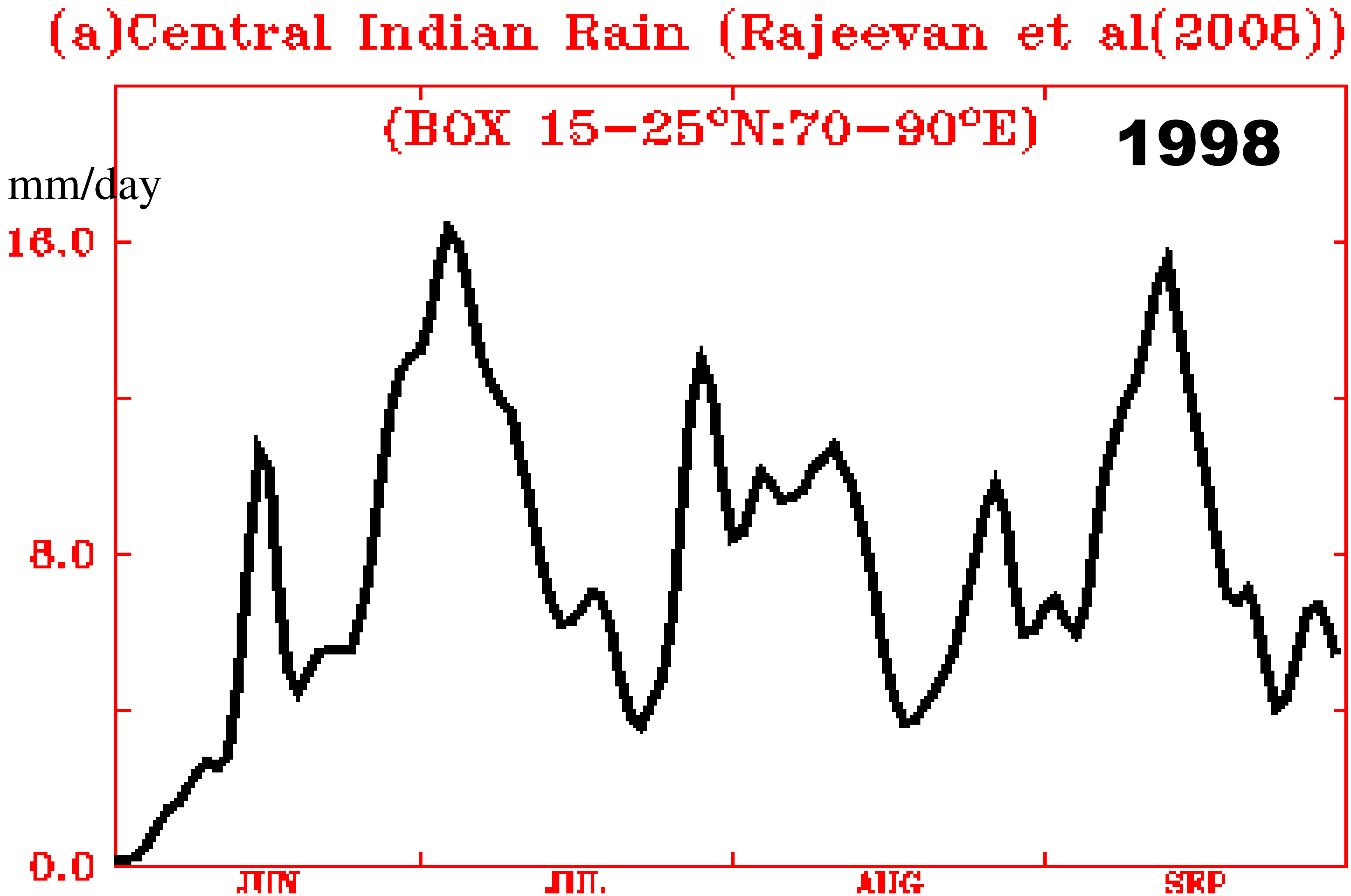


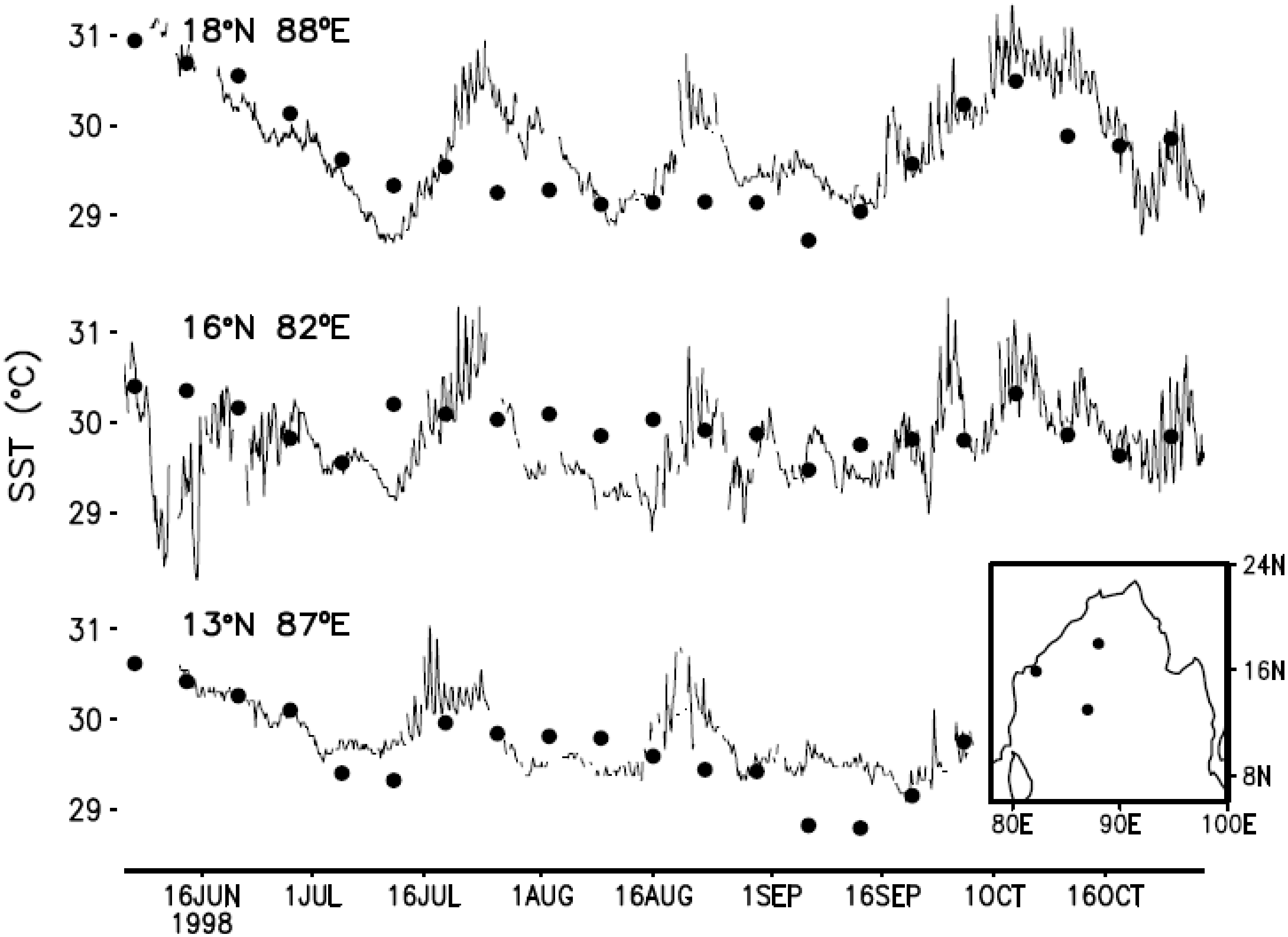
Active Break cycle of Monsoon

~100 day composites – Joseph & Sijikumar (2004), Journal of Climate

Zonal Wind through peninsular India at 850hPa during 1 June to 30 September 1998 (wind averaged over area 12.5N – 17.5N, 70E – 95E)

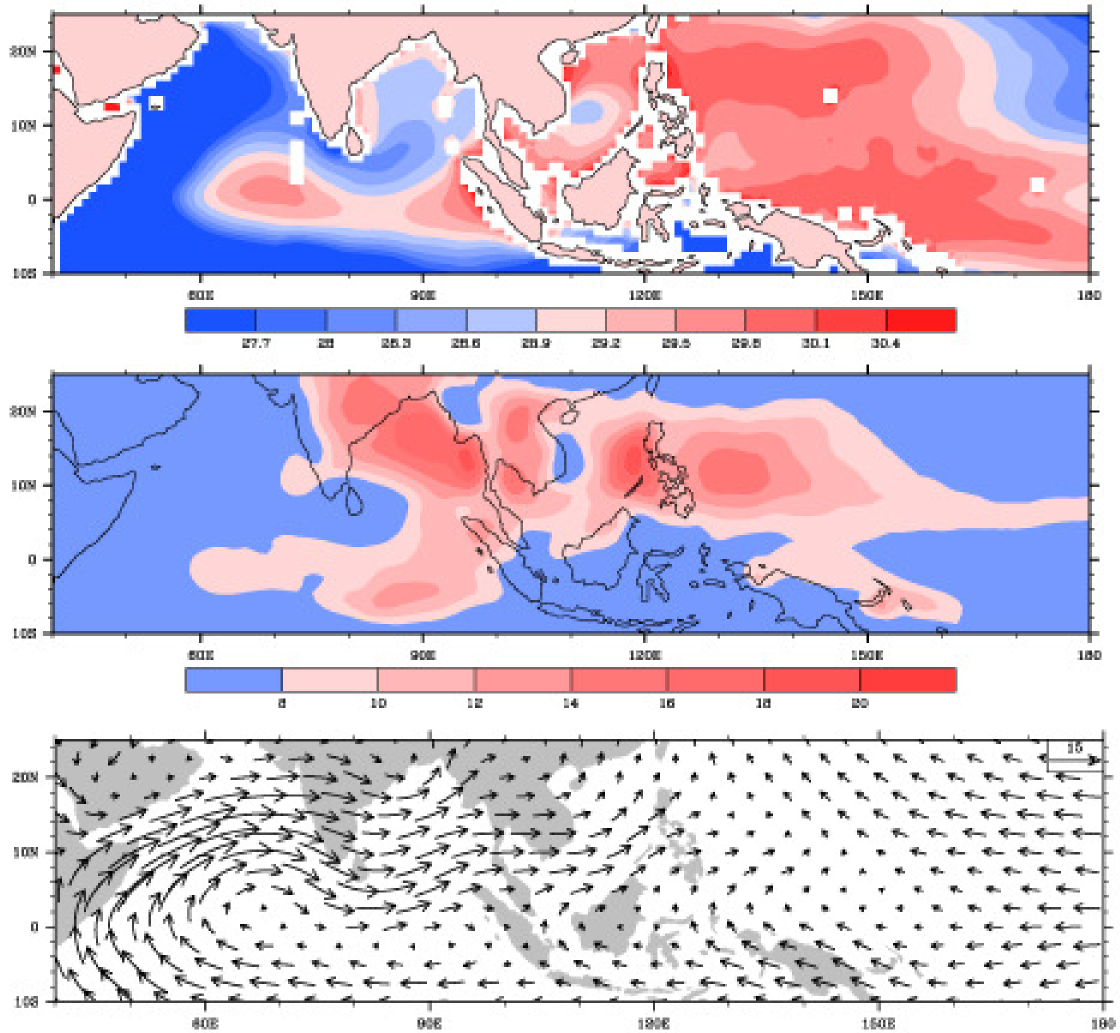


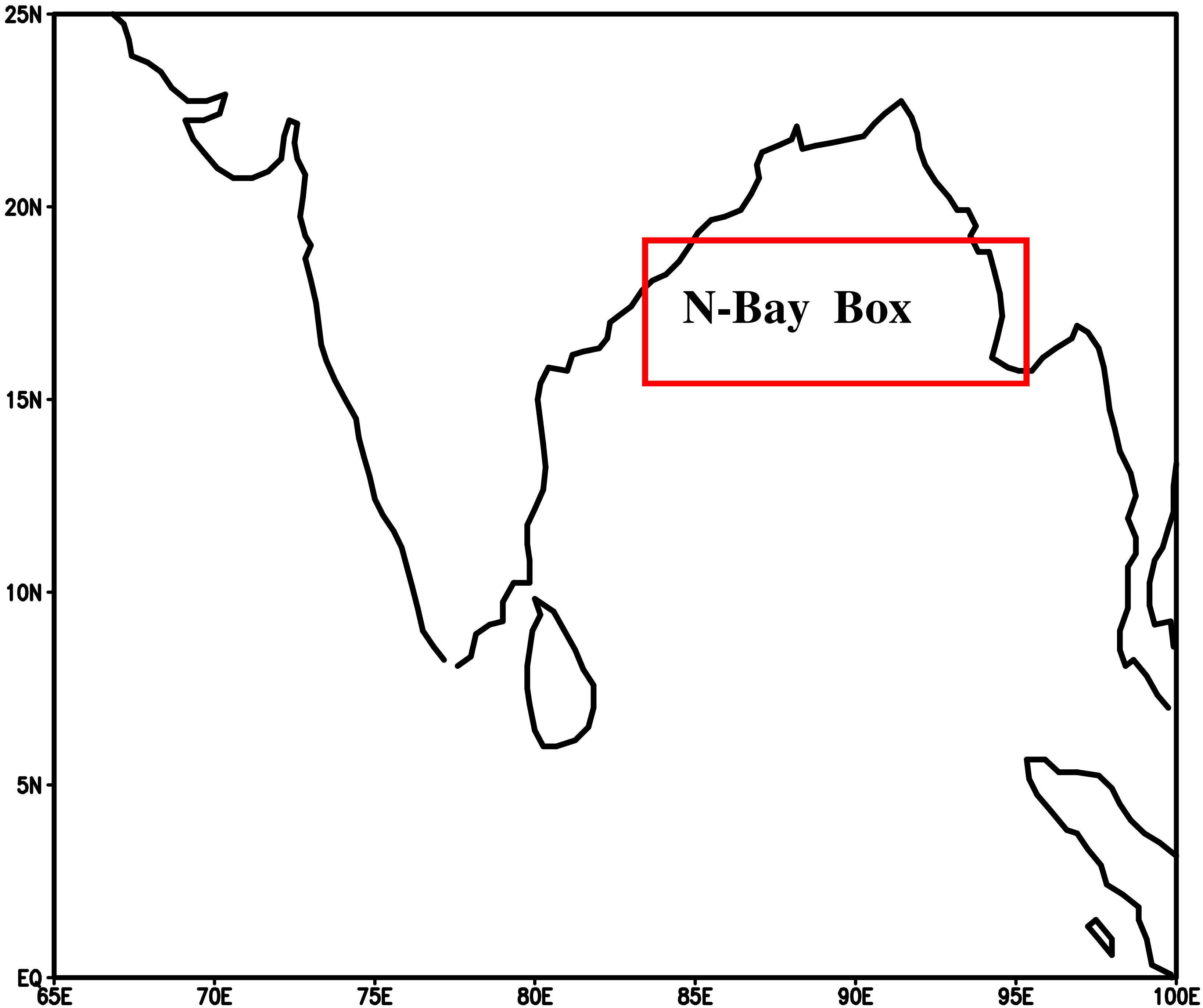

(a)Central Indian Rain (Rajeevan et al(2008))
(BOX 15-25°N:70-90°E)
1998
mm/day
16.0
8.0
0.0
JUN
JUL
AUG
SEP

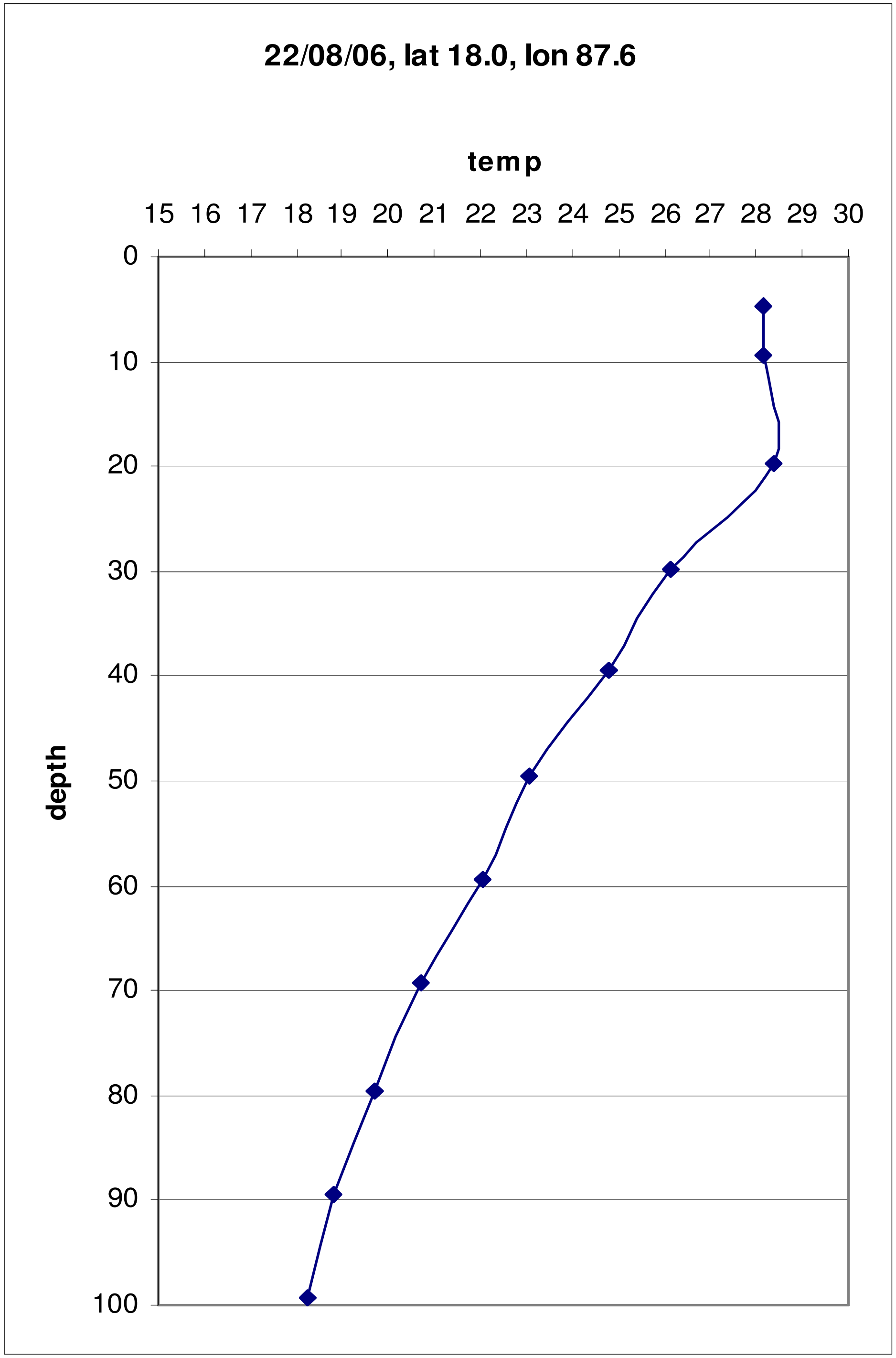


OSCILLATIONS OF BAY OF BENGAL SST (BUOY) IN 1998

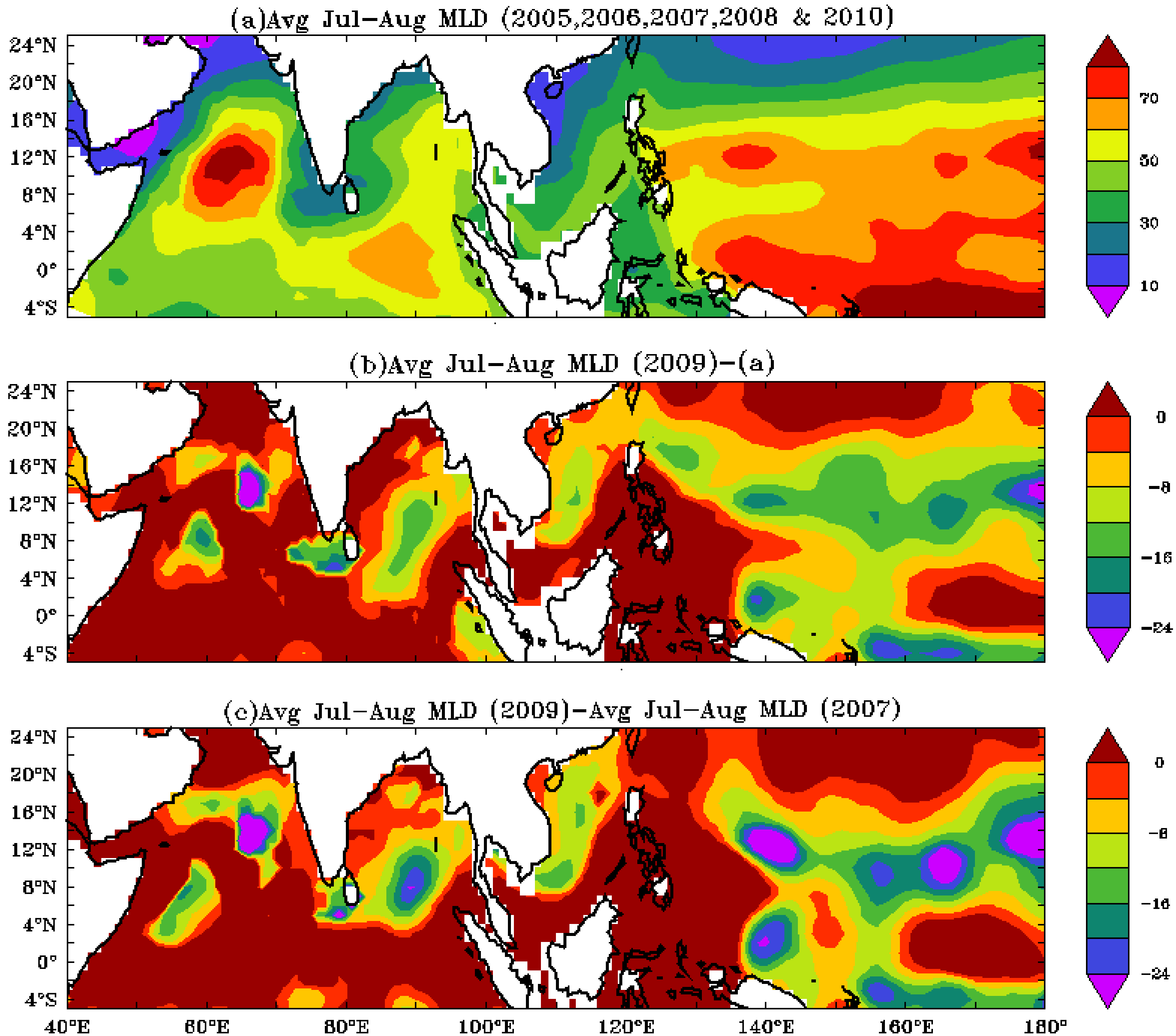
7 year Jul&Aug mean TMI SST, GPI Rain & 850 hPa Wind



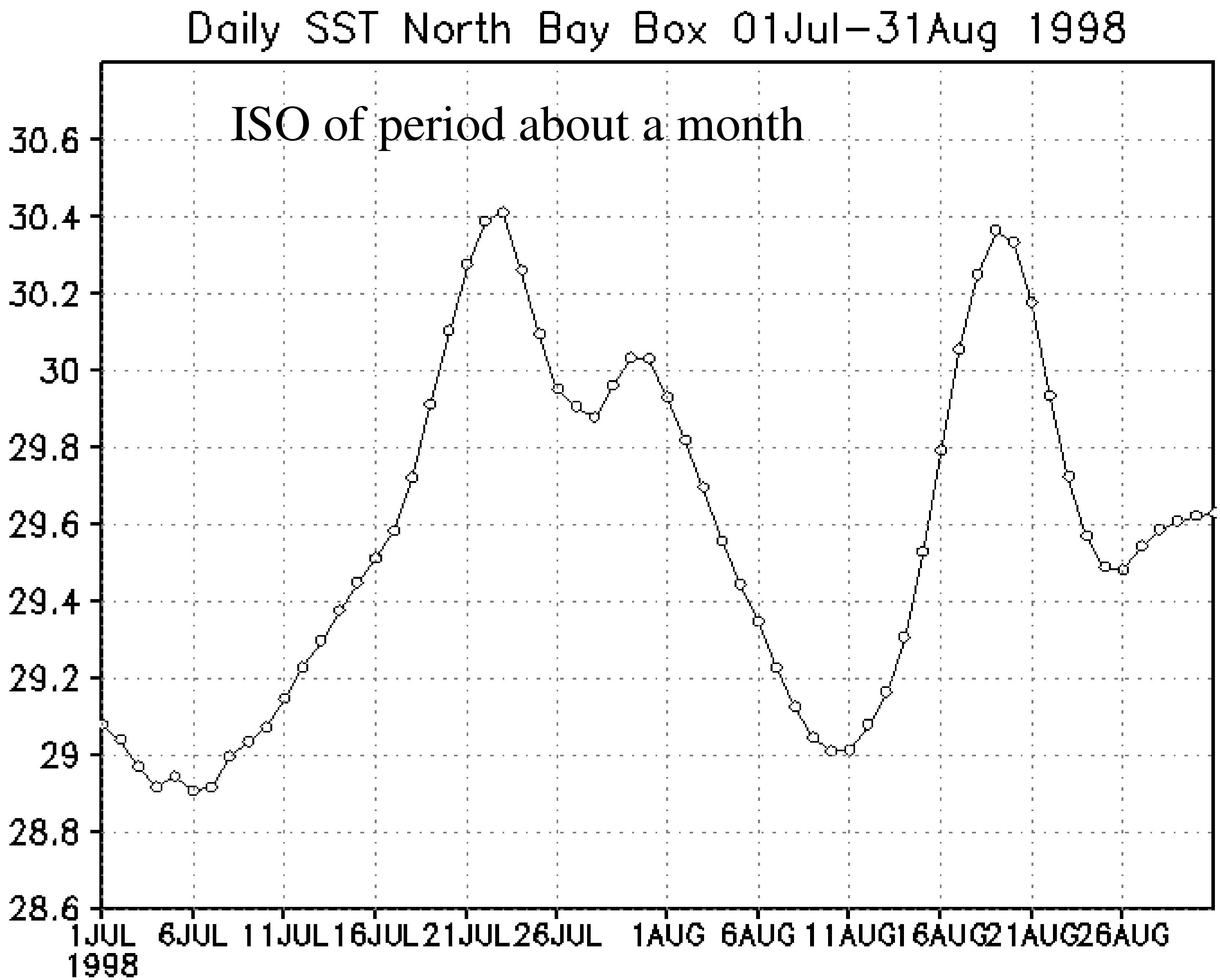

N-Bay Box
25N
20N
15N
10N
5N
EQ
65E
70E
75E
80E
85E
90E
95E
100E

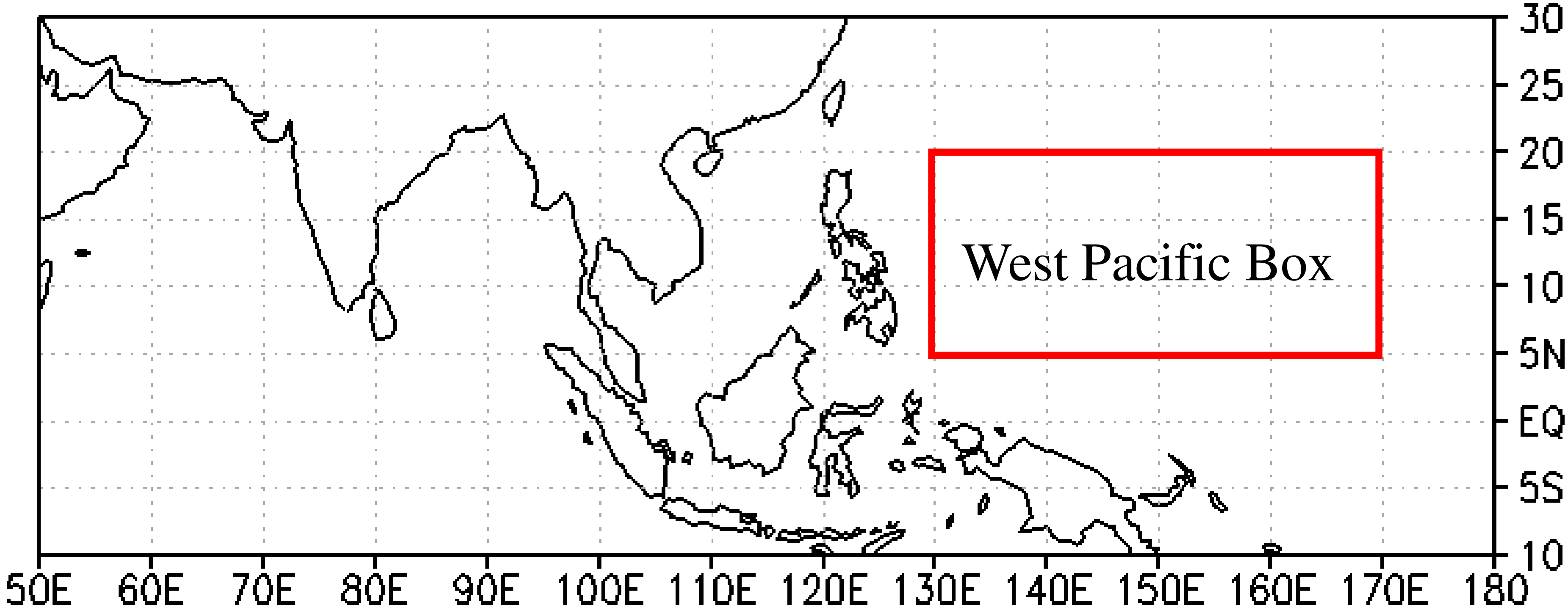


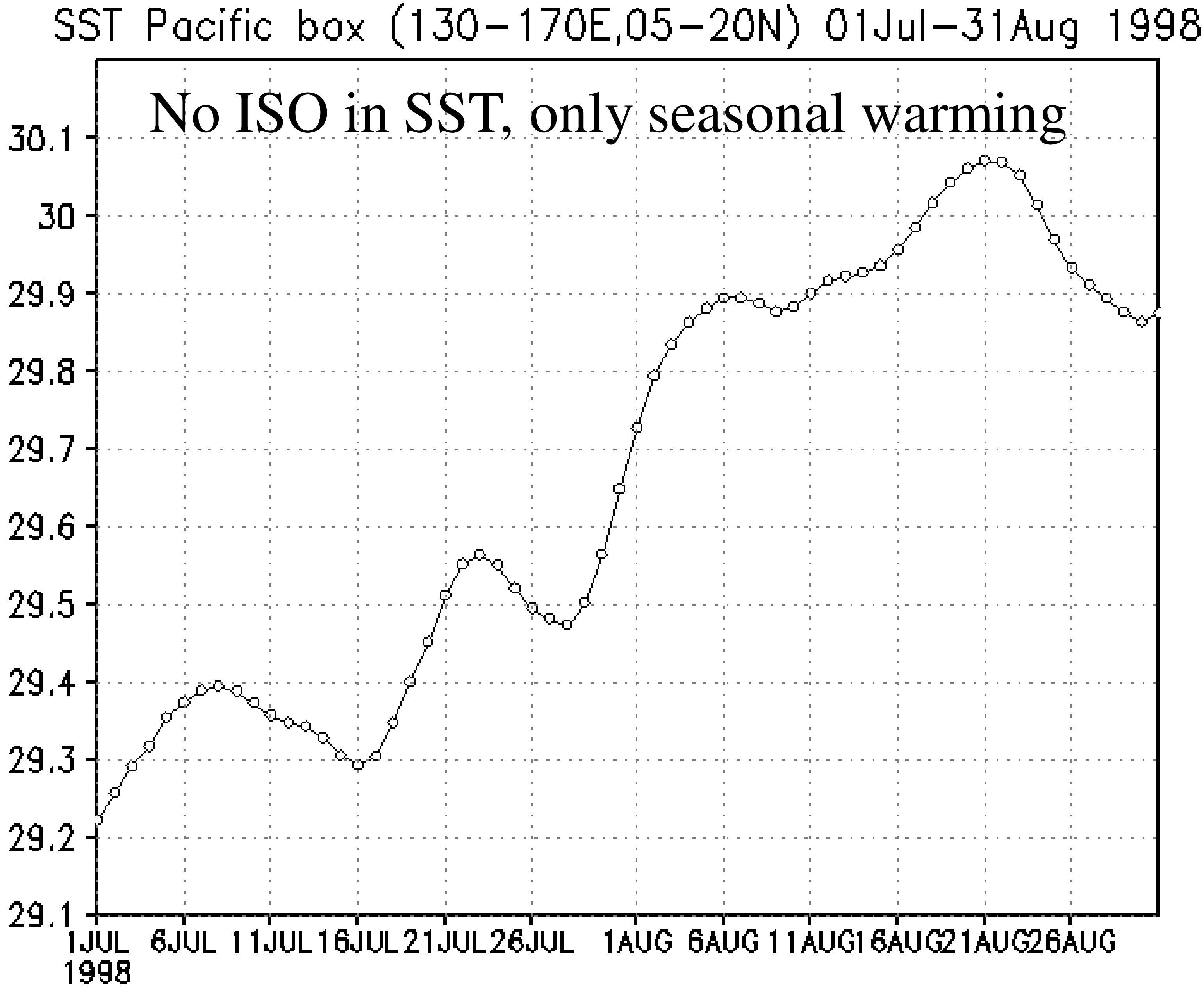
A typical vertical profile of ocean temperature in North Bay of Bengal during the monsoon season. The mixed layer thickness of 20 metres is typical. With fresh water from rain and discharge from rivers, barrier layers form of even smaller thickness.



(a)Avg Jul-Aug MLD (2005,2006,2007,2008 & 2010)
(b)Avg Jul-Aug MLD (2009)-(a)
(c)Avg Jul-Aug MLD (2009)-Avg Jul-Aug MLD (2007)
24°N
20°N
16°N
12°N
8°N
4°N
0°
4°S
40°E
60°E
80°E
100°E
120°E
140°E
160°E
180°
70
50
30
10
0
-8
-16
-24

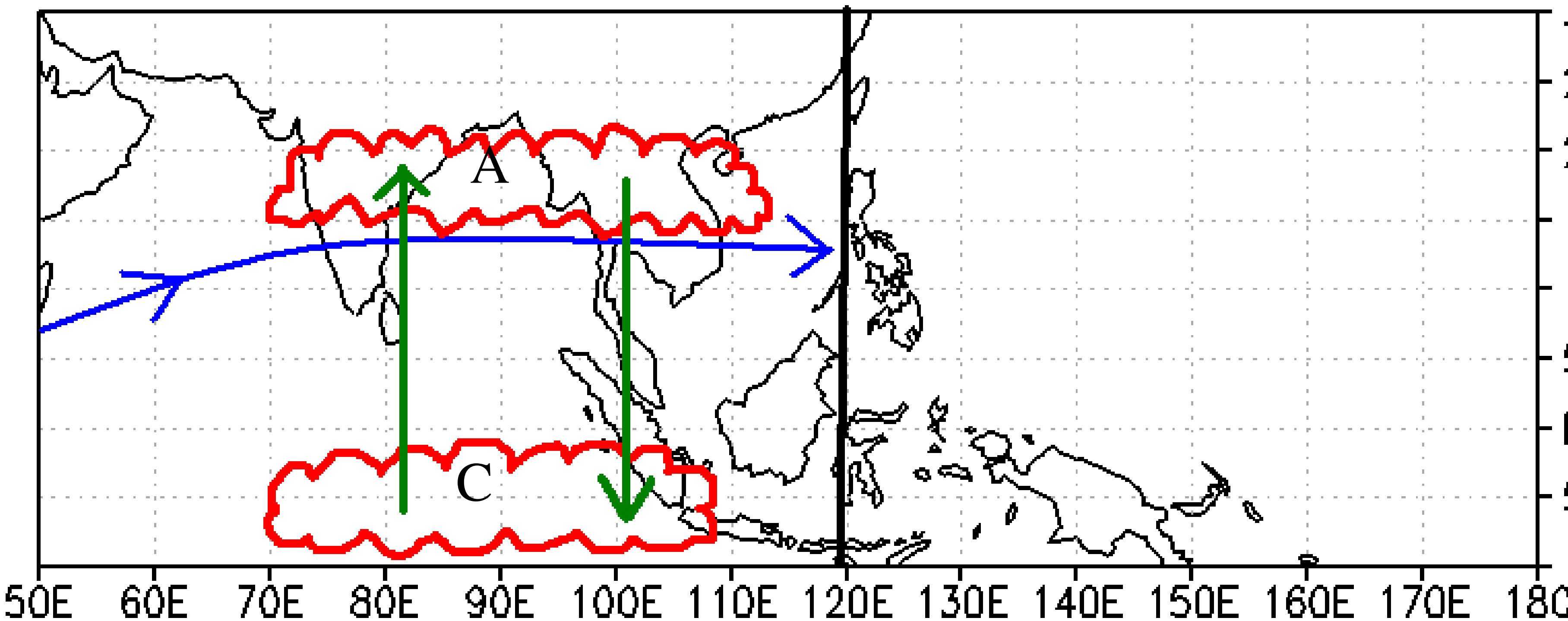

Daily SST North Bay Box 01Jul-31Aug 1998
ISO of period about a month
30.6
30.4
30.2
30
29.8
29.6
29.4
29.2
29
28.8
28.6
1JUL 1998
6JUL
11JUL
16JUL
21JUL
26JUL
1AUG
6AUG
11AUG
16AUG
21AUG
26AUG


West Pacific Box
30
25
20
15
10
5N
EQ
5S
10
50E
60E
70E
80E
90E
100E
110E
120E
130E
140E
150E
160E
170E
180

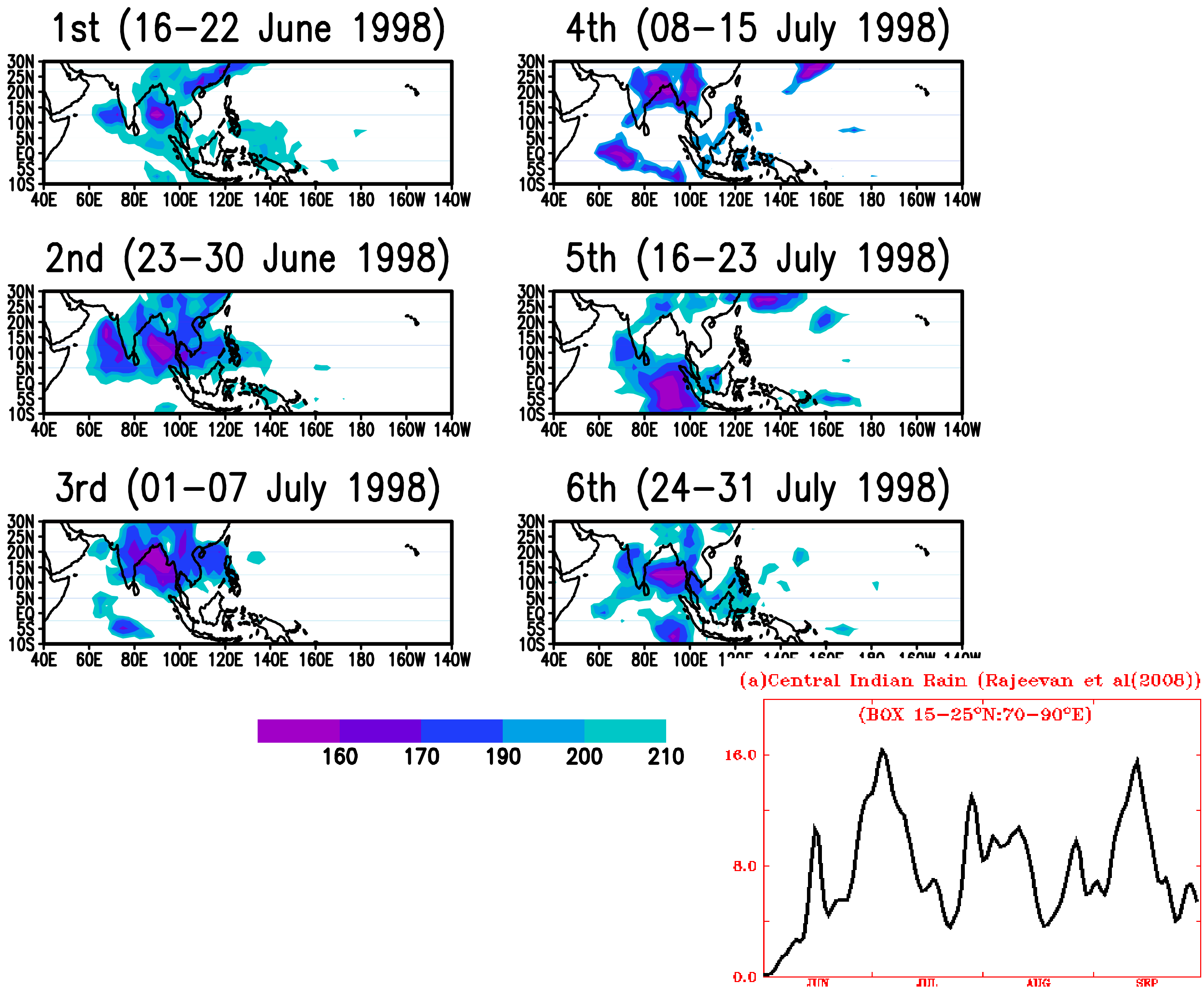


SST Pacific box (130-170E,05-20N) 01Jul-31Aug 1998
No ISO in SST, only seasonal warming
30.1
30
29.9
29.8
29.7
29.6
29.5
29.4
29.3
29.2
29.1
1JUL 1998
6JUL
11JUL
16JUL
21JUL
26JUL
1AUG
6AUG
11AUG
16AUG
21AUG
26AUG

In La Nina: AB cycle (ISO) of period about a month (Jul & Aug)

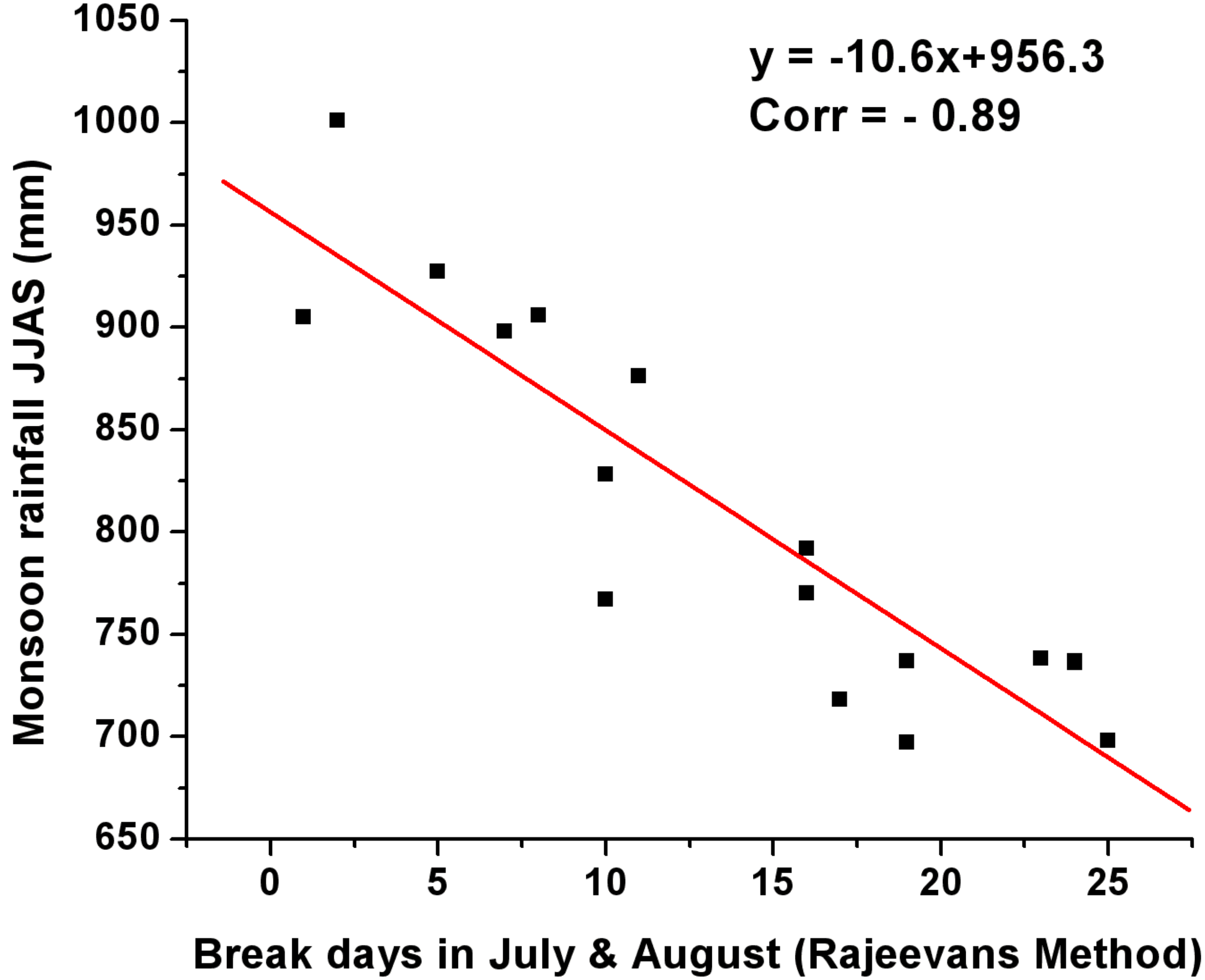


Hypothesis: In a La Nina situation west Pacific warms only slowly in the seasonal cycle in the absence of a shallow ML. When north Bay cools in the Active phase, convection shifts from A to C (Break phase) and then back to A.

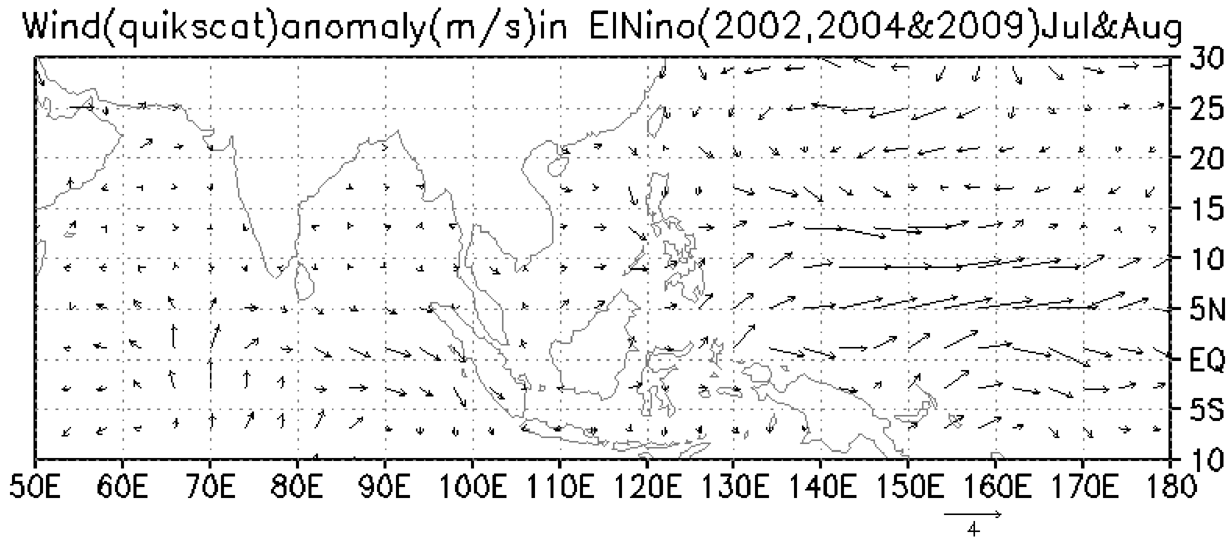

1st (16–22 June 1998)
2nd (23–30 June 1998)
3rd (01–07 July 1998)
4th (08–15 July 1998)
5th (16–23 July 1998)
6th (24–31 July 1998)
30N 25N 20N 15N 10N 5N EQ 5S 10S
40E 60E 80E 100E 120E 140E 160E 180 160W 140W
160 170 190 200 210
(a)Central Indian Rain (Rajeevan et al(2008))
(BOX 15–25°N:70–90°E)
16.0
8.0
0.0
JUN JUL AUG SEP

A high percentage of strong El ninos are associated with drought Indian monsoons. It is found that in El Nino years the Active-break cycle is longer and long breaks occur. We have analysed strong El Ninos of last 100 years. We find a high correlation between number of break monsoon days during July and August and the Indian summer Monsoon Rainfall (ISMR). Lengthening of the AB cycle by El Ninos must be the cause of El Nino – Monsoon Drought relation

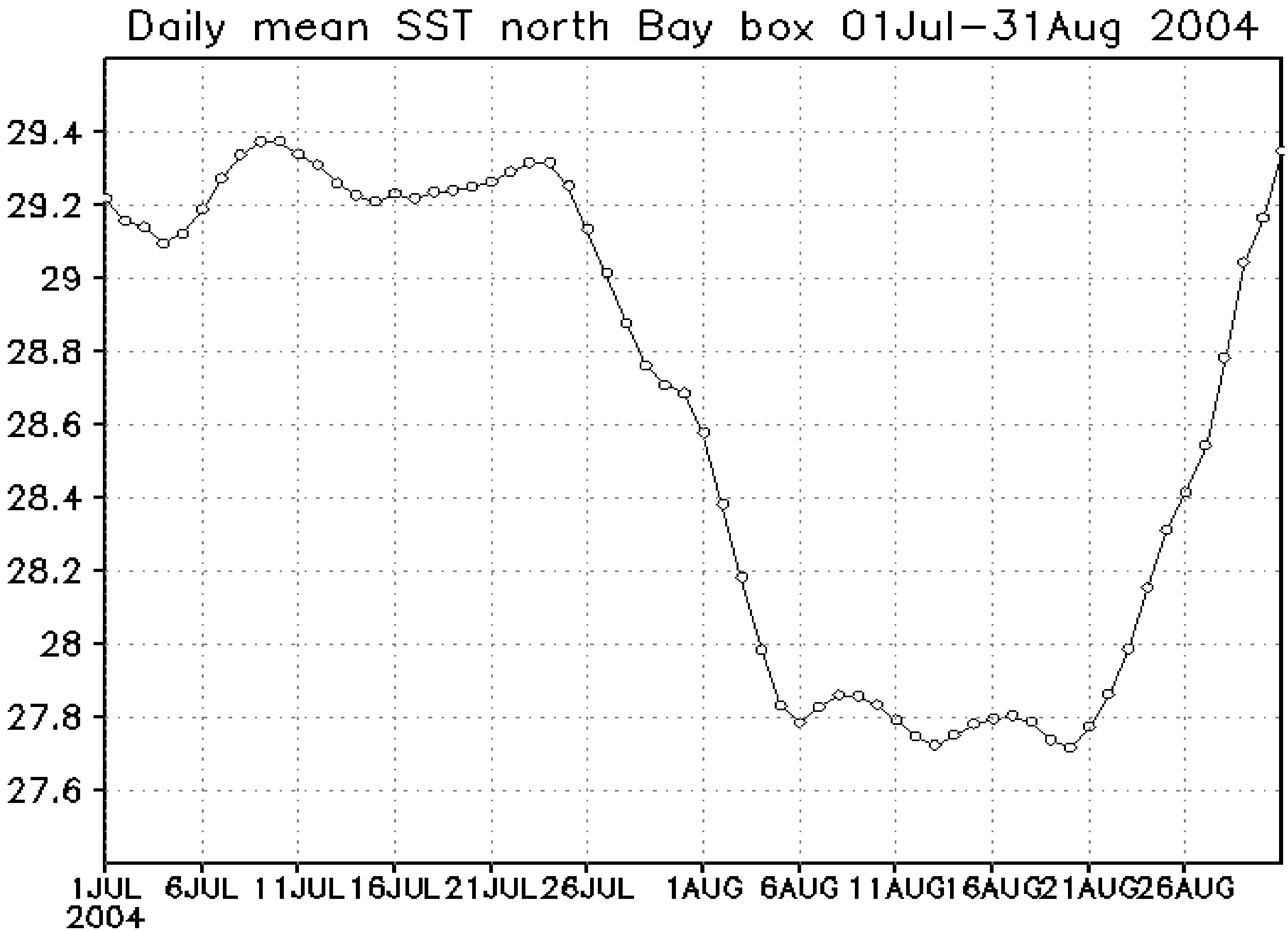
YEAR	ElNino Index	Break days	Monsoon rain (mm)	Departure (percent)
1902	2.1	16	792	-9
1905	1.6	17	718	-17
1918	1.9	24	736	-25
1925	2.0	8	906	-3
1930	2.2	11	876	-5
1940	1.6	1	905	-3
1957	1.8	7	898	-2
1965	2.0	23	738	-18
1972	2.5	19	697	-24
1982	3.3	10	767	-15
1986	1.7	16	770	-13
1987	1.6	19	737	-19
1991	2.1	10	828	-9
1994	1.6	2	1001	+13
1997	3.4	5	927	+2
2002	1.7	24	737	-19
2009	CPC 1.9	25	698	-22

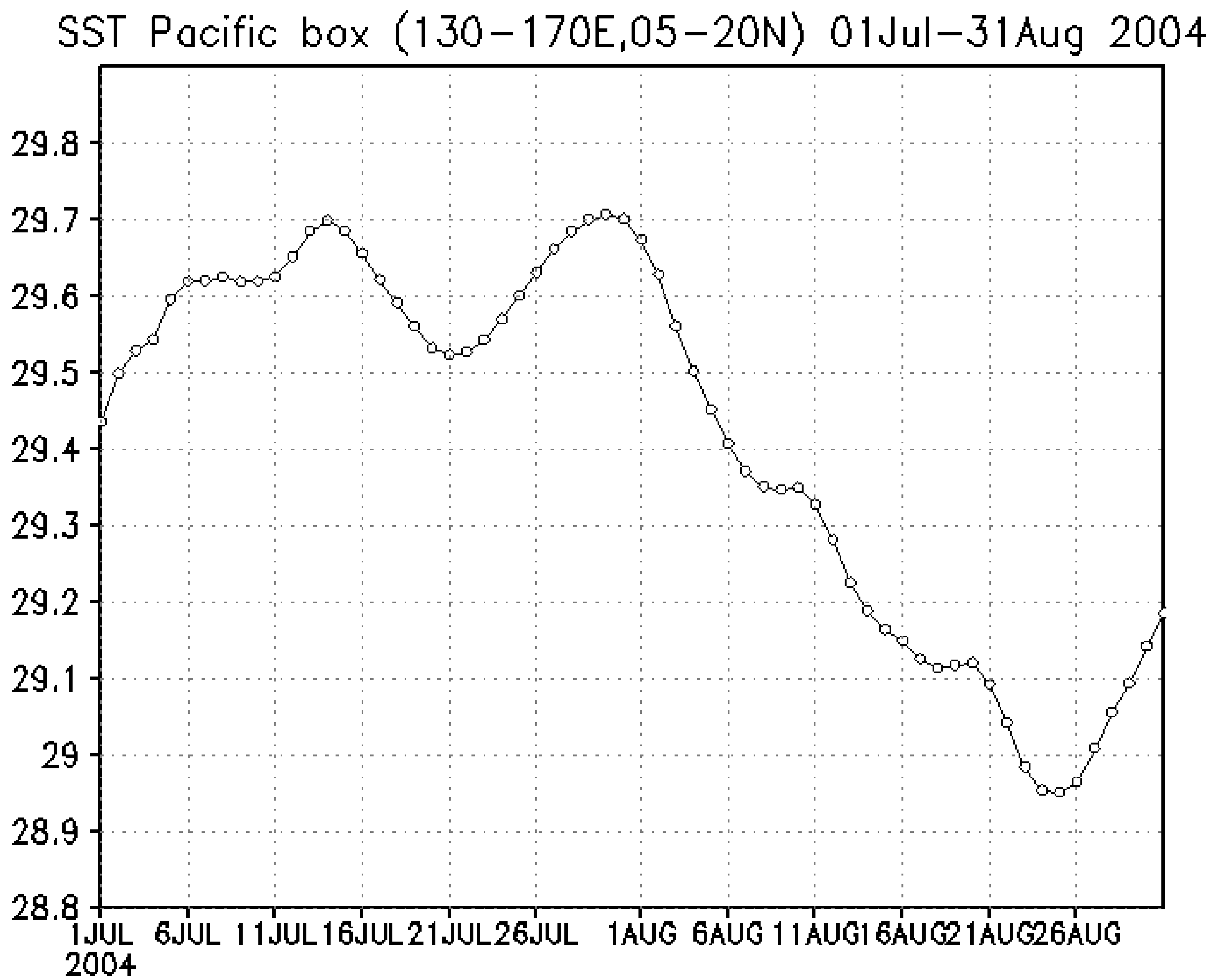


y = -10.6x+956.3
Corr = - 0.89
Monsoon rainfall JJAS (mm)
1050
1000
950
900
850
800
750
700
650
0
5
10
15
20
25
Break days in July & August (Rajeevans Method)



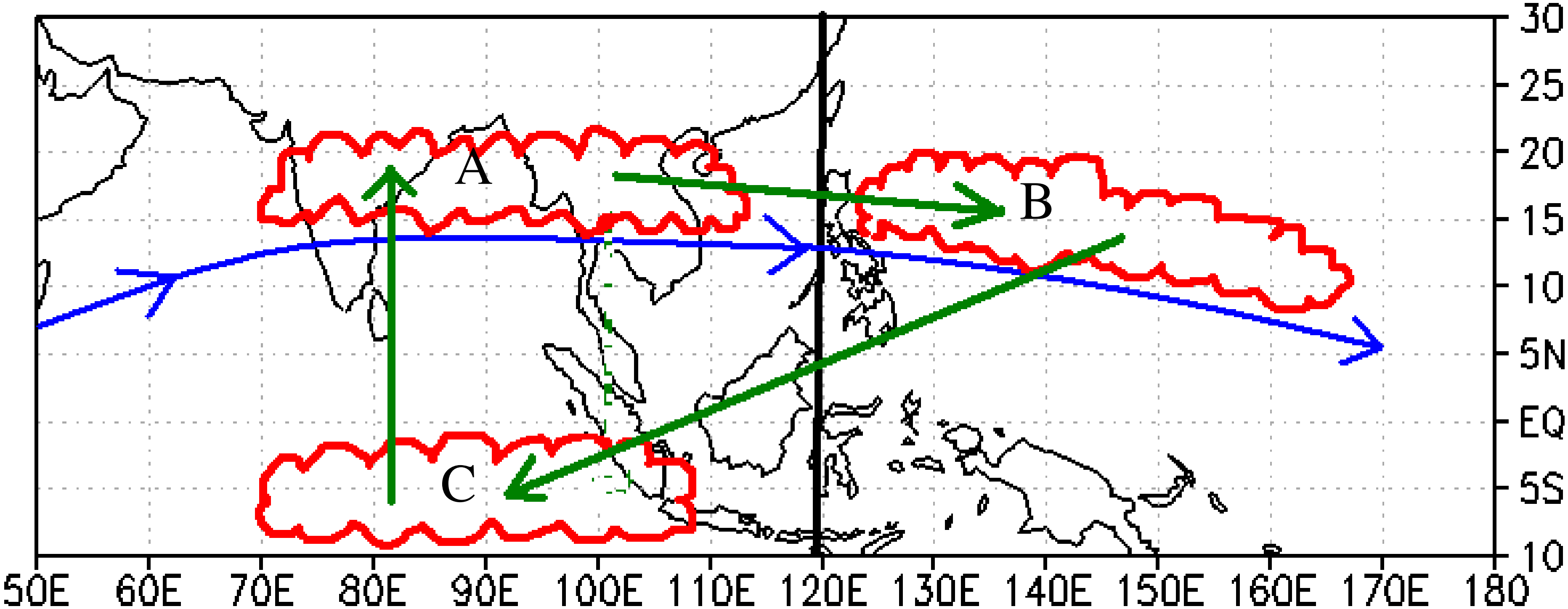
In El Ninos, monsoon westerlies (LLJ) extend upto the date line (as in the composite surface wind anomaly in 3 El Ninos shown in the figure above) and in the West Pacific Box, cyclonic wind stress curl makes the mixed layer shallow.


Daily mean SST north Bay box 01Jul-31Aug 2004
29.4
29.2
29
28.8
28.6
28.4
28.2
28
27.8
27.6
1JUL 2004
6JUL
11JUL
16JUL
21JUL
26JUL
1AUG
6AUG
11AUG
16AUG
21AUG
26AUG

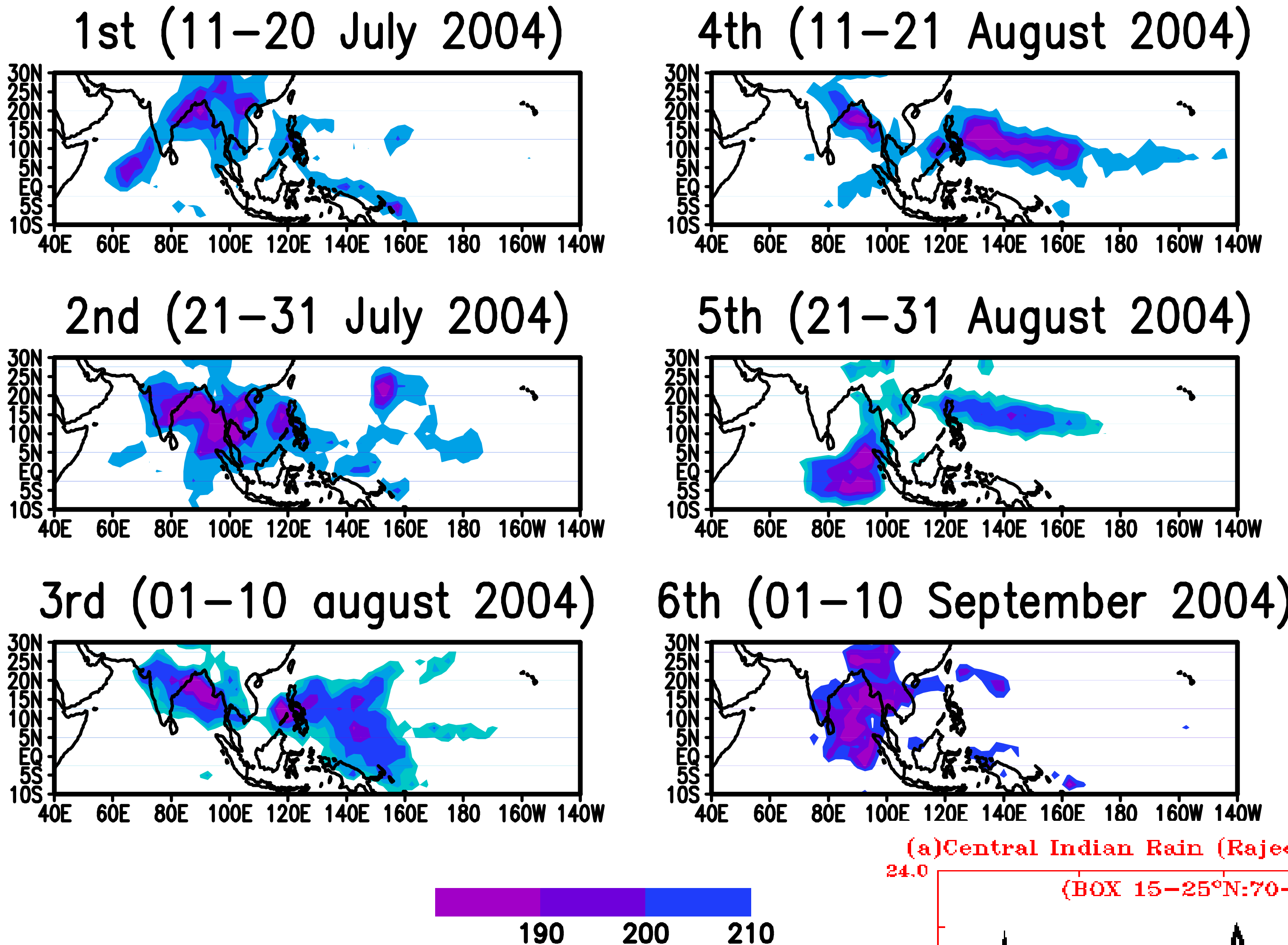


SST Pacific box (130-170E,05-20N) 01Jul-31Aug 2004
29.8
29.7
29.6
29.5
29.4
29.3
29.2
29.1
29
28.9
28.8
1JUL 2004
6JUL
11JUL
16JUL
21JUL
26JUL
1AUG
6AUG
11AUG
16AUG
21AUG
26AUG

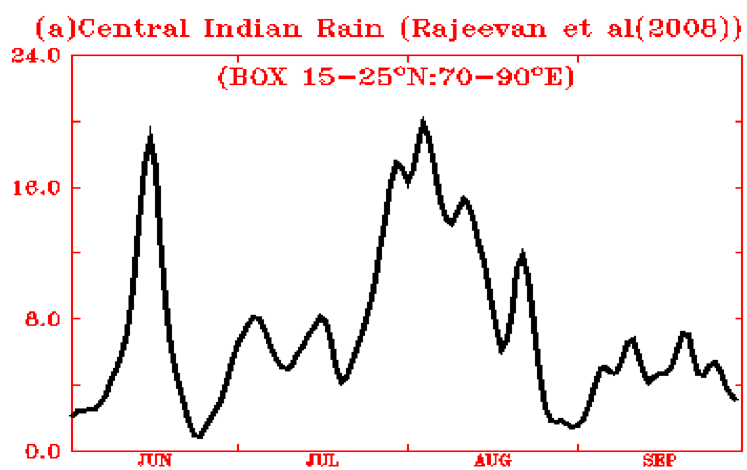
In El Nino: AB cycle of period about 2 months (Jul & Aug)

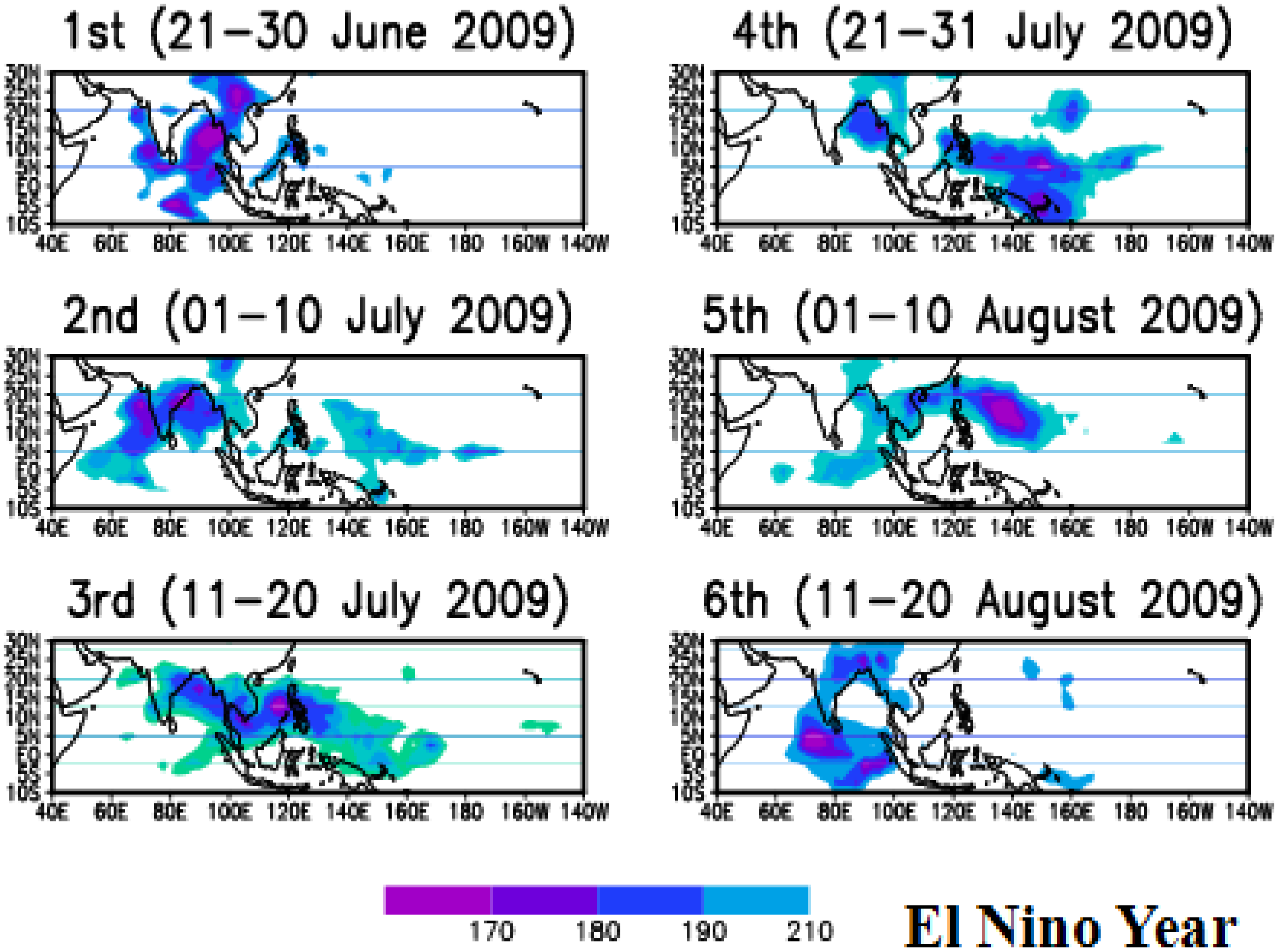


Hypothesis: In an El Nino situation, the west Pacific having a shallow ML, warms rapidly while there is active convection at A. When A cools, convection shifts to B. When area B cools, convection shifts to C resulting in a typical break monsoon. From C convection shifts to A. Thus the AB cycle lasts 2 months.

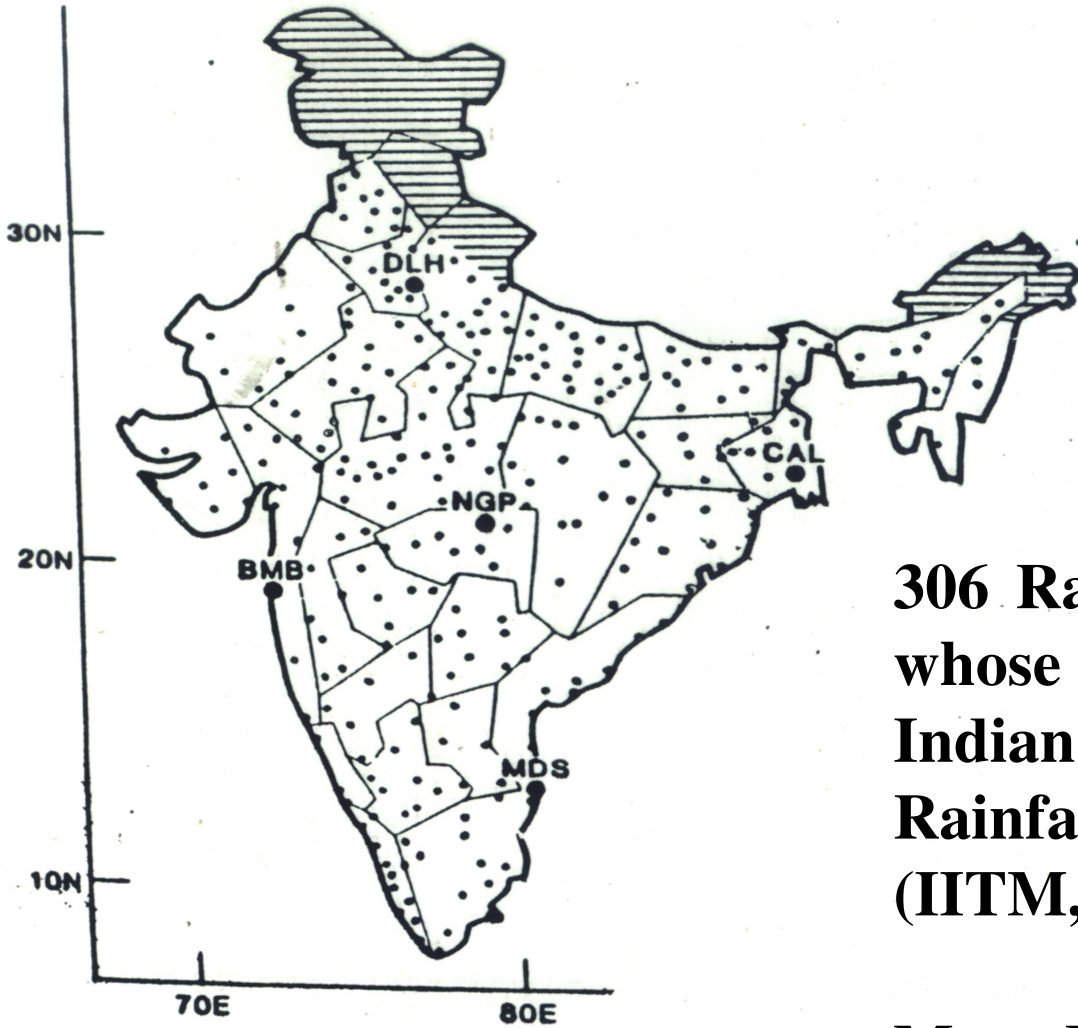

1st (11–20 July 2004)
2nd (21–31 July 2004)
3rd (01–10 august 2004)
4th (11–21 August 2004)
5th (21–31 August 2004)
6th (01–10 September 2004)
30N 25N 20N 15N 10N 5N EQ 5S 10S
40E 60E 80E 100E 120E 140E 160E 180 160W 140W
190 200 210

El Nino year


(a)Central Indian Rain (Rajeevan et al(2008))
(BOX 15–25°N:70–90°E)
24.0
16.0
8.0
0.0
JUN
JUL
AUG
SEP


1st (21-30 June 2009)
4th (21-31 July 2009)
2nd (01-10 July 2009)
5th (01-10 August 2009)
3rd (11-20 July 2009)
6th (11-20 August 2009)
30N 25N 20N 15N 10N 5N EQ 5S 10S
40E 60E 80E 100E 120E 140E 160E 180 160W 140W
170 180 190 210
El Nino Year

All India Monsoon Droughts

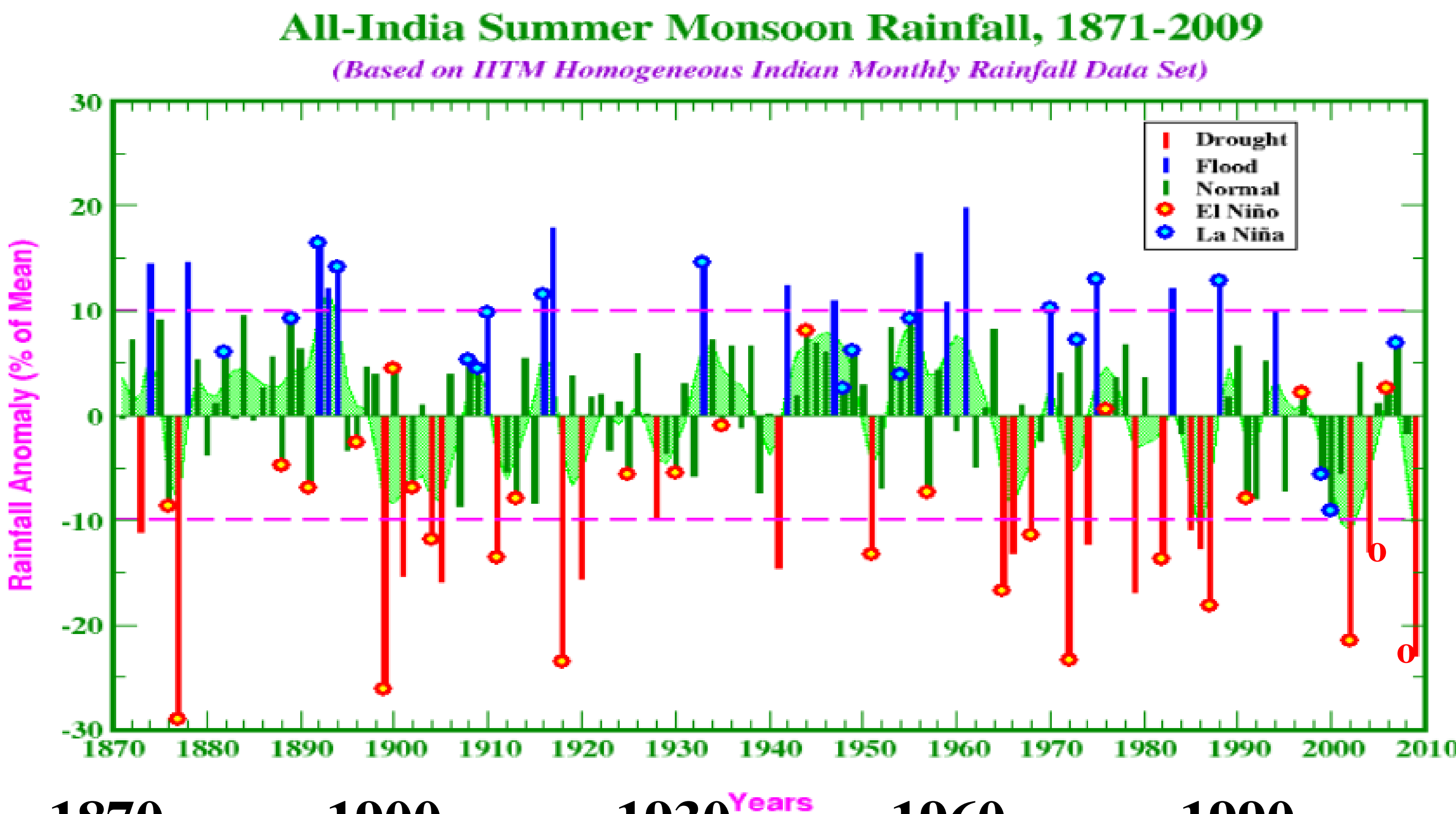


306 Rain Guage Stations whose data used for Indian Summer Monsoon Rainfall time series (IITM, Pune)

<u>1871-2003</u>

Mean ISMR = 84.4 cm

Std. Dev. = 8.3cm

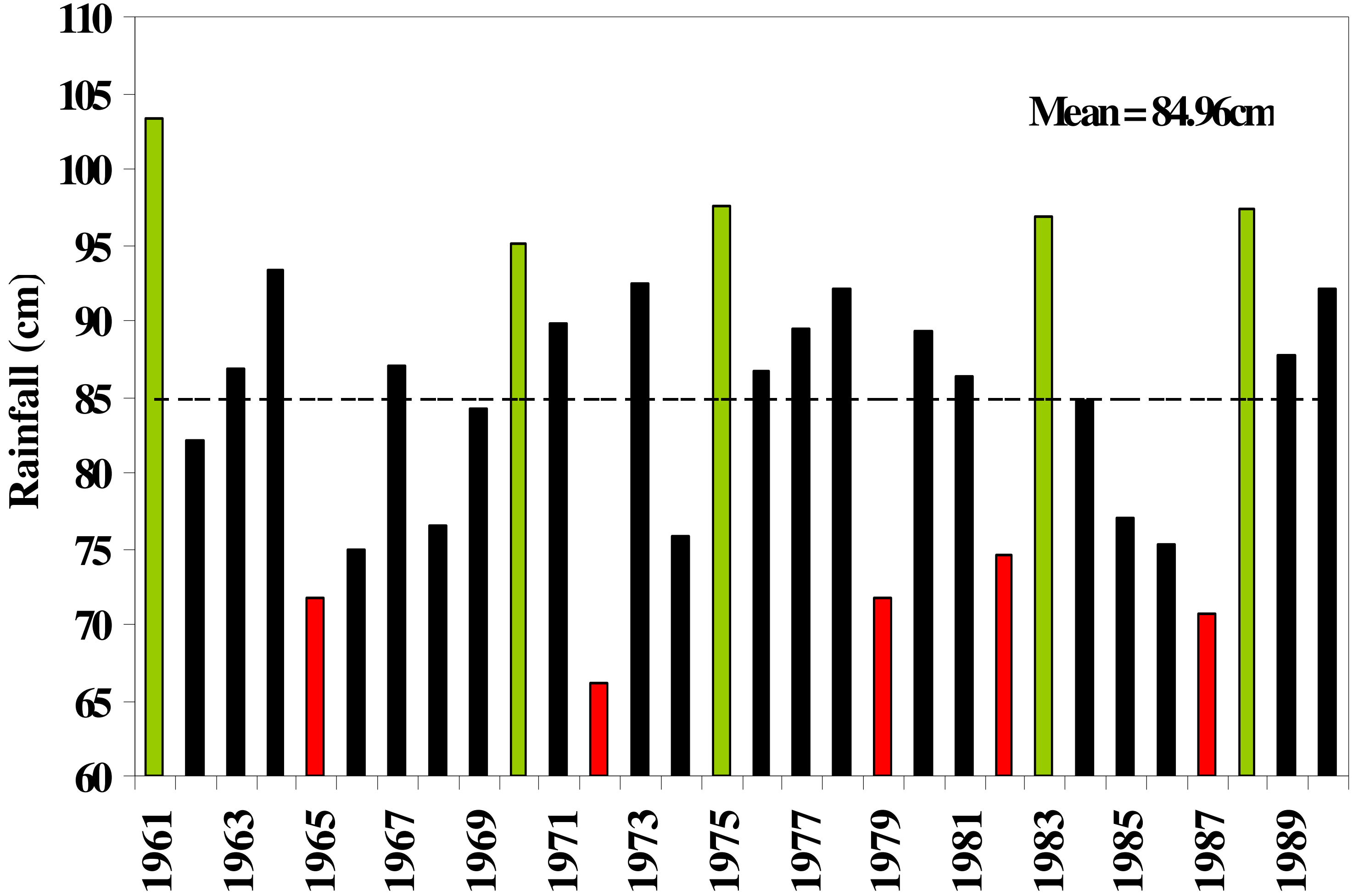


1870 1900 1930 1960 1990 2020

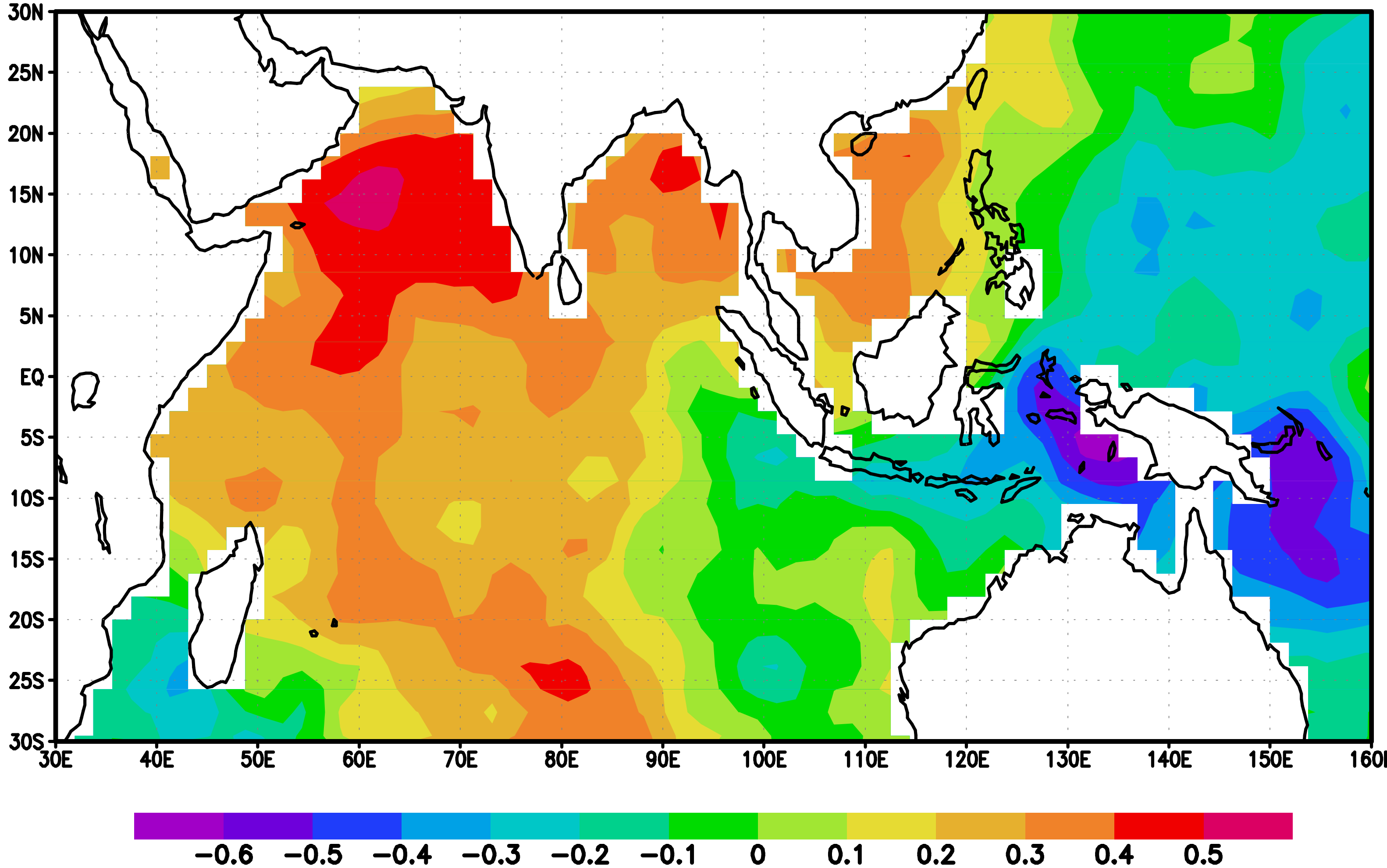
WET DRY WET DRY ?

ALTERNATE 30 YEAR EPOCHS OF DRY & WET TILL 1990.

Indian Monsoon Rainfall (JJAS) during 1961 to 1990
Severest 5 Excess (Deficient) Monsoons in Green (Red)

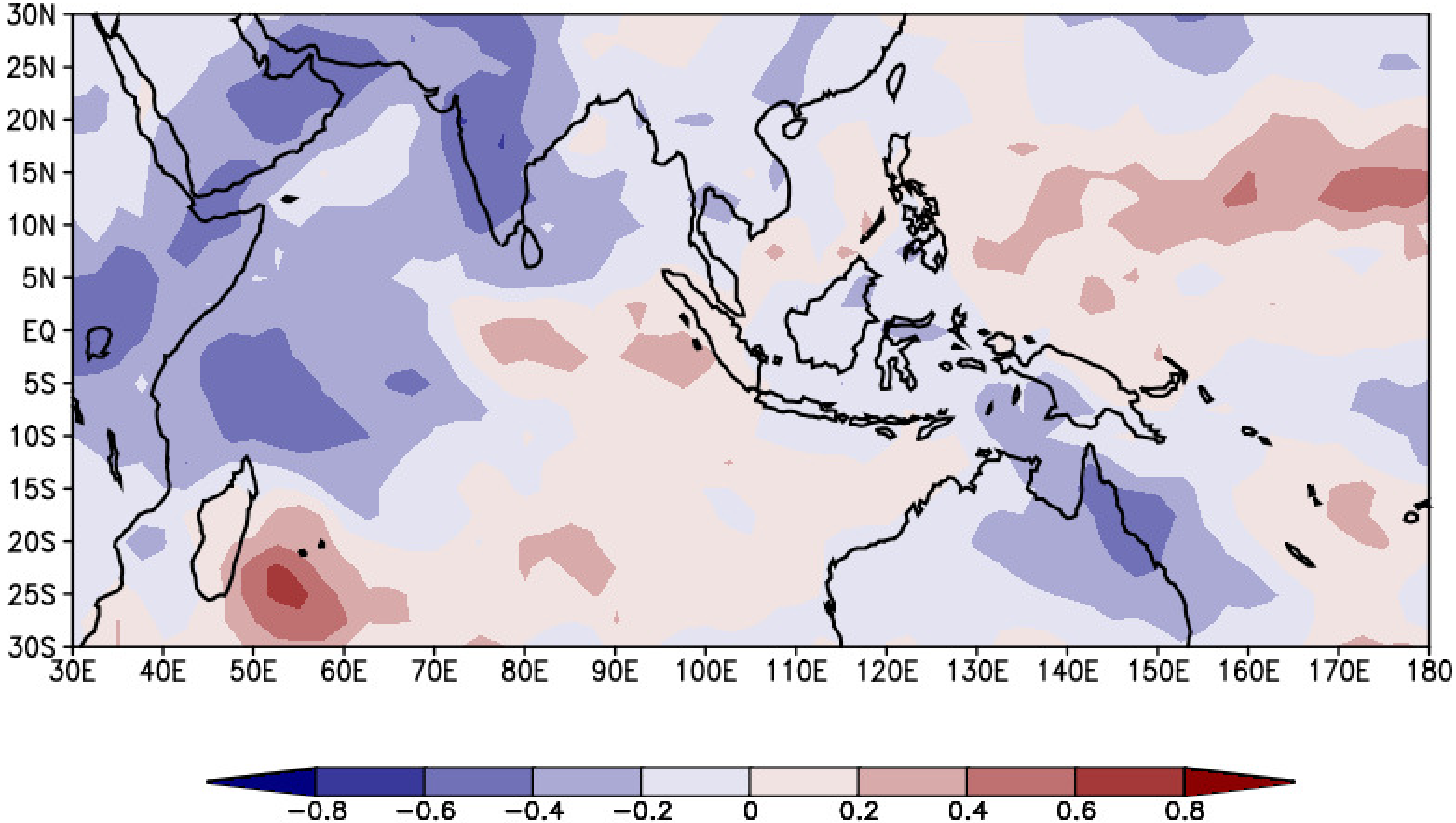


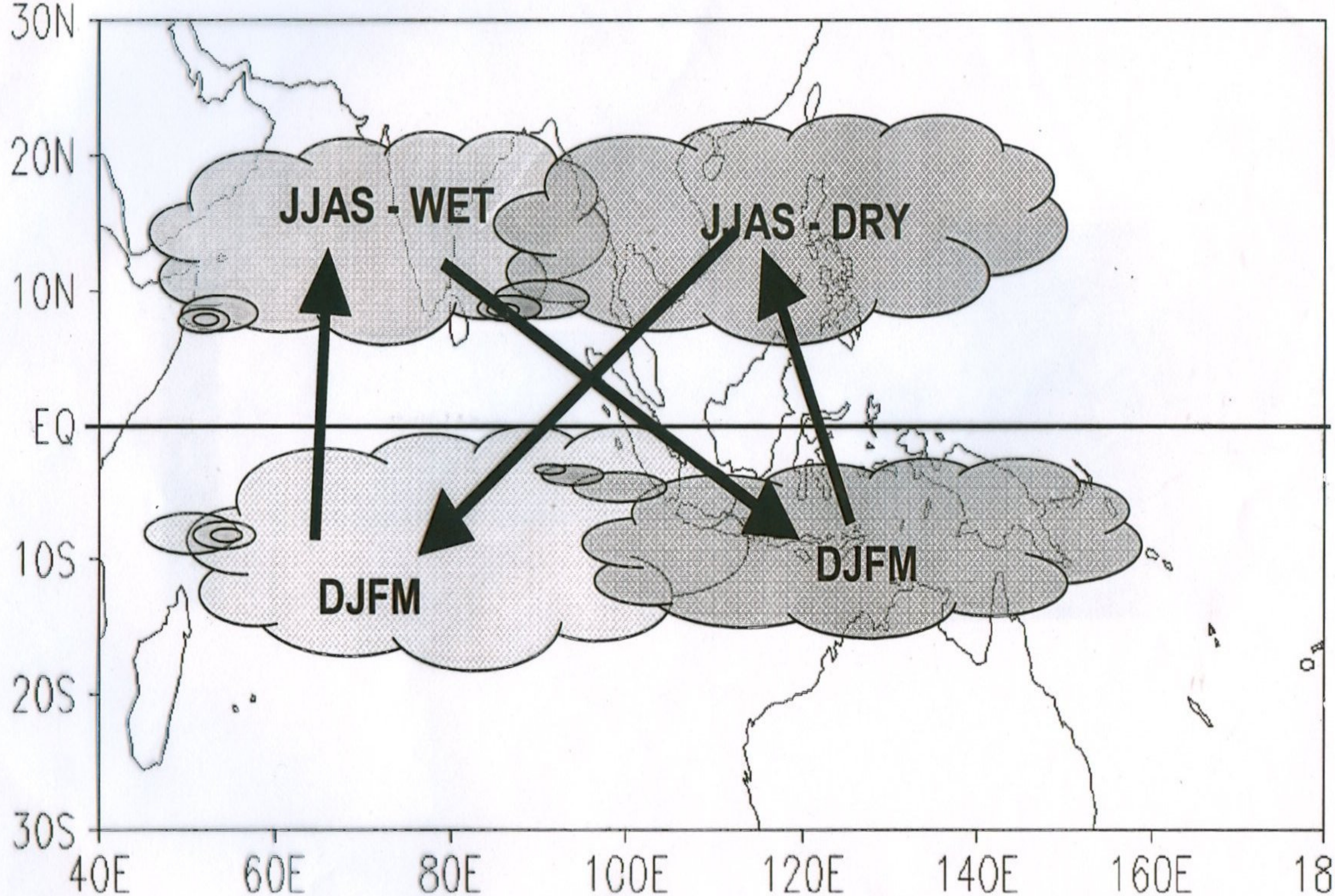
SST ANOMALY SEPT TO NOV AFTER DRY MONSOON



GrADS: COLA/IGES

Corr between ISMR and Jul-Aug OLR (1979 to 2009)





Interannual variability of convection - conceptual

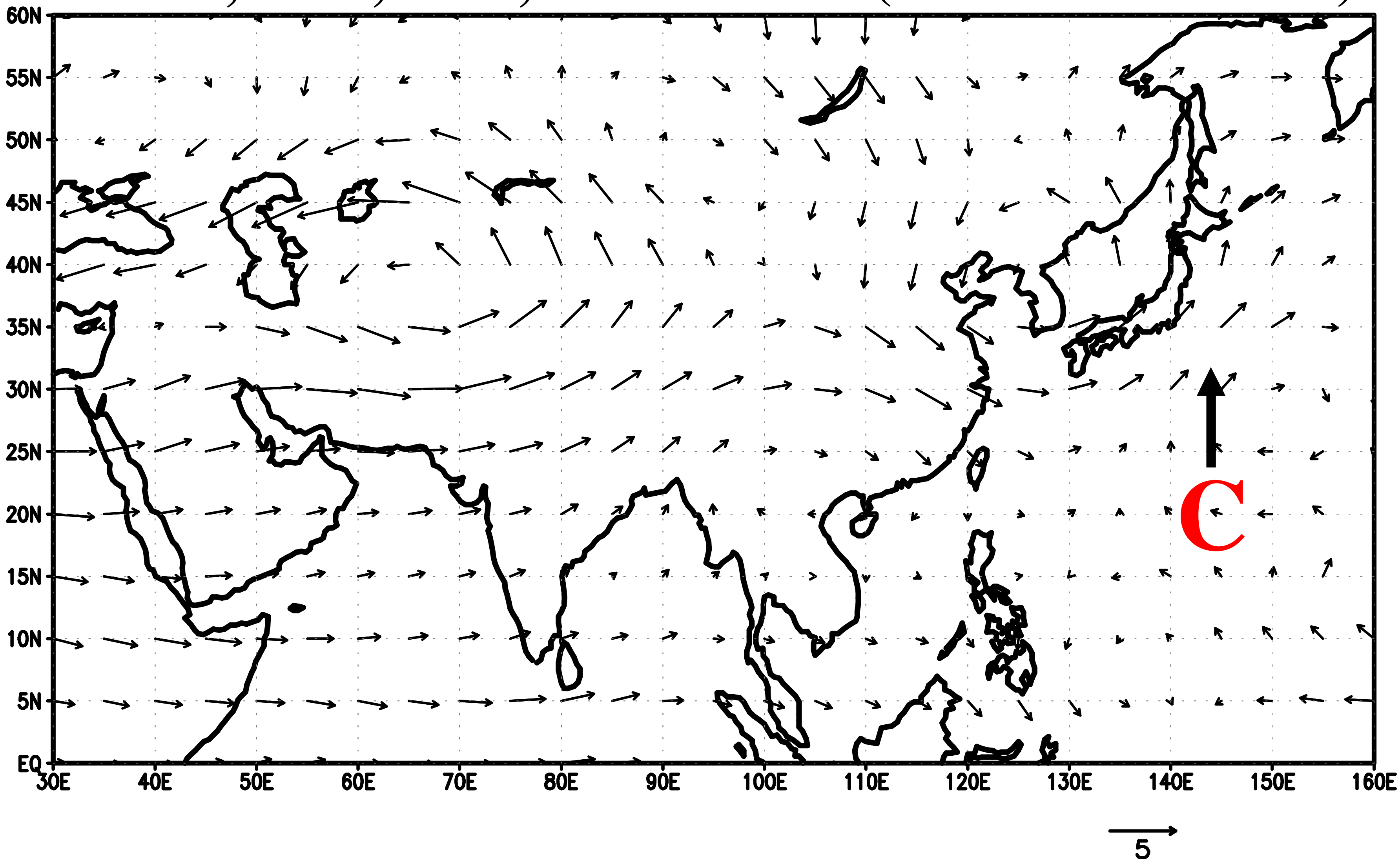
It is hypothesised that the Divergence area associated with the Convective Monsoon Heat Source induce a stationary Rossby Wave train (Asia Pacific Wave) in the westerlies (Sub-tropical Jetstream wave guide) – Wave number 6 or 7.

During DRY and WET Indian monsoon this wave (Asia Pacific Wave) has opposite spatial phase, possibly due to the east-west shift of the monsoon heat source –

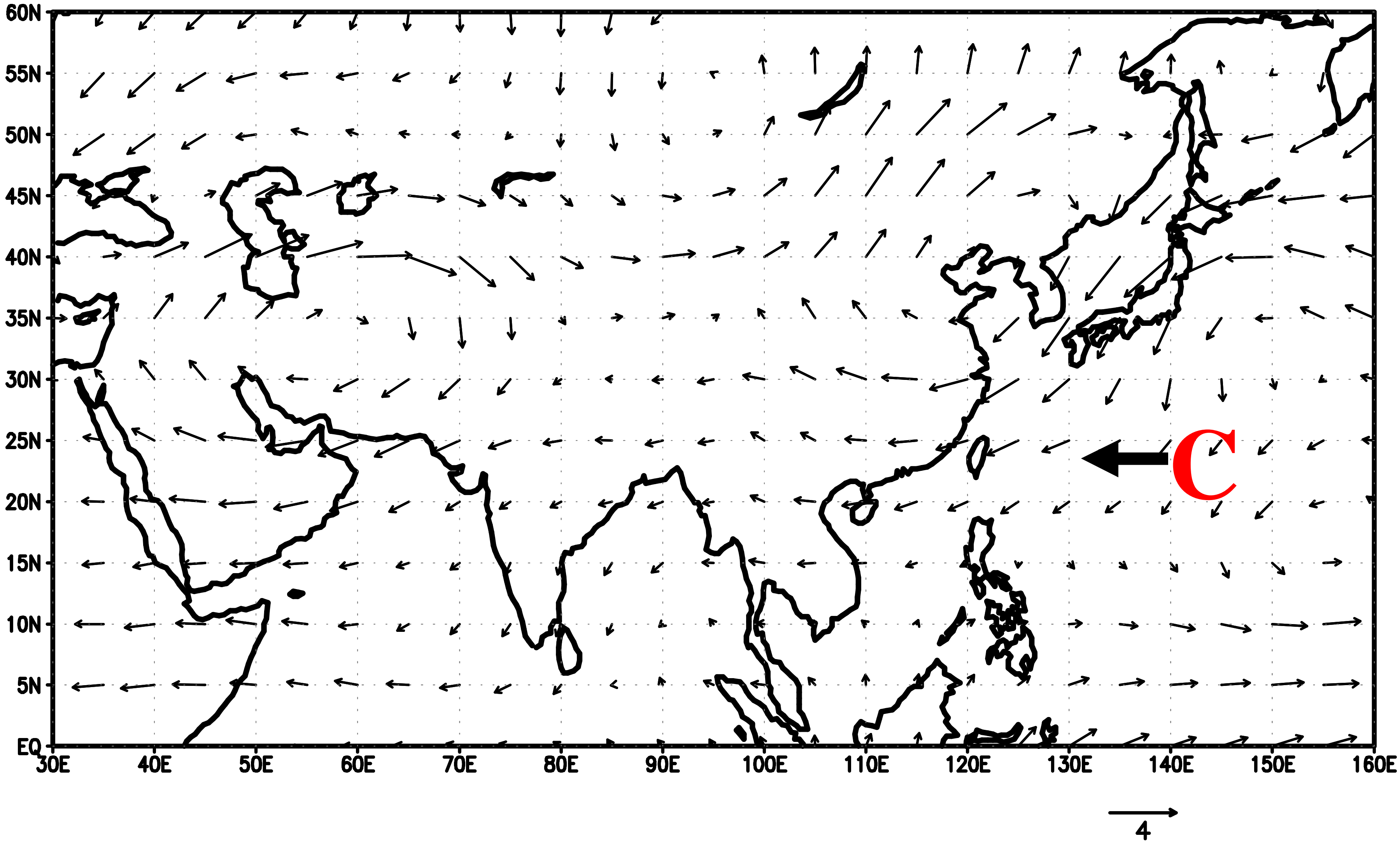
Joseph & Srinivasan(1999) TELLUS

Composite JJAS 200hPa wind anomaly of

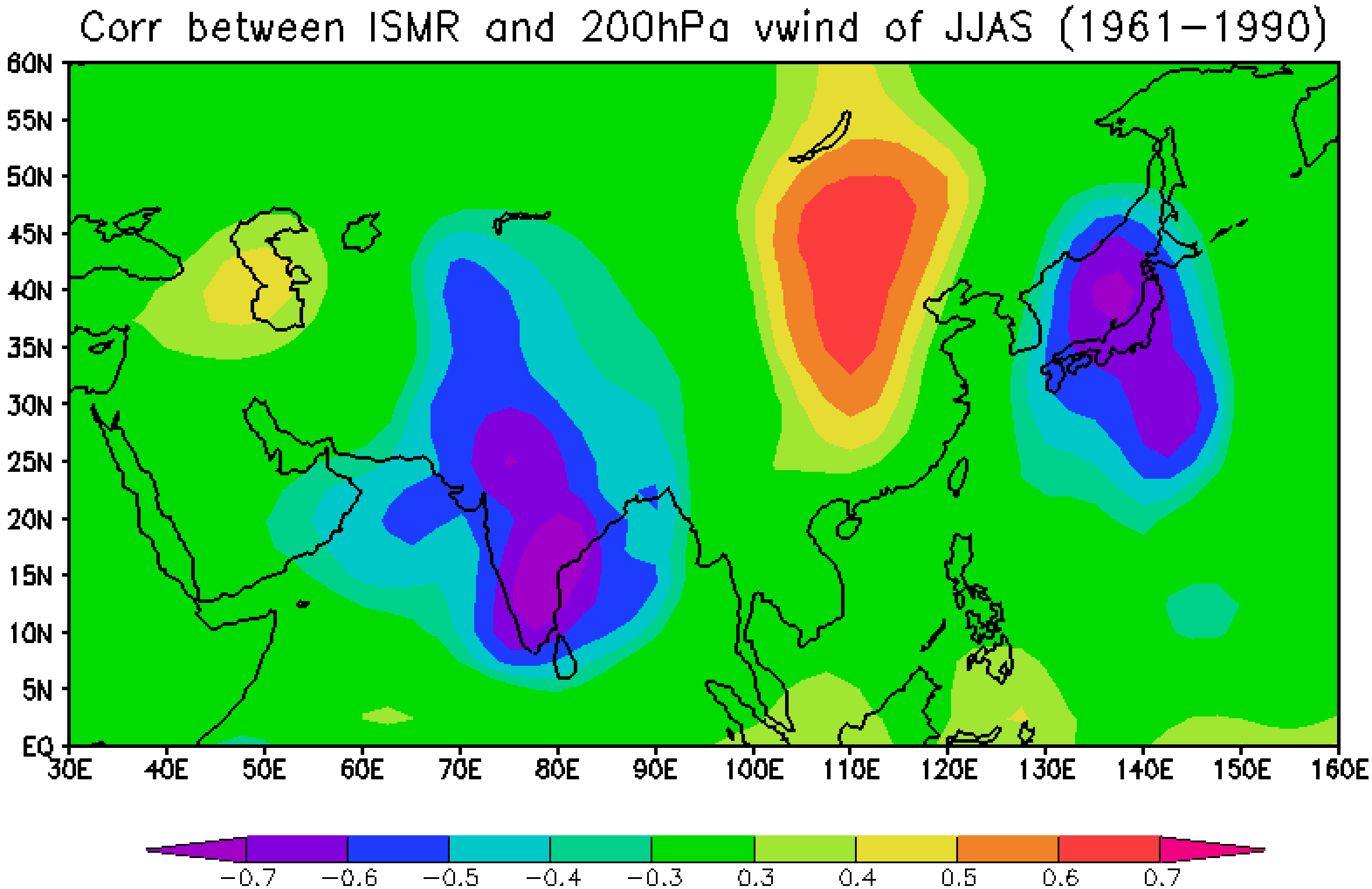
1965, 1972, 1979, 1982 & 1987 (5 DRY monsoons)



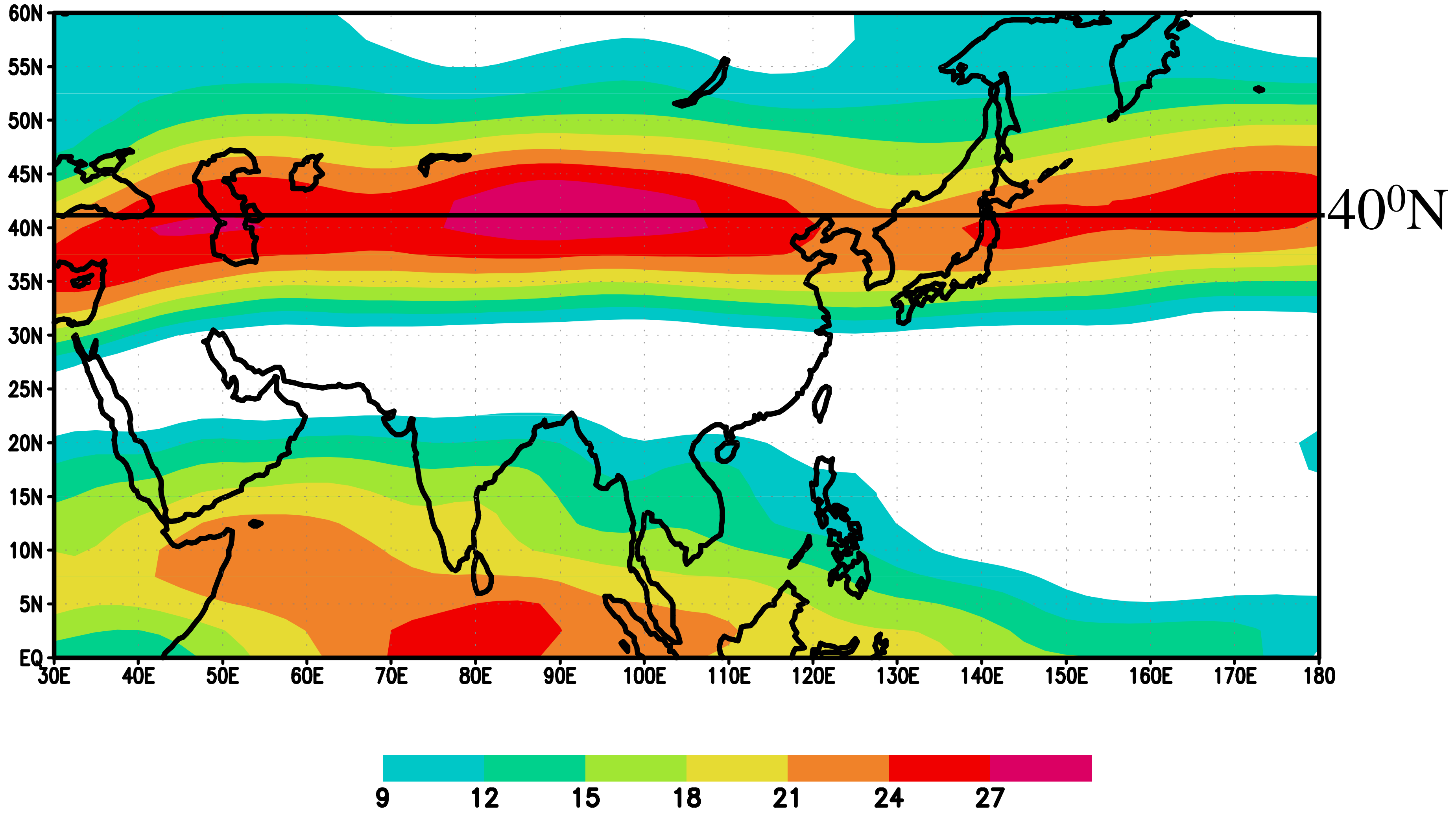
Composite JJAS 200hPa wind anomaly of 1961, 1970, 1975, 1983 & 1988 (5 WET monsoons)



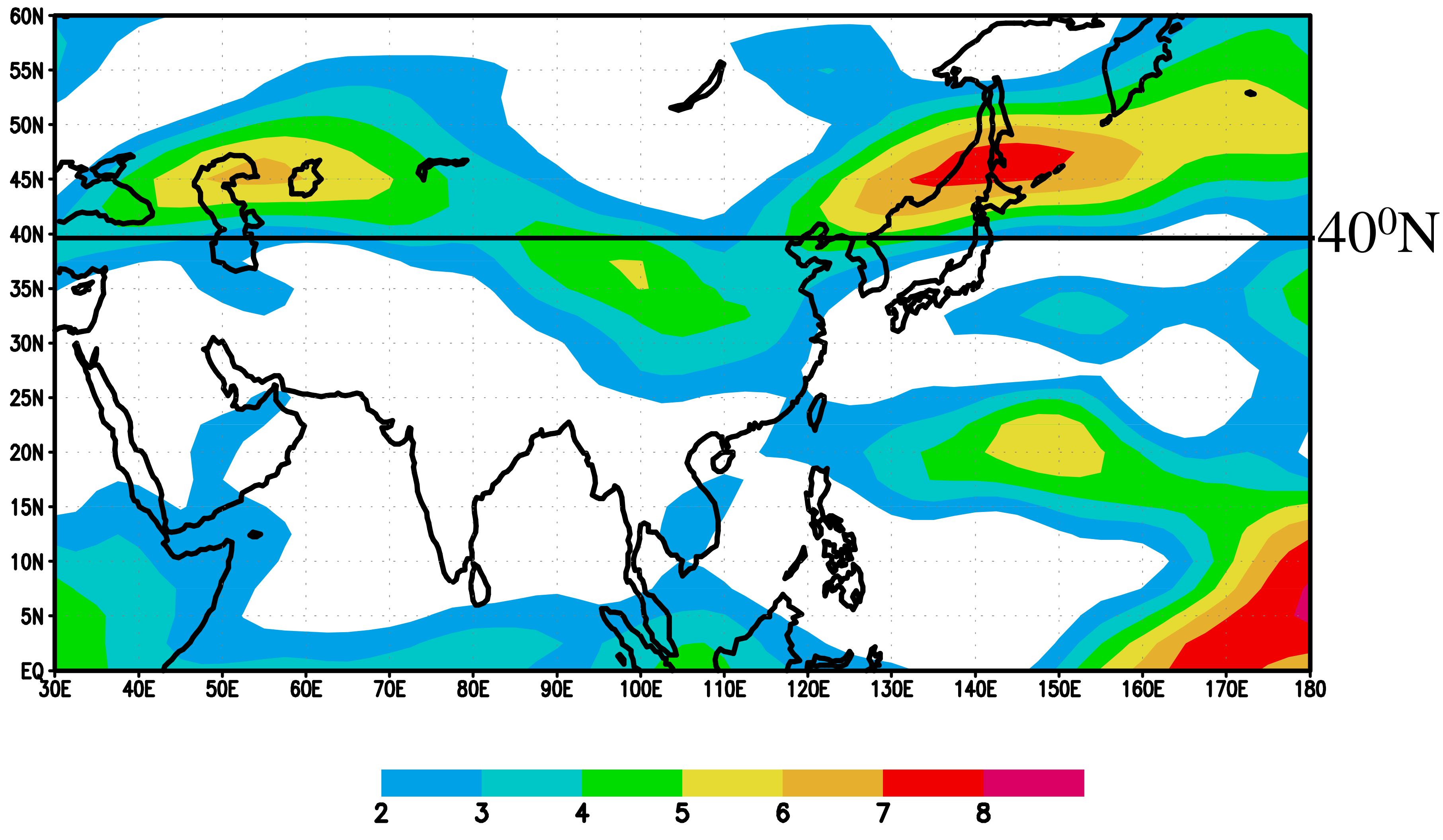
ASIA PACIFIC WAVE



June-Sept 200 hPa U wind– mean of 1950 to 1959
(Magnitude 9m/s and more at 3m/s intervals)



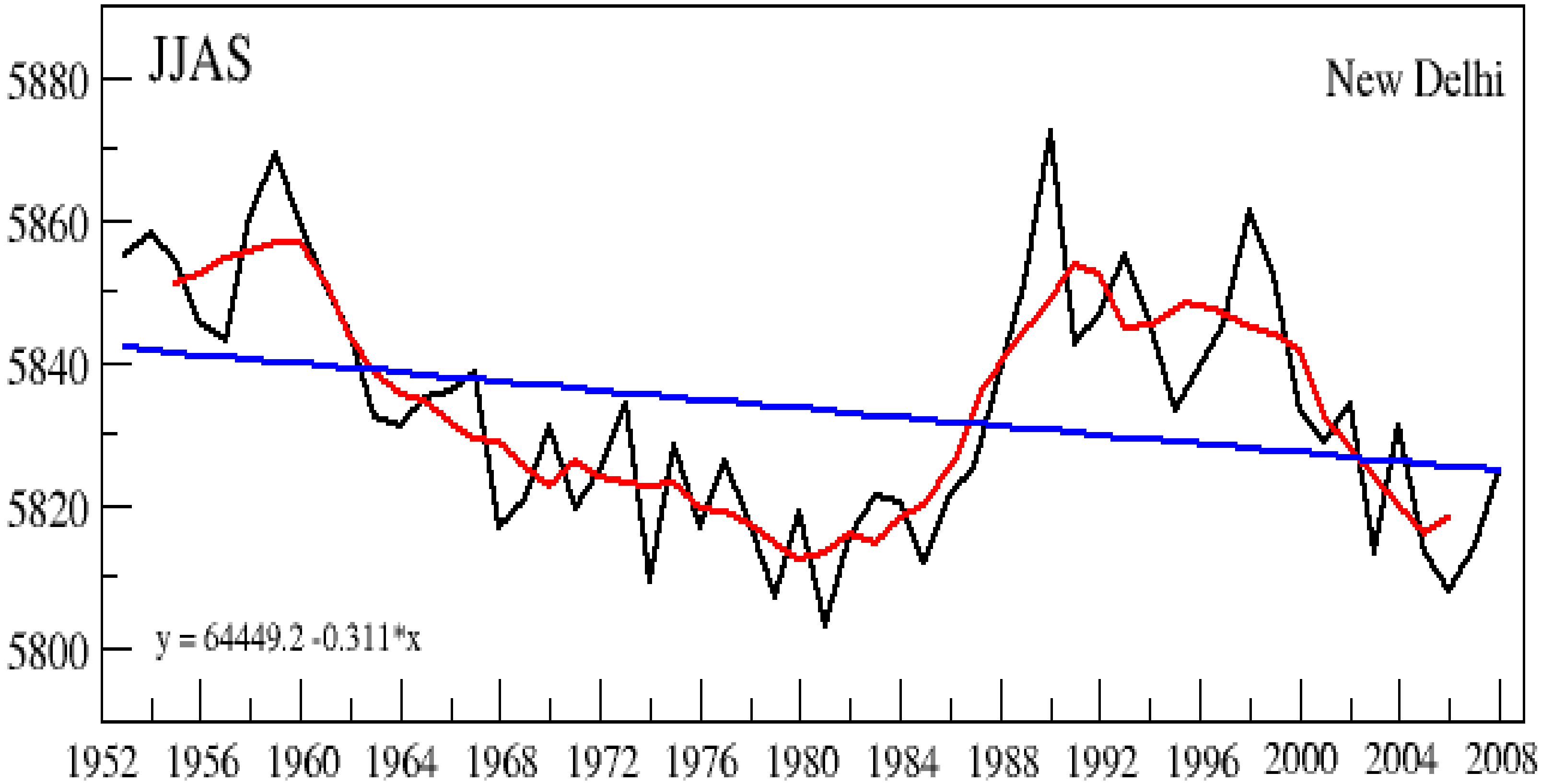
U-Wind 200 hPa (mag in m/s) decade 1970s minus 1950s
(2m/s and more at intervals of 1m/s)



It is hypothesised that in the DRY epochs when the mid latitude westerlies move southwards over Asia, the divergence area around the monsoon convective heat source acts on the westerlies and produce the Asia Pacific Wave which has one spatial phase in deficient monsoon years (trough over India) and another spatial phase in excess monsoon years (ridge over India)

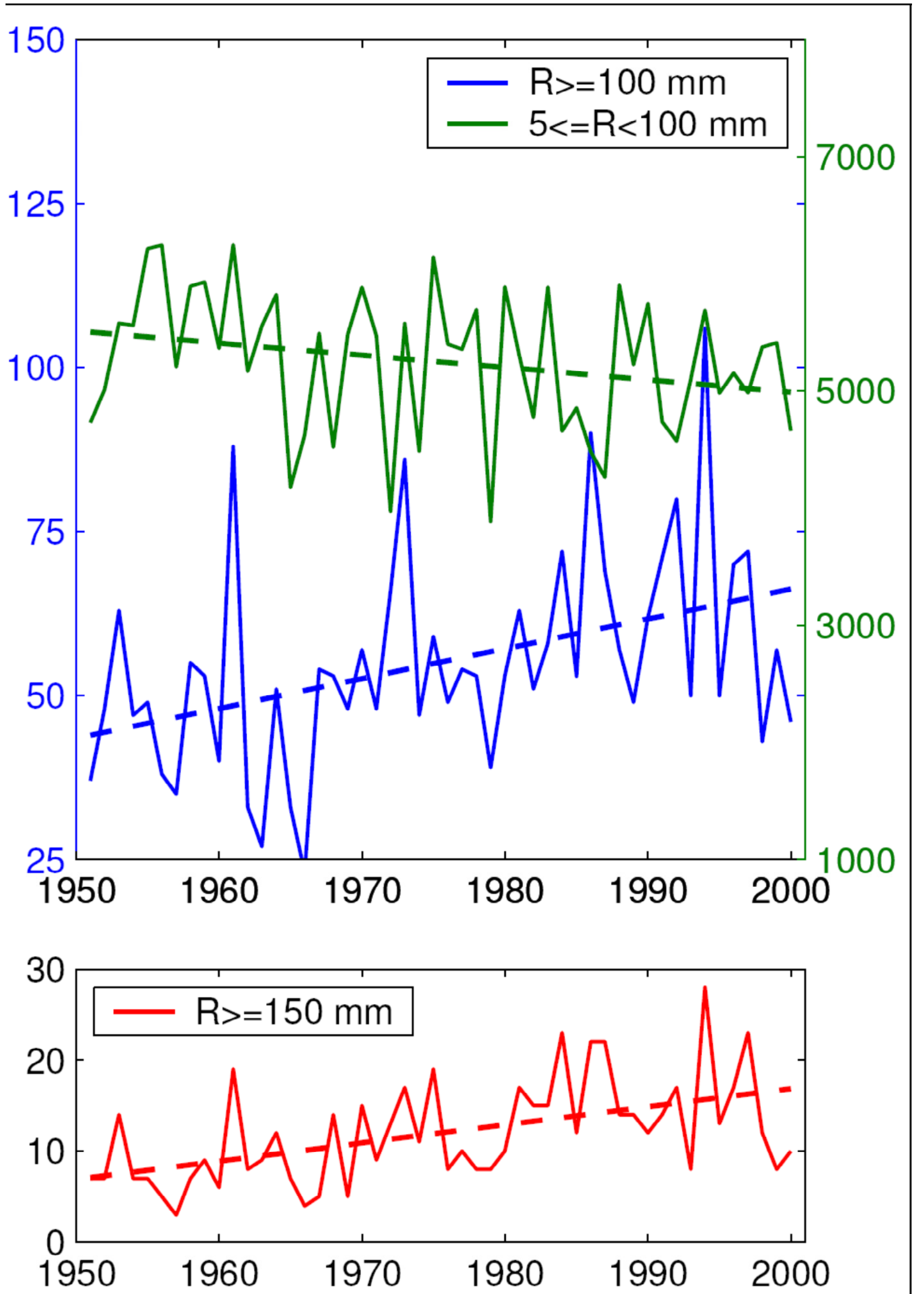
Joseph (1976) used the height of 500 hPa surface of stations over north and central India (Delhi, Jodhpur and Nagpur) to show westerly intrusions. Let us see the changes to 500 hPa surface at Delhi since 1950s

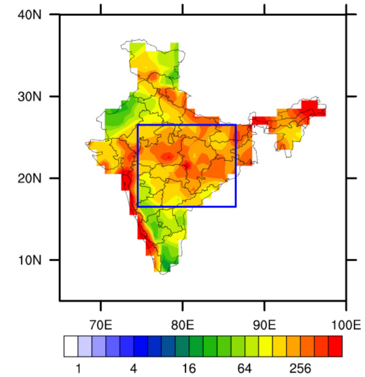
500 hPa Geopotential Height



500 hPa height has a decreasing trend suggesting that westerlies have a southward trend. It is feared that this will give India frequent monsoon drought years in the coming decades.

One day heavy rainfall occurrences
(in 100kmX100km areas)





Low & Moderate events

Heavy events (>10cm)

V. Heavy events (>15cm)

Source: Goswami et al., Science, Dec., 2006

24 hour Rainfall recorded at 0830IST on 02 July 1984

Colaba - 54cm

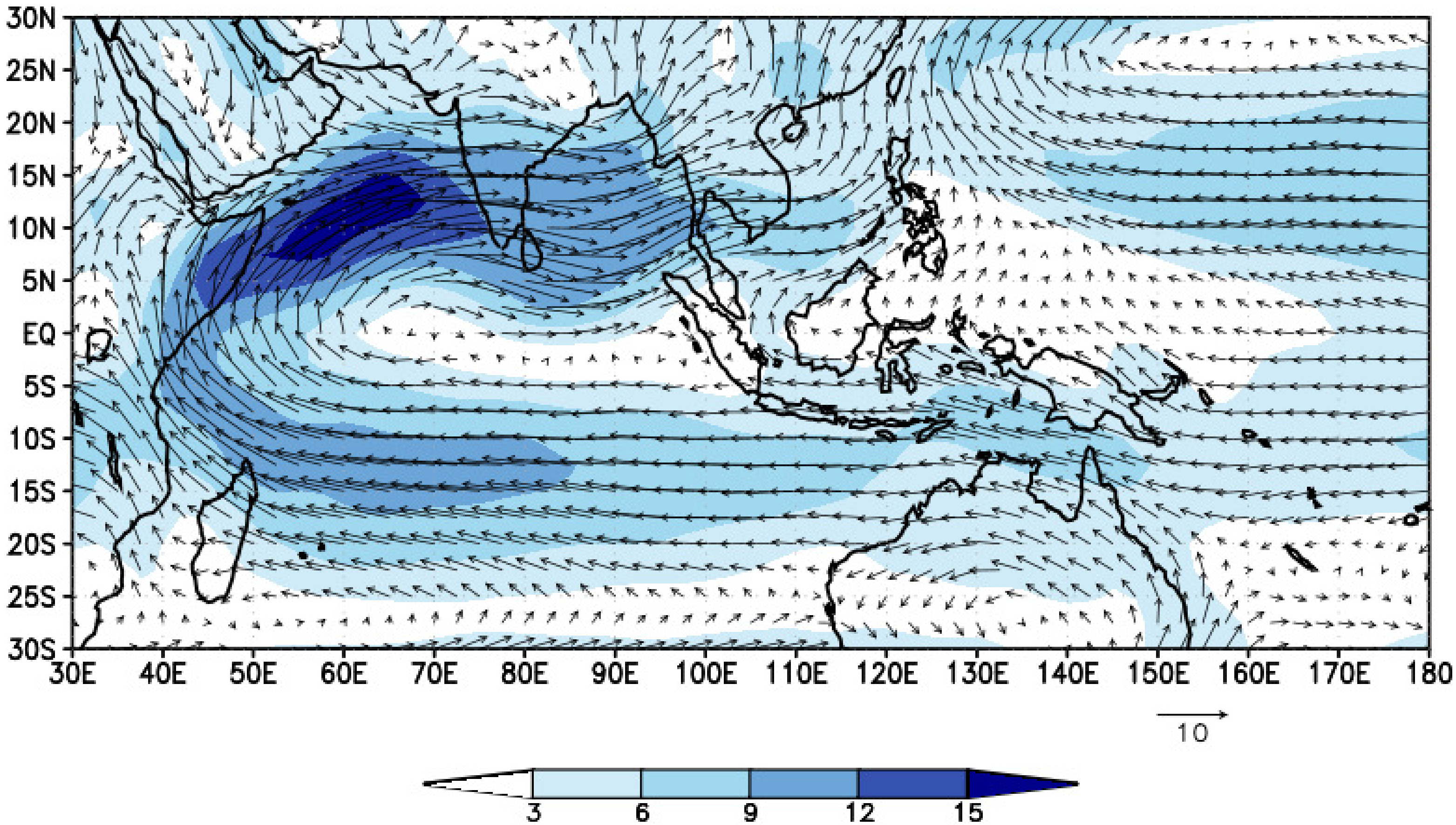
Santacruz - 24cm

24 hour Rainfall recorded at 0830IST on 27 July 2005

Colaba - 7cm

Santacruz - 94cm

Jul-Aug 850 hPa wind for the period 1951 to 2009



What are the environmental conditions that produce heavy rainfall?

(1) Large cyclonic vorticity in the atmospheric boundary layer. In monsoon it is provided by the Low Level Jetstream and synoptic systems like monsoon depressions. Also high vertical velocity available, say on hill slopes

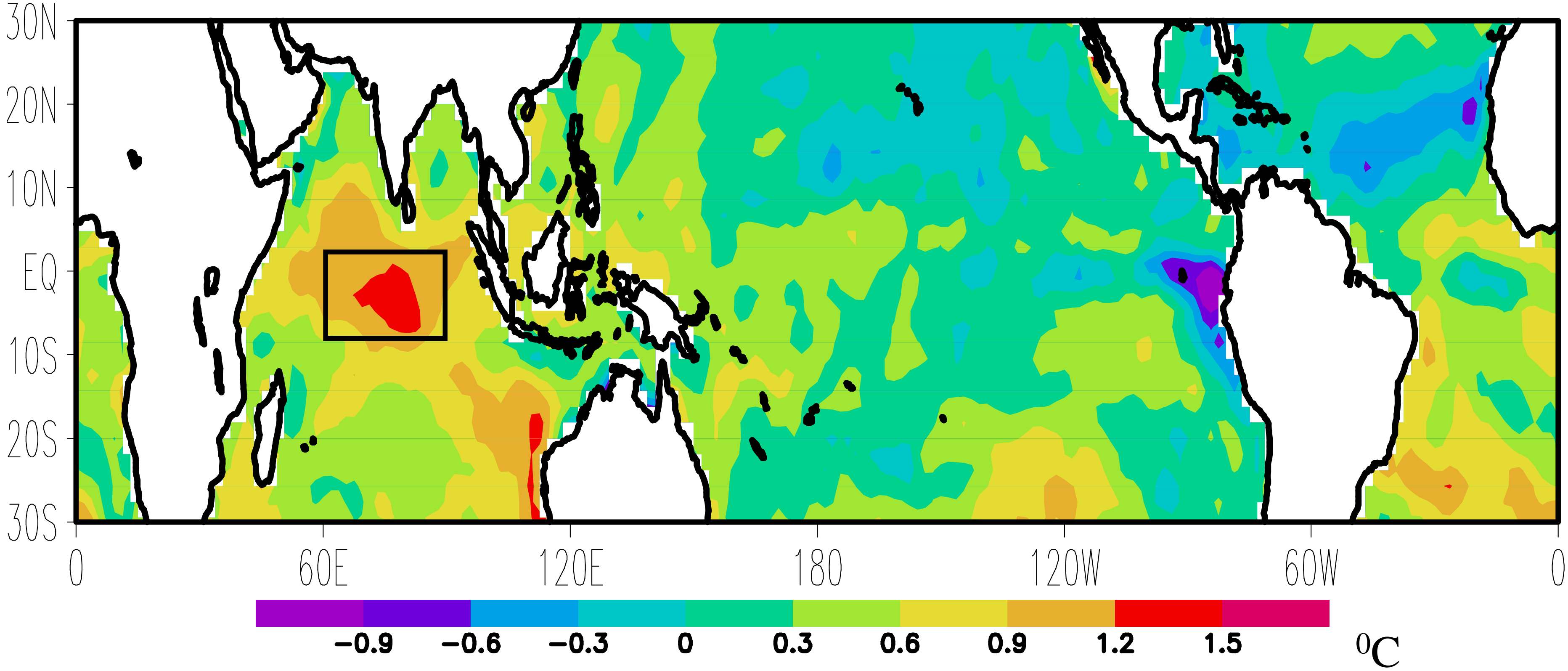
(2) High moisture content in the air. Increased moisture by global warming ?

(3) Large values of Convective Available Potential Energy (CAPE). Again global warming?

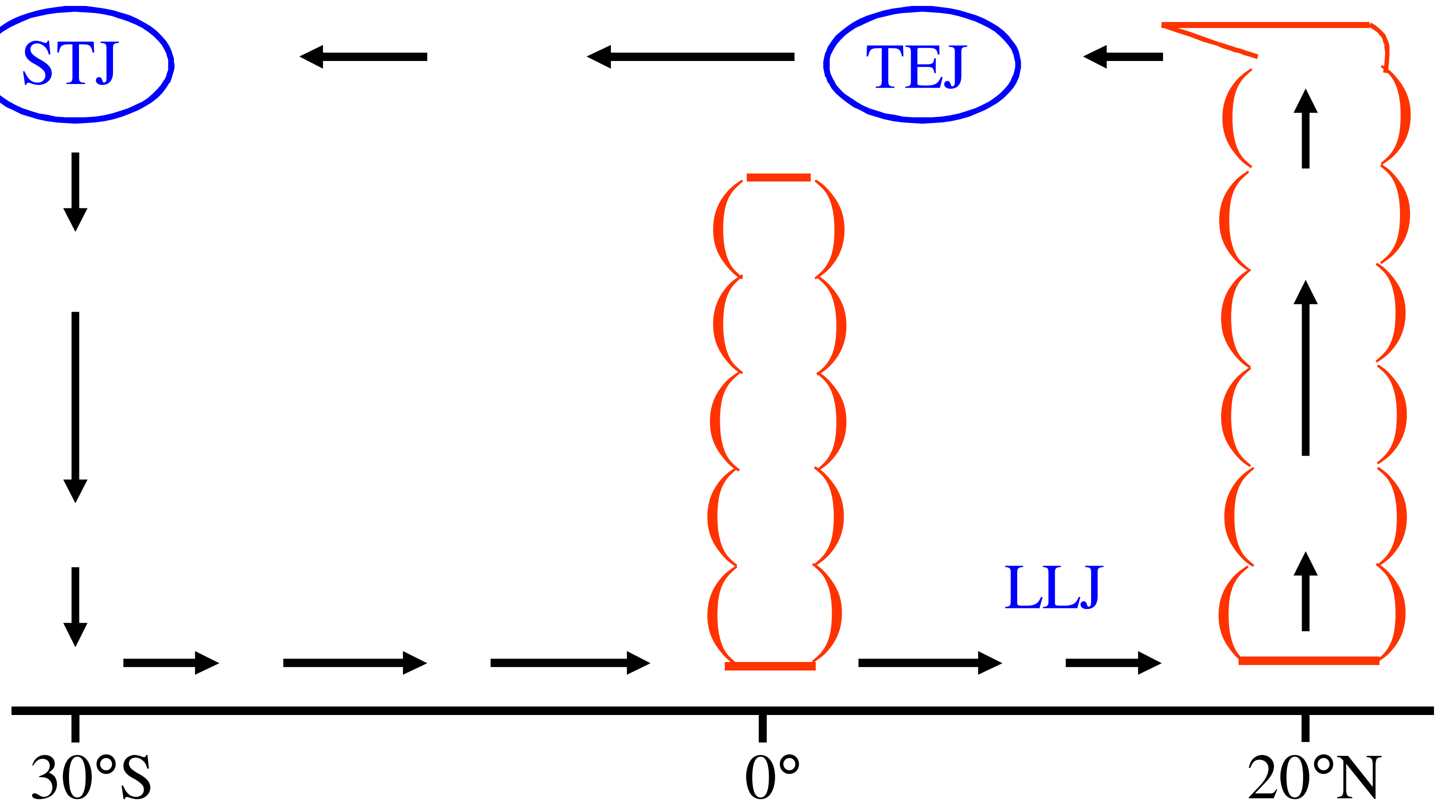
Rapid Warming of the Equatorial Indian Ocean.
&
Decrease in annual frequency of Monsoon Depressions

RAPID WARMING OF INDIAN OCEAN 1950 to 2003

(June-Sept SST 1999-2003 minus 1950-1954)



From Joseph and Sabin - Paper presented at WMO conference on Reanalysis at Tokyo, January 2008



Monsoon Hadley Cell with its Ascending limb at 20°N and descending limb at 30°S shown. With increasing SST near equator when equatorial convection strengthens, the Monsoon Hadley Cell gets weakened which weakens LLJ, TEJ and STJ.

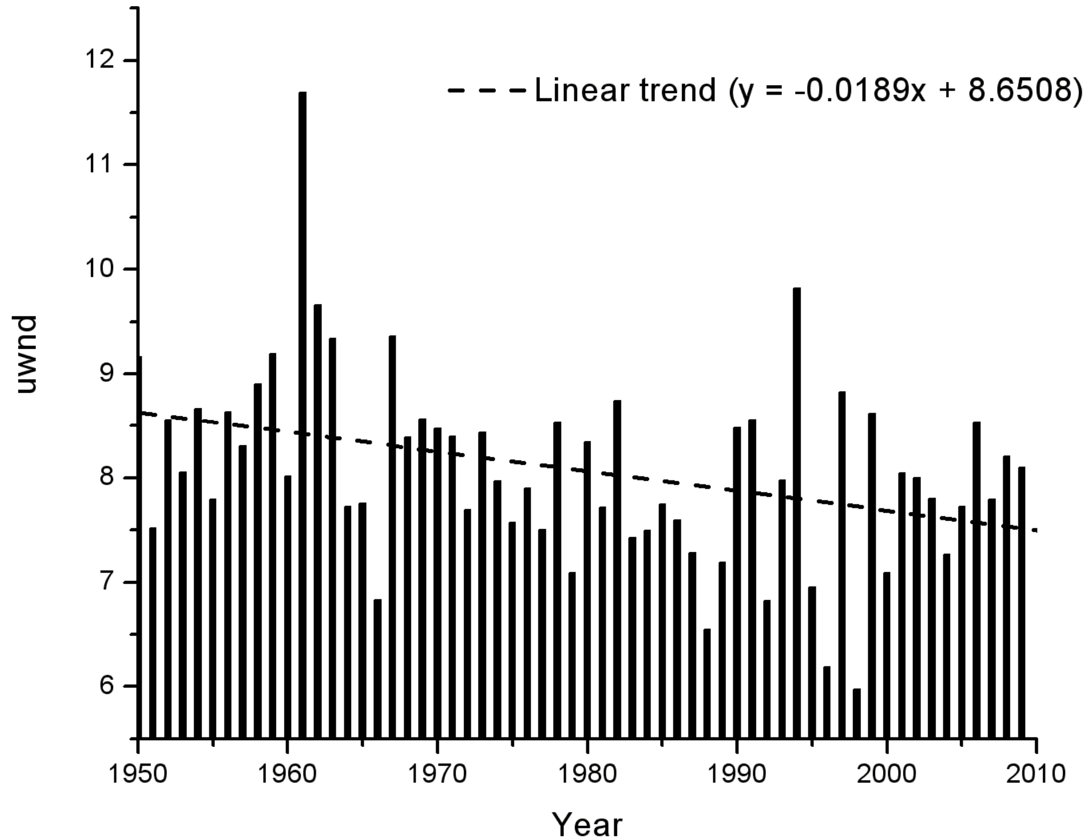
MONSOON HADLEY CELL

- During the months June to September, the upward limb of the monsoon Hadley Cell is at lat. 20N and the downward limb at 30S. When equatorial convection increases, the tropo-spheric temperature gradient between equator and 20N decreases, weakening the monsoon Hadley Circulation and Jetstreams.

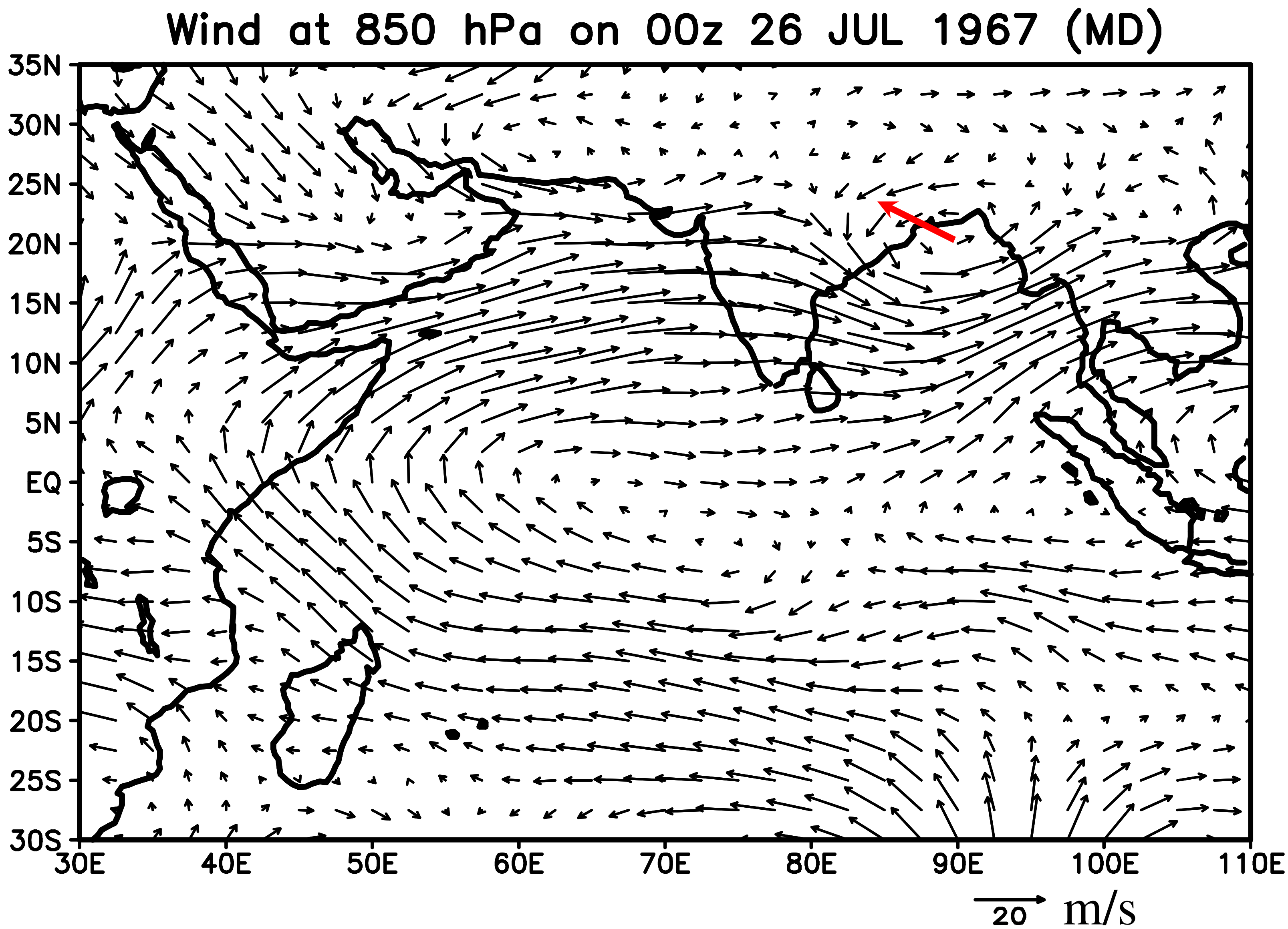
- The Low Level Jetstream (1.5Km), the Tropical Easterly Jetstream (14Km) and the southern Hemisphere Sub-Tropical Jetstream (12Km) are found to weaken since 1950 .

June to September 850 hPa wind through peninsular India and Bay of Bengal averaged over the box (75E to 90E, 10N to 20N) from 1950 to 2009

- **According to Sikka (1977) one of the synoptic conditions for the genesis of MD is strong LLJ through peninsular India and Bay of Bengal.**



A TYPICAL MONSOON DEPRESSION VORTEX

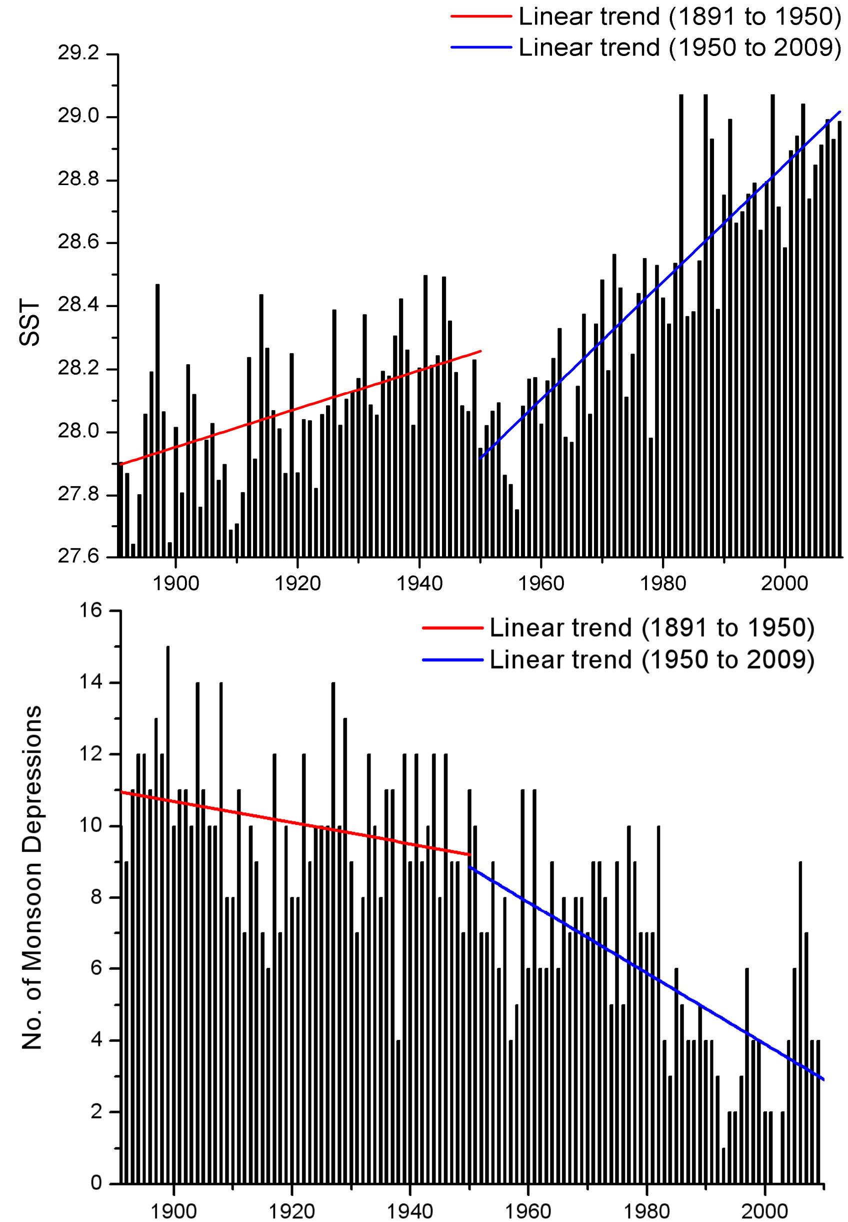


Rapid warming of Indian Ocean and the corresponding change in frequency of MD’s

- **We observe that the trend in equatorial SST has a rapid increase from 1950 to 2009.**

- **Corresponding trend in the frequency of MD has a rapid decreasing trend.**

In the earlier 60 years (1891 to 1950) these trends are weak



Conclusions

1. Monsoon Onset date has large inter-annual variability. One factor is global SST anomalies in El Nino years
2. Long Break Monsoon Spells & long AB cycles in El Nino years (main cause of monsoon droughts in El Nino years)
3. All India Monsoon Droughts are likely to be more frequent in coming decades due to southward trend of mid-latitude westerlies
4. One day Heavy Rainfall frequency in 100kmX100km areas(central India) on rise.
5. Decreasing Monsoon Depressions