

Another deficient monsoon 2004 - A comparison with drought year 2002 and possible causes

RAJENDRA KUMAR JENAMANI*, S. R. KALSI, H. R. HATWAR and S. K. SUBRAMANIAN

**Meteorological Office, IGI Airport, New Delhi – 110 037, India*

India Meteorological Department, New Delhi – 110 003, India

(Received 23 March 2005, Modified 09 November 2006)

e mail : rjenamani1@yahoo.co.in/rjenamani@hotmail.com

सार – भारतवर्ष में वर्ष 2004 की ग्रीष्म मानसून ऋतु के दौरान हुई कुल वर्षा सामान्य से 13 प्रतिशत कम थी। इसके पूर्व वर्ष 2002 में भारत को दूसरी विकट परिस्थिति का सामना करना पड़ा जब बड़े पैमाने पर सूखा पड़ा था और संपूर्ण भारत में वर्षा सामान्य से 19 प्रतिशत कम हुई थी। इस शोध पत्र में हमने दोनों ही मानसून ऋतुओं के प्रेक्षणों की महत्वपूर्ण विशेषताओं की संक्षेप में तुलना भिन्न विशेषताओं का पता लगाने के लिए की है। इन तुलनाओं से अनेक समान तथा विरोधी विशेषताओं का पता चलता है। यद्यपि दोनों ही मानसून ऋतुओं में वर्षा की कमी थी, केरल में मानसून की वर्षा आरंभ होने की तिथियाँ या तो सामान्य तिथि से पहले या उसके नजदीक थीं। मानसून वर्षा का मध्य भारत तक बढ़ना भी दोनों ही मानसून ऋतुओं में सामान्य था। जबकि जून के दौरान भारतीय ग्रीष्मकालीन मानसून वर्षा (आई. एस. एम. आर.) अच्छी थी। दोनों ही वर्षों में जुलाई में मानसून के आगे बढ़ने की अवधि के दौरान कुछ लम्बे अंतराल संपूर्ण भारत में मानसून के सक्रिय होने में अप्रत्याशित विलंब के कारण बने। यद्यपि दोनों ही मानसून ऋतुओं में जुलाई माह में बहुत ही कम वर्षा हुई थी लेकिन वर्ष 2002 की भारतीय ग्रीष्मकालीन मानसून वर्षा अब तक के पुराने रिकार्डों की न्यूनतम थी। वर्ष 2002 में एक भी अवदाब नहीं बना जबकि वर्ष 2004 में उनकी आवृत्ति सामान्य के आधे से कम थी। हिन्द महासागर और प्रशांत महासागर क्षेत्र की समुद्री तथा वायुमंडलीय दशाओं की मासिक अनियमितताओं की अन्य स्थितियों का एलनिनों की स्थितियों सहित विस्तृत विश्लेषण करने से पता चलता है कि इनसो (इ. एन. एस. ओ.) तथा भूमध्य रेखीय हिन्द महासागर दोलन अथवा इक्व्यू के कारण जुलाई 2002 में सूखा पड़ा था परन्तु जुलाई 2004 के सूखे का कारण यह नहीं था। इसका कारण जुलाई 2002 की अब तक की पुराने रिकार्डों की न्यूनतम भारतीय ग्रीष्मकालीन मानसून वर्षा (आई. एस. एम. आर.) की स्थितियों सहित उत्तरी पश्चिमी प्रशांत महासागर क्षेत्र में बहुत ही तीव्र गति के टाइफून का बनना तथा उसका सामान्य संवहन से अधिक तीव्र गति से दुबारा मुड़ना है, वर्ष 2004 में जुलाई में भारतीय ग्रीष्मकालीन वर्षा कम होने का कारण विरोधी परिस्थितियाँ थीं जिसका संबंध कुछ टाइफून बनने तथा कम संवहन से था। वर्ष 2002 में भी भारतीय क्षेत्र एकदम वाकर परिसंचरण के अवतलन क्षेत्र के अंतर्गत आ गया था जिसका यह विस्तार पश्चिमी प्रशांत महासागर क्षेत्र के इसी ऋतु के वर्ष 2004 के विस्तार के विपरीत था। उस समय किए गए अध्ययन से पता चला था कि उस अवतलन का विस्तार पश्चिमी प्रशांत महासागर के विस्तृत क्षेत्र तथा उससे लगे भारतीय क्षेत्र दोनों में ही था।

ABSTRACT. The rainfall over India as a whole during the summer monsoon season of 2004 was deficient with -13% below normal. Earlier in 2002, India has faced another worst situation when large-scale drought occurred and all India rainfall was below -19%. In the present study, we have compared briefly salient observational features of both the monsoons to find out their distinct characteristics. Comparisons show appearance of many similar as well as contrasting features. Though, both seasons were deficient, their dates of onset of monsoon over Kerala were either before or near the normal date. Progress up to central India was also normal in both the seasons. While Indian Summer Monsoon Rainfall (ISMR) during June was good, a few longest stagnation periods during advancing stage in July of both the years made unexpected delay of monsoon in covering entire India. Rainfall of July also suffered the most in both the seasons with a record lowest ISMR in 2002. Not a single depression formed in 2002 while in 2004, their frequency was less than half of normal. Analysis of other large-scale monthly anomalous ocean and atmospheric conditions over Indo-Pacific region including El-Nino conditions confirms that ENSO and Equatorial Indian Ocean Oscillation or EQUINOO have caused drought in July 2002, but not in July 2004. This is because very high typhoon formation and their recurvature with significantly higher than normal convection over northwest Pacific associated with record lowest ISMR in July, 2002 in contrast to occurrence of deficient ISMR in July 2004 which was associated with few typhoon formation and less convection. Also in 2002, Indian region was happened to fall exactly under the subsidence branch of Walker circulation with ascending branch over the western Pacific in the season in contrast to 2004, when subsidence was observed to be both over large part of western Pacific and adjoining Indian region.

Key words – Indian Summer Monsoon Rainfall (ISMR), Synoptic and semi-permanent systems, Drought, El-Nino, OLR anomalies, EQUINOO.

1. Introduction

Monsoon rainfall is central to India's agriculture, hydrological projects/power sectors etc. and thus provides livelihood to 65% of the population of the country. Any significant short fall in this rainfall results severe socioeconomic impacts on their daily life. Sometimes, it may force many rural poor people to migrate to cities for getting a better livelihood. Hence, when drought prevails over any parts of India, government initiates many schemes including food for work for solving partially its impacts. The occurrence of deficient monsoon of 2004 after the drought of 2002 was heavy burden on economy. The drought in 2002 saw food grains production and gross domestic product fall by nearly 18% and 2% respectively as compared to the previous year. Recurrence of sub-due rainfall in the monsoon 2004 have further pulled down its growth rate when India was struggling to get higher growth rate as with other countries. Both events were also unanticipated until July end in respective years. These have naturally led to a lot of concern and speculation about causes of these frequent failures of monsoon in recent years.

Rainfall over India as a whole during the summer monsoon season of 2002 and 2004 was -19% and -13% below normal respectively. The respective rainfall was -31% and -13% in the first half with highest deficiency of -52% and -19% in July month in both years. It is well known that the monsoon behaviour of each year is unique. It manifests itself in a variety of ways in its advance or withdrawal phase and even during the season itself. There is a rich spectrum of variation in circulation and rainfall patterns experienced during the season at intraseasonal time scale (Rao, 1976, Jenamani, 2001, Kalsi *et al.*, 2004, etc.). However, these variations are sometimes random and finally constitute the typical variability of Indian Summer Monsoon Rainfall (ISMR) that appears to be distributed normally in interannual time scale with few extreme seasons (Gadgil *et al.*, 2002).

In the present study, first, abnormal characteristics of advance and stagnation of both "deficient monsoon of 2004" and "drought 2002" have been discussed briefly with a comparison to earlier deficient years. We have also discussed and compared characteristics of temporal and spatial variation of their rainfall followed by analysis of their important synoptic systems, semi-permanent systems and regional circulation anomaly. Then, we have studied possible causes of deficient rainfall during both years with special emphasis to July month by considering impact of middle latitude westerly or blocking high (Raman and Rao, 1981) and ENSO (Rasmusson and Carpenter, 1983). Possible role of Southern Hemispheric Equatorial Trough or SHET and Equatorial Indian Ocean Oscillation or EQUINOO and typhoon formation over Pacific in causing

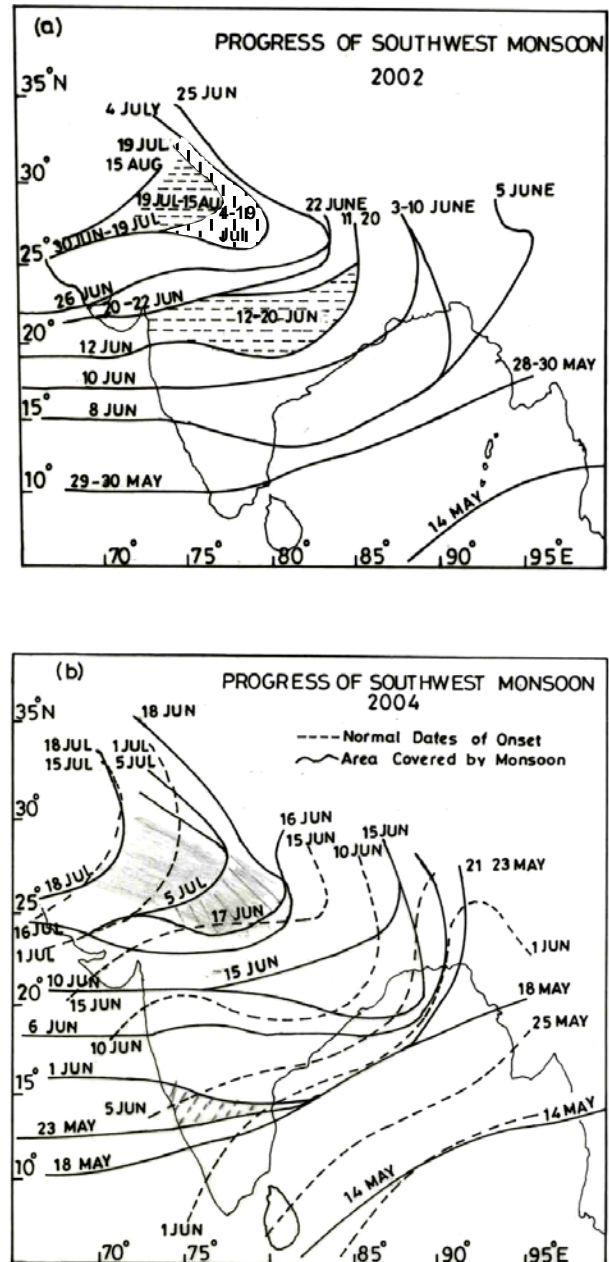


Fig. 1(a&b). The progress of monsoon (a) 2002 and (b) 2004 (Hatching area indicates area of stagnation of monsoon)

deficient rainfall in both the monsoons has also been studied (De *et al.*, 1995, Sikka and Gadgil, 1980, Gadgil *et al.*, 2003 and Kalsi *et al.*, 2004). With occurrence of two deficient monsoons very recently, we have also computed 21-year running Correlation Coefficients (CC) of ISMR with SST anomalies of four Nino regions of equatorial Pacific, such as Nino 4, Nino 3.4, Nino 3 and Nino 1+2, SOI, with updated data to understand how these

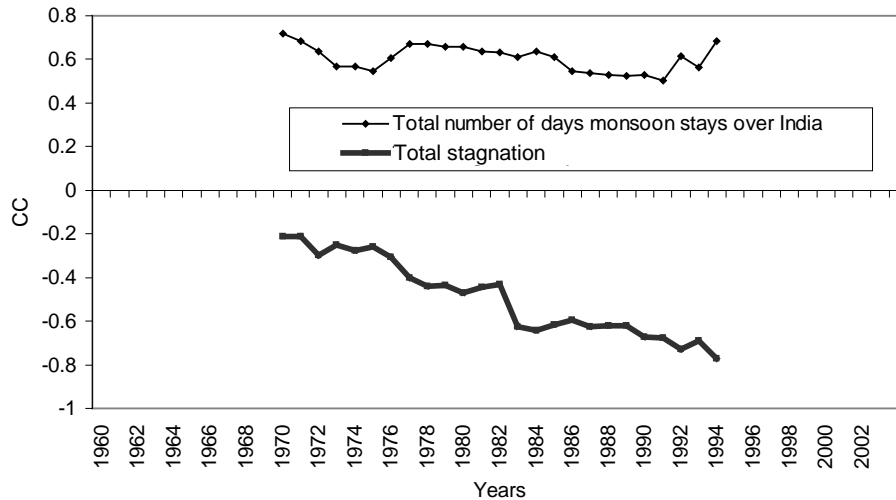


Fig. 2. 11-years running correlation coefficients(CC) of ISMR with duration of total number of days monsoon stays over India and total stagnation days

climatic parameters have been able to control the monsoon rainfall as found earlier by various authors.

2. Data and methodology

Onset and withdrawal dates of monsoon, monthly frequencies of cyclonic storms and depressions during monsoon season over Indian region, weekly, seasonal and monthly area weighted rainfall, both sub-division wise and India as a whole were collected from IMD. The duration of monsoon were taken as the time span between the date of full coverage along India and the date at which monsoon withdrawal commence. Stagnation dates were obtained from Desai and Kulkarni (2001). For calculation of monsoon disturbance days and break monsoon days of earlier years, “India Daily Weather Report” and “Weekly Weather Report” published by IMD, Pune and Ramamurthy (1969), were considered. We have referred Jenamani and Desai (1999) while updating data of the total days of disturbances and break monsoon dates to keep the continuity. Daily weather charts were used for studying characteristics of the monsoon trough. NCEP analysis data are used for studying the seasonal mean characteristics (position and intensity) of other semi-permanent systems like Tibetan anticyclone, heat low, etc., characteristics of large scale circulation and out going long wave radiation anomalies, SST of Indo - Pacific region and El-Nino characteristics of 1950-2004.

3. Observational features of monsoon 2004 and 2002

3.1. Advance and stagnation

The onset of the southwest monsoon over Kerala in 2002 was on 29 May, while in 2004, it was on 18 May

with 3 days and 14 days earlier than its normal date of 1 June respectively [Figs. 1(a&b)]. No intense low pressure system was present as onset vortex in 2002, other than the off-shore trough along the west coast. However in 2004, except the off-shore trough, a severe cyclonic storm was present as onset vortex. Figs. 1(a&b) also show that though further progress of monsoon up to central India could be possible within the normal dates in both seasons, monsoon covered entire India later than the normal date with record late in 2002. It may be noted that no significant rainfall has been recorded over the region of extreme northwest India during this advance phases of monsoon in both the years. Also, both monsoons had three hiatus each with stagnation of 7 days or more in its northern limit (Fig. 1), before it covered the entire country. These are from 13-19 June, 5-18 July and 20 July-14 August in 2002 and from 23-31 May, 19 June-4 July and 9-17 July in 2004. It shows that both monsoons have experienced once in each year the prolonged stagnation of 15 days. Its comparison with stagnation data since 1960 shows that it has occurred 6-times in the past during 1968, 1969, 1982, 1986, 1991, 1995 and 2002. To find whether occurrences of such longer duration hiatuses as happened in 2004 and 2002, have any relationship with seasonal rainfall, we have also compared their respective ISMR. It shows 7 times out of these 8 years, were drought or near drought and hence chance of occurrence of such prolonged stagnation in any year has probability of 86% to become deficient in the end of the season.

It may be noted that monsoon covered the entire India in 2002, on 15th August, 31 days later than normal, while in 2004, it covered on 18th July, 3 days later than normal date. The monsoon in 2002 started withdrawing from India on 16 September around the normal date while

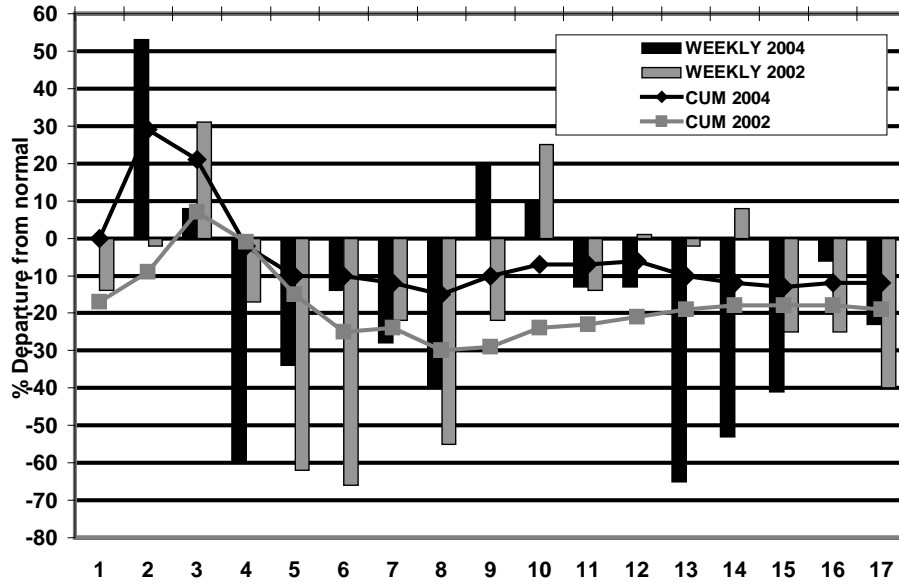


Fig. 3. Week by week cumulative rainfall departure over India for monsoon 2002 and 2004 by considering weeks of monsoon, 1st week ends on 9th (12th) of June and last week end on 25 (29) September, for 2002 (2004)

in 2004, it was on 24 September. We have also computed CC of ISMR with duration of monsoon and total stagnation days along with their 11-years running CC in Fig. 2 to find the trend. Their CC for total period have been found as 0.7 and -0.5 respectively with former CC is stable through out data period while later CC has been showing significant strengthening from -0.2 in 1960s to -0.8 till recent. Such observed trend in later case is mainly due to the date of covering of monsoon the entire India later than the normal followed by less ISMR for season as whole, in some recent years.

3.2. Temporal and spatial characteristics of rainfall distribution in 2004 and 2002

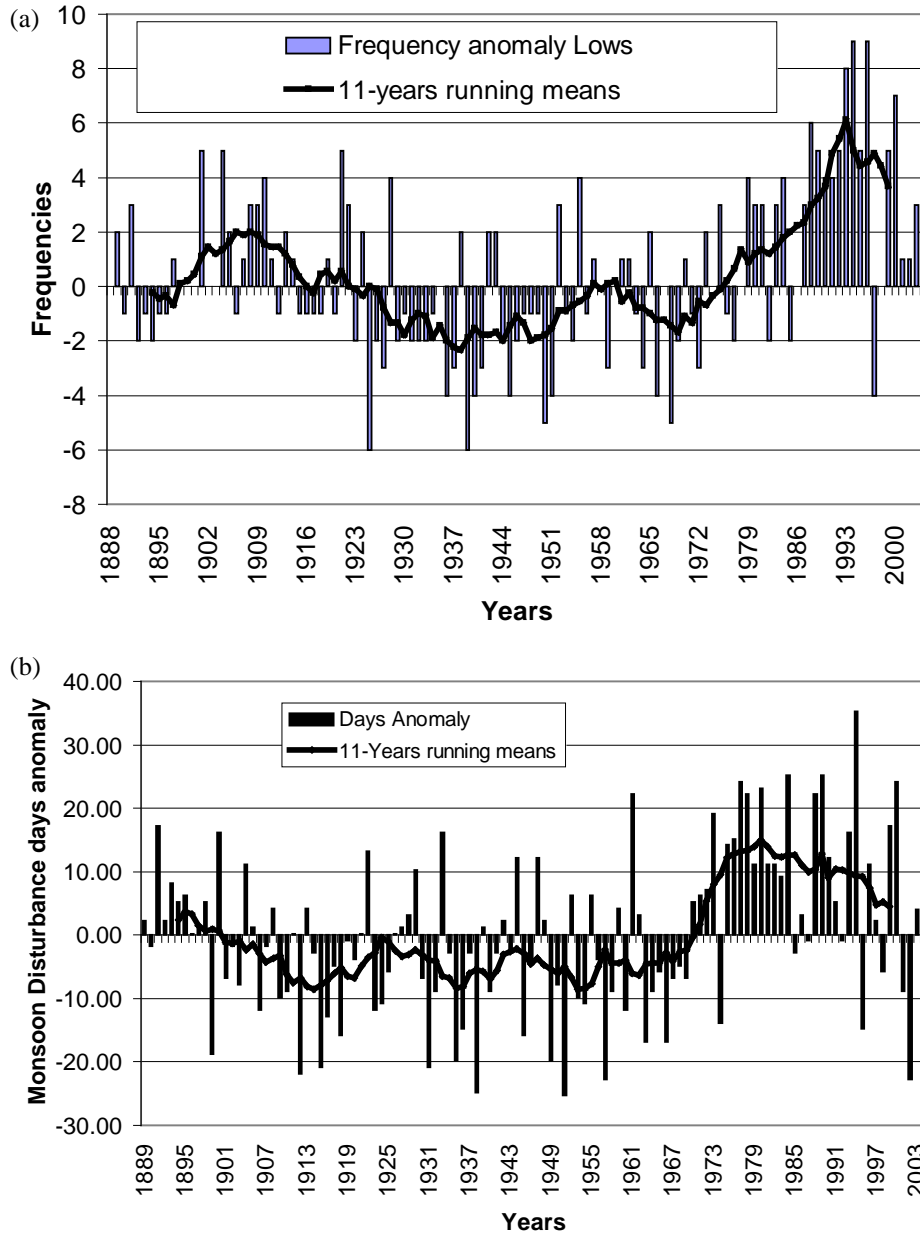
It is interesting to note that the deficiency occurred mainly in July for both the years. In 2004, ISMR departure in July was -19%, while in June, it was -2% and in 2002, when more intense drought had occurred, these were -52% and 4 % respectively. In fact July 2002 has lowest ever ISMR in the history of monsoon rainfall record since 1871. ISMR was -4%, -10%, -5% and -29% in August and September of 2002 and 2004 respectively. Monthly ISMR distribution of earlier drought years e.g., 1951, 1965, 1972, 1982 and 1987 shows occurrence of such less rainfall in all months while normal ISMR occurred in June of recent 2 drought years. It also shows in June, India has been continued to get good rains in many years since 1975 while in July, it has been received less rainfall in these years. Table 1 shows that in the past 133 years, there have been 24 deficient

TABLE 1
ISMR in % departure during deficient rainfall years for the period 1871-2004

Years of monsoon	ISMR departure	Years of monsoon	ISMR departure
1873	-12.8	1965	-18.2
1877	-41.4	1966	-13.2
1899	-29.4	1968	-10.3
1901	-13.1	1972	-23.9
1904	-11.8	1974	-12
1905	-17.4	1979	-18.9
1907	-10	1982	-14.5
1911	-14.7	1986	-12.7
1913	-10	1987	-19.4
1918	-24.9	2002	-19
1920	-16.7	2004	-13
1941	-13.3		
1951	-18.7		

monsoon years. It also shows the frequency of droughts has varied on the decadal time scale e.g., 9 droughts occurred in 1965-1987, while no drought occurred in 1921-1940, 1952-1964 and in recent 1988-2001.

It may be noted that spatial rainfall distribution over the country in day to day of June and July is most crucial for farmers since it is the time of sowing or transplantation



Figs. 4(a&b). Anomalies and 11-years running means of (a) frequency of low pressure areas and (b) total monsoon disturbance days for the period 1889-2002

of different crops. Timely rainfall distribution over an area is necessary for a good harvest. However, in the monsoon seasons of 2002 and 2004, many prolonged dry spells have been observed. For this, we have also shown in Fig. 3 week by week variation of rainfalls for both 2002 and 2004 over India as a whole. It shows that season of 2004 has started with very good rainfall spell till the end of 3rd week (26th June) with cumulative ISMR departure as + 20 %, where as 2nd week ISMR had highest departure of +52%. In 2002, though rainfall in first 2 weeks were

little sub-dued, cumulative ISMR departure was + 7 % by the end of 23 June due to very good rainfall in that week when weekly ISMR was +30%. But subsequently, rainfall was deteriorated in both years in all weeks till end of July. In 2002, cumulative weekly ISMR departures in June-July were much sub-dued compared to 2004. This is because in 2004, departure was less than -50% only for one week ending on 2 July, while in 2002, such significant below normal ISMR was for 3 weeks ending on 7th, 14th and 28th July. By end of July, both cumulative ISMR were -13%

TABLE 2
Characteristics of semi-permanent systems in 2002 and 2004

Semi-permanent systems	June		July	
	June 2002	June 2004	July 2002	July 2004
Heat low	0 to -1 hPa	1 to 2 hPa	1 to 2 hPa	2 hPa
Monsoon trough	Established on 8 June	Established on 14 June	Gradually shifted northwards from 1 July. Lay at foot hills of Himalayas from 5-13 July & 20-28 July	Western end at foot hills during most of the days Lay at the hills 8-12 July and 16-18 July
Mascarene high	+1 hPa	4 - 6 hPa	Very weak (-3 to -7 hPa)	Weak(-1 to -2 hPa)
Tibetean anticyclone (200 hPa)	25° N / 90° E (normal) Stronger than normal	25° N / 90° E Weaker than normal	28° N / 90° E (much south of normal position) Intensity- much weaker than normal with anomalous cyclonic circulation at 30° N / 110° E	28° N / 90° E Intensity- much weaker than normal with anomalous Cyclonic circulation at 35° N / 110° E
Semi-permanent systems	August		September	
	August 2002	August 2004	September 2002	September 2004
Heat low	-1 to -2 hPa	0-1 hPa	1 hPa	1 hPa
Monsoon trough	At foot hills 27- 28 August	Very weak in last week at foot hills 26-31 August	Very weak	Very weak
Mascarene high	3 to 4 hPa	1-2 hPa	1 hPa	Weak (-2 to -3 hPa)
Tibetean anticyclone (200 hPa)	30° N / 80° E (south west of normal position) Intensity- little stronger	28° N / 80° E (south west of normal position) Normal but with anomalous Cyclonic circulation at western part of ridge	20° N / 90° E (south of normal position) intensity-little stronger	27° N / 90° E stronger than normal

and -31% respectively. In August (Fig. 3), because of good rainfall for a few weeks, cumulative ISMR in 2002 and 2004 improved to -7% and -20% respectively.

In September 2002, occurrence of few normal spells resulted season to end in -19% while in 2004, occurrence of very much sub-dued rainfall in subsequent weeks with weekly ISMR less than -50% in the ending of 4th and 11th of September further deteriorated the seasonal cumulative ISMR departure value to -13 % in the end of season. In fact, monthly ISMR was -29% due to occurrence of such bad spells in September 2004 which is very much less than September 2002 when monthly ISMR was -10%.

We have also compared spatial distribution of seasonal rainfall in meteorological sub-divisions for both 2002 and 2004. In 2002, situation was worst as only 15 out of 36 meteorological sub-divisions, received normal to excess rainfall. Out of the remaining 21 sub-divisions, only both east and west Rajasthan are in the scanty category and remaining 19 sub-divisions are in the deficient category. However in 2004, 23 out of 36 meteorological sub-divisions, received normal to excess

rainfall while remaining 13 sub-divisions are in the deficient category with not a single one in the scanty category. The number of sub-divisions which had severe / moderate drought in 2002 is 12 (Kalsi *et al.*, 2004). No sub-division received severe drought in 2004 while moderate drought are observed only over west Rajasthan (-39%), west Uttar Pradesh (-35%), Punjab (-45%) and Himachal Pradesh (-46%). The whole region of northwestern and peninsular India are affected by large rainfall deficiency in 2002 while in 2004, only extreme parts of northwest India, coastal Karnataka and Kerala received deficient rainfall. In fact, higher rainfall in 2004 compared to 2002 rainfall over peninsular India has helped in reducing the deficiency to -13% at the end of the season. Quantitative comparison between both years shows rainfall departures in monsoon 2004 over many sub-divisions were higher than 2002 except Himachal Pradesh, Jammu and Kashmir, Jharkhand and Vidarbha which have been received rainfall of -20 % or less in 2004 compared to monsoon 2002. In 2002, 29% area of the country was under drought with 10% area under severe drought and 19% under moderate drought while in 2004, 19% area was under moderate drought with no area having severe drought.

TABLE 3

Comparison of SST anomalies over different sectors of equatorial Pacific

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nino 4												
1972	-0.60	0.08	0.06	0.53	0.70	0.53	0.63	0.43	0.45	0.82	0.94	0.84
1979	0.31	0.08	0.34	0.10	0.07	0.08	-0.06	-0.12	0.20	0.07	0.31	0.46
1982	0.10	0.15	0.30	0.52	0.80	1.07	0.73	0.53	0.65	0.87	0.75	0.80
1987	0.82	0.87	0.93	0.81	0.56	0.84	0.82	0.90	1.00	1.10	1.32	1.09
2002	0.61	0.70	0.57	0.69	0.76	0.94	0.84	0.89	0.93	1.05	1.35	1.14
2004	0.70	0.60	0.30	0.30	0.50	0.50	0.81	0.09	1.10	1.10	1.20	1.10
Nino 3.4												
1972	-0.64	-0.21	-0.06	0.41	0.67	0.80	1.07	1.41	1.31	1.77	2.11	2.11
1979	0.02	-0.01	0.46	0.21	0.12	0.22	-0.26	-0.44	0.95	0.26	0.37	0.54
1982	0.24	0.00	0.06	0.35	0.85	1.21	1.00	1.20	1.56	2.03	2.30	2.71
1987	1.43	1.32	1.33	1.13	1.06	1.49	1.70	1.85	1.84	1.46	1.48	1.10
2002	0.02	0.25	0.18	0.27	0.46	0.89	0.88	1.06	1.28	1.44	1.76	1.59
2004	0.20	0.20	-0.10	0.20	0.30	0.30	0.59	0.80	0.80	0.80	0.80	0.80
Nino 1+2												
1972	0.24	0.97	1.02	1.02	1.36	2.05	2.39	2.56	1.71	1.81	1.89	2.05
1979	0.39	-0.14	-0.03	0.06	-0.02	0.48	0.50	0.49	0.89	0.86	0.69	0.61
1982	-0.09	-0.35	-1.08	-0.83	-0.18	0.08	0.79	1.04	1.39	2.19	3.08	3.49
1987	0.92	1.30	1.72	1.84	1.43	1.25	1.10	1.02	1.04	1.64	1.12	0.83
2002	-0.74	0.22	1.24	1.20	0.65	-0.14	-0.67	-0.77	-0.52	0.41	0.74	0.80
2004	0.10	-0.20	-0.50	-0.20	-1.30	-1.40	-1.05	-1.20	-0.40	0.00	0.30	0.10

4. Possible causes

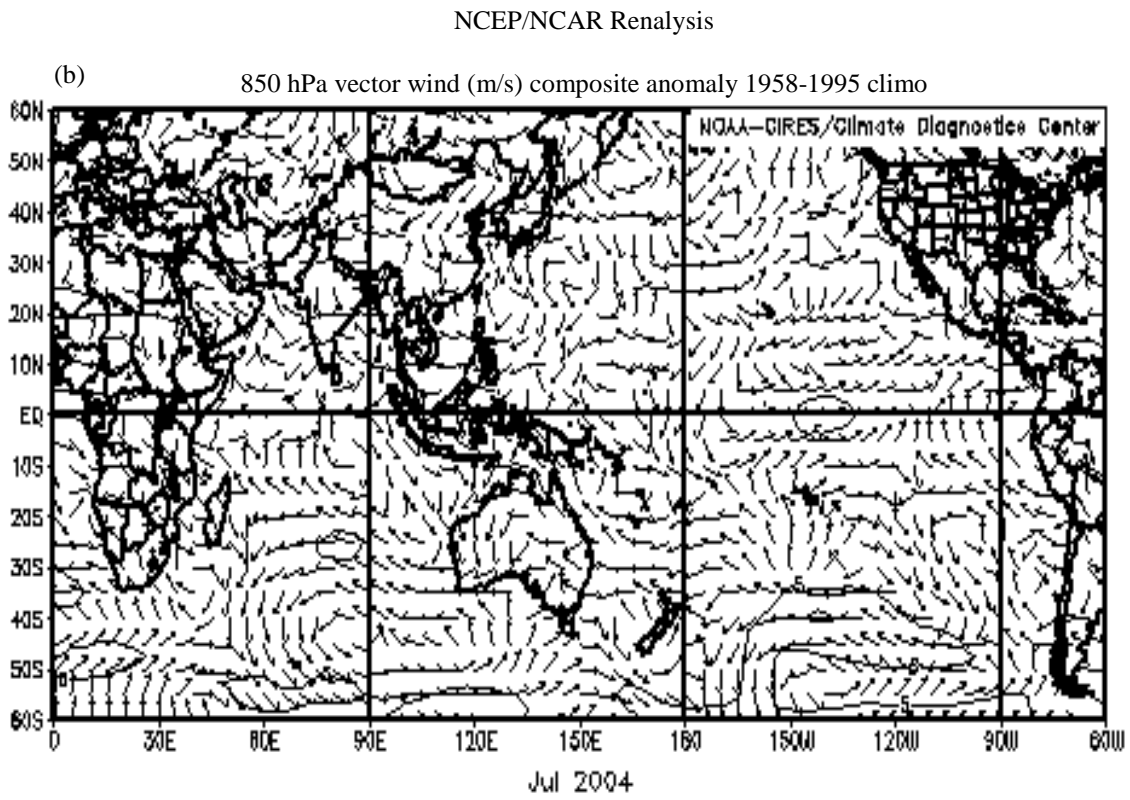
4.1. Impacts of lack of formation of monsoon disturbances and their movement

In monsoon 2004, only 3 depressions formed against climatological normal of 7 - 8 during the whole monsoon season (Jenamani, 2004) while in 2002, for the first time in history of IMD, no Cyclonic Storm or Depression formed. In fact, such tendency of formation of depression less than normal is a part of general decreasing trend of formation of depressions which has started since 1960s and detected by Jenamani and Dash (2001) and Singh (2001). Dash *et al.* (2004) studied the main cause of such decreasing trend and found that various atmospheric dynamical parameters in the head Bay of Bengal at various levels which were favouring for intensification of lows to depressions before start of this trend are becoming some how unfavourable during recent years. One may ask then how ISMR became normal consecutive for 13 years

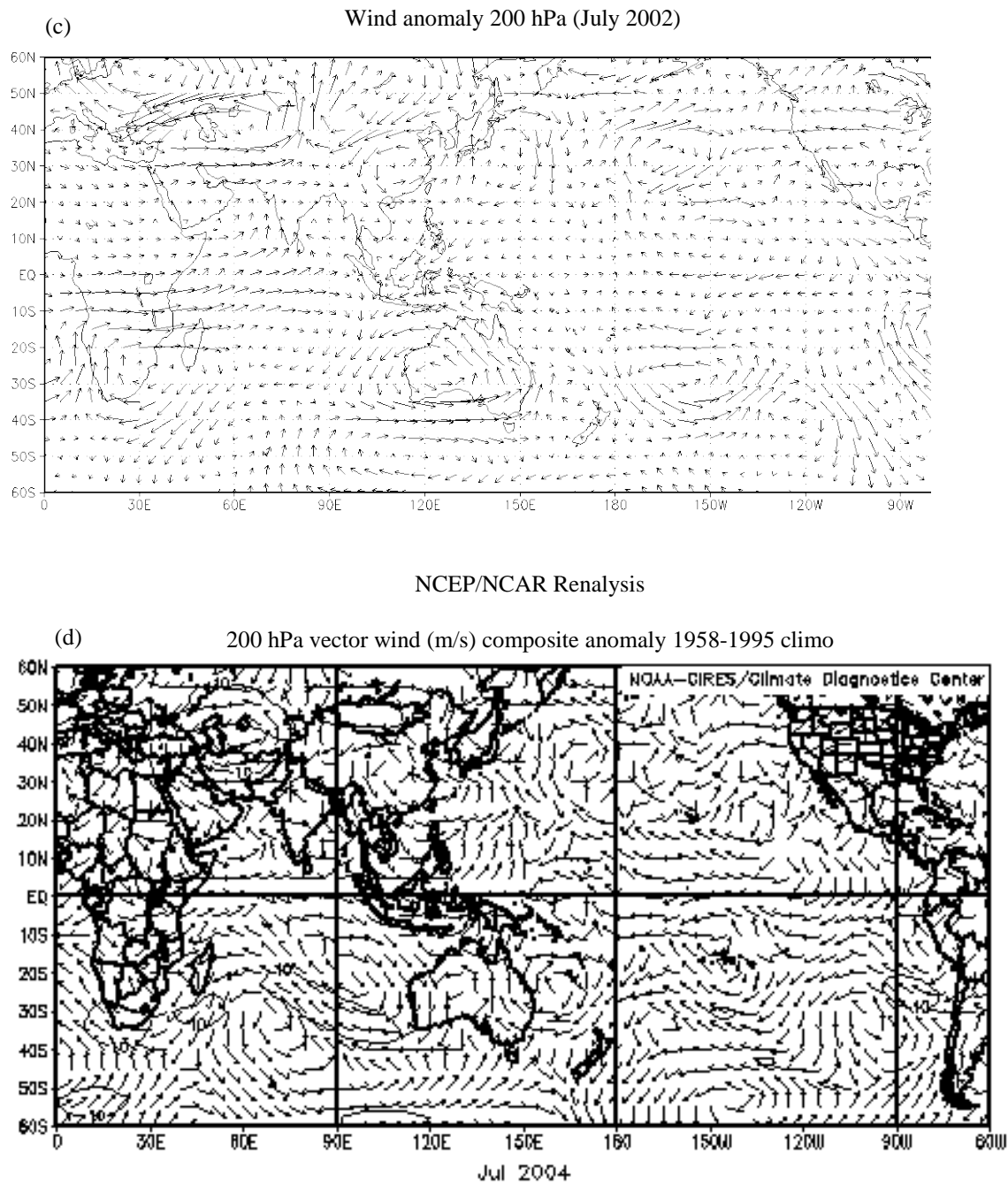
in the period 1988-2001, though this period falls in the decreasing trend of depressions.

This could be possible as in the absence of depressions; very high number of lows with their presence over India for longer duration are formed during these years (Jenamani, 2004). One may note formation of this higher frequency of lows from the study of 11-years running means of seasonal frequency anomalies of those lows and their total life period for the period 1889-2004 in Figs. 4(a&b) respectively which shows that their number, has increased significantly from 1970 onwards. However, if total number of monsoon disturbances is considered then not much decadal change of these systems have been occurred (Jenamani and Dash, 2001). Hence such increase of number of lows and total monsoon disturbances days in recent years are mainly responsible to make possible compensation of ISMR after 1970s in place of country used to get from depressions before 1970s. During both 2002 and 2004, however nearly normal number *i.e.*, 8

(a) Wind anomaly 850 hPa (July 2002)



Figs. 5(a&b). Circulation anomalies of (a) 850 hPa July 2002 and (b) 850 hPa July 2004



Figs. 5(c&d). Circulation anomalies of (c) 200 hPa July 2002 and (d) 200 hPa July 2004

low-pressure areas/well marked low-pressure areas formed along with few feeble lows and hence during both years, not many lows were formed to make possible compensation of ISMR as was earlier years. In 2002, most of these low-pressure areas were also short lived and this is the reason why total number of disturbance days in

Fig. 4(b) in 2002 was very less. But in 2004, some monsoon disturbances lasted very long, 2 depressions which formed over east coast of India were having life period of around 11 days each. Total monsoon disturbance days were also 62 days in 2004 compared to 35 days in 2002. Hence, formation of few depressions and longer life

period of monsoon disturbance are the main synoptic reason why ISMR deficiency in 2004 was not as less as 2002.

4.2. *Unfavourable semi-permanent systems and circulation patterns*

Semi-permanent systems are foremost components of monsoon. A close monitoring of these systems particularly Tibetan anticyclone and monsoon trough may give some early indication of drought (Jenamani and Desai, 1999). Their late establishment may results drought while their early establishment may results normal or excess at the end of the season. Month-wise characteristics of semi-permanent systems except low level jet and tropical easterly jet for both 2002 and 2004 are given in Table 2. Table 2 shows in June, except Mascarene high, remaining semi-permanent systems were week in 2004 compared to 2002.

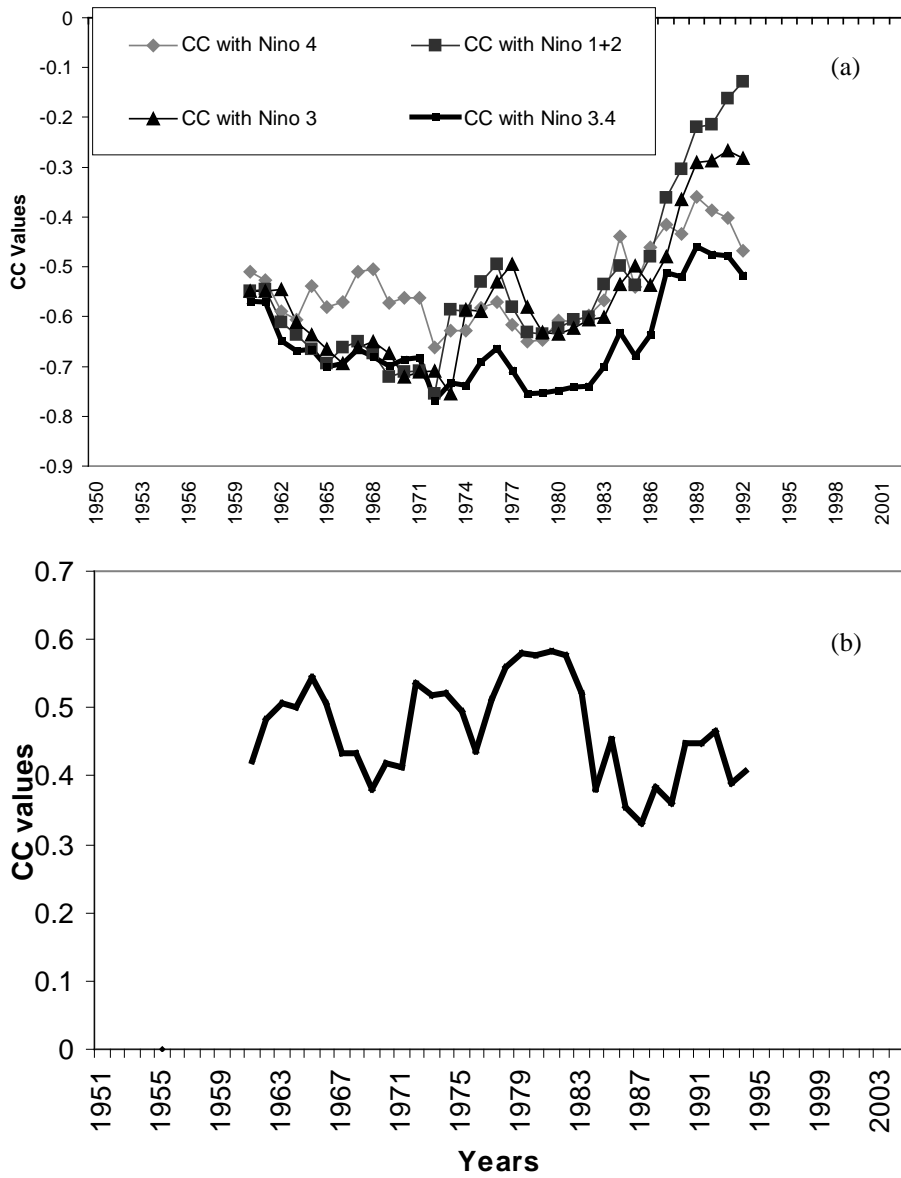
It may be noted that monthly ISMR of June 2004 was less than that of June 2002. It is further interesting to note that in July of both 2002 and 2004, all of these systems were highly unfavourable. Pressure anomalies over Heat low area were higher than normal during both July while below normal over Mascarene high area, which shows both semi-permanent systems were unfavourable during these two years. The highest pressure anomalies were in July 2002 over Mascarene high area. Monsoon trough was either week or lay at foothills of Himalayas in most of the days in July in both years. During drought 2002, two prolonged break spells occurred in July. If total number of days of break monsoon of July 2002, is compared with earlier years for whole period of 1889-2004 (Jenamani and Dash, 2005 and Ramamurthy, 1969), then July 2002, had longest break monsoon spell with 18 days in 116 years data. The earlier longest spells were in 1910 and 1918 with 17 days spells each and during both years, July ISMR were very much below normal having deficiency around -48% like July ISMR of 2002 drought. But in July 2004, except two shorter duration spells of total 8 days as noted in Table 2, eastern end of the trough lay over head Bay in most of the days. This is also one of the causes why ISMR departure in 2002 in the first half was much less compared to 2004.

Table 2 also shows Tibetan anticyclone was also not favourable in July during both years as it was south of the normal position and very week. However, in August, except occurrence of shorter period breaks in both the season, all of these semi-permanent systems again became favourable. In September, none of these systems were favourable except Mascarene high in 2004. Because of the occurrence of break in August last week (Table 2), monsoon trough could not get re-established and hence

became less marked early in September in both years. Such incidents of occurring of break monsoon towards August end which have resulted deficient monsoon at the end of season have been studied by Jenamani and Thapliyal (1999).

Figs. 5(a&b) and Figs. 5 (c&d) show circulation anomalies of 850 and 200 hPa over Indo-Pacific region respectively for both July of 2002 and 2004. In July of both years at 850 hPa [Figs. 5(a&b)], the low level jet or cross equatorial flow in the Arabian Sea was extremely weak as northeasterly anomalies were observed from Kerala coast towards Somali coast suggesting weaker southwesterly flow over the Arabian Sea and hence low level jet was very weak. Figs. 5(a&b) also shows that over the main land of Indo-Gangetic plains, easterlies were very weak in both July as strong westerly anomalies were observed over the region from an anomalous anticyclone centered at 25° N / 75° E over Gujarat region of northwest India and ridge is passing through the region instead of monsoon trough through the same position. The main difference between July of these two years is prevailing of northerly or northwesterly winds over Bay of Bengal in 2002, which while in 2004, these winds are easterlies. In former case, since winds are mostly northerly which is an out flow from the anticyclone centered over central India, hence all along east coast, winds were from land and hence mostly dry while in latter case, wind anomalies along east coast of India are easterly having origination from sea and hence moist due to which one may note from spatial distribution of rainfall that southeastern peninsular India and all sub-division along east coast received normal rainfall in July of 2004 instead deficient rain over these areas as was the case in July 2002.

In Figs. 5(c&d), as noted earlier from Table 2, the upper air Tibetan anticyclone in July at 200 hPa was south (by about 5° in both 2002 and 2004) of its normal position and was very weak. The anticyclone was so weak that an east west trough was replaced the sub-tropical ridge over the same area in anomalous flow pattern and was found roughly along 35° N and 38° N respectively at 200 hPa in 2002 and 2004 respectively. Also, instead of two anomalous sub-tropical anticyclones at both end of the ridge which happens normally in high rainfall years, two anomalous cyclonic circulations are observed at both the ends of anomalous trough in both the July of 2002 and 2004. The western one centered around 40° N / 60° E in both years while the eastern end centered around 50° N / 105° E in 2002 and 50° N / 95° E in 2004. The tropical easterly jet in both anomalies shows that it was also weaker than normal as stronger westerly anomalies (5m/s to 10 m/s) were observed over southeastern Arabian Sea off Kerala coast at 200 hPa.



Figs. 6(a&b). 21-year running correlation coefficients (CC) (a) between ISMR and SST anomalies values in monsoon season over Nino 4, Nino 3, Nino 3.4 and Nino 1+2 region for the period 1950-2002 and (b) between ISMR and SOI for the period 1950-2002

4.3. *Impact of mid-latitude westerlies in July 2004 and 2002*

In July [Figs. 5(c&d)] at 200 hPa, strong westerly anomaly around ~10m/s to 15 m/s were observed respectively during both July 2002 and 2004 at upper troposphere over northwestern India in association with strong anomalous cyclonic circulation centered at 40° N / 60° E during both years. Further, presence of an

anomalous anticyclone centered on 50° N / 105° E and the other one centered near 50° N / 95° E in both July shows intense blocking high was present in respective July. Hence middle-latitude effect is one of the causes for sub-rud rainfall in both July (Ramana and Rao, 1981). In daily weather charts, penetration of such stronger mid-latitude westerlies in July in intraseasonal scale due to presence of stronger blocking high in the north of the region during both years were observed.

TABLE 4

Comparison of characteristics of other Indo-Pacific features between July 2002 and 2004

Year	Vel. Potential in $10^6 \text{ m}^2 \text{ s}^{-1}$ Western/Central Pacific	Vel. Potential in $10^6 \text{ m}^2 \text{ s}^{-1}$ Indian Region	Number of tropical Storms/ days in North west Pacific	OLR anomalies over North west Pacific in Wm^{-2}	Pressure anomalies over North west Pacific in hPa	CPOLR in Wm^{-2}	OLR anomalies In Western EQIO in Wm^{-2}	OLR anomalies in Eastern EQIO in Wm^{-2}	Zonal winds anomalies EQIO in m/s
2002	-4	7	7/51(two continued from previous month)	-10 to -20	-3 to -4	-10	>20	<-20	8-11 for 27 days
2004	4	1	1/11(two continued from previous month)	10 to 20	1-2	10-30	20	0-10	8-11 for 8 days

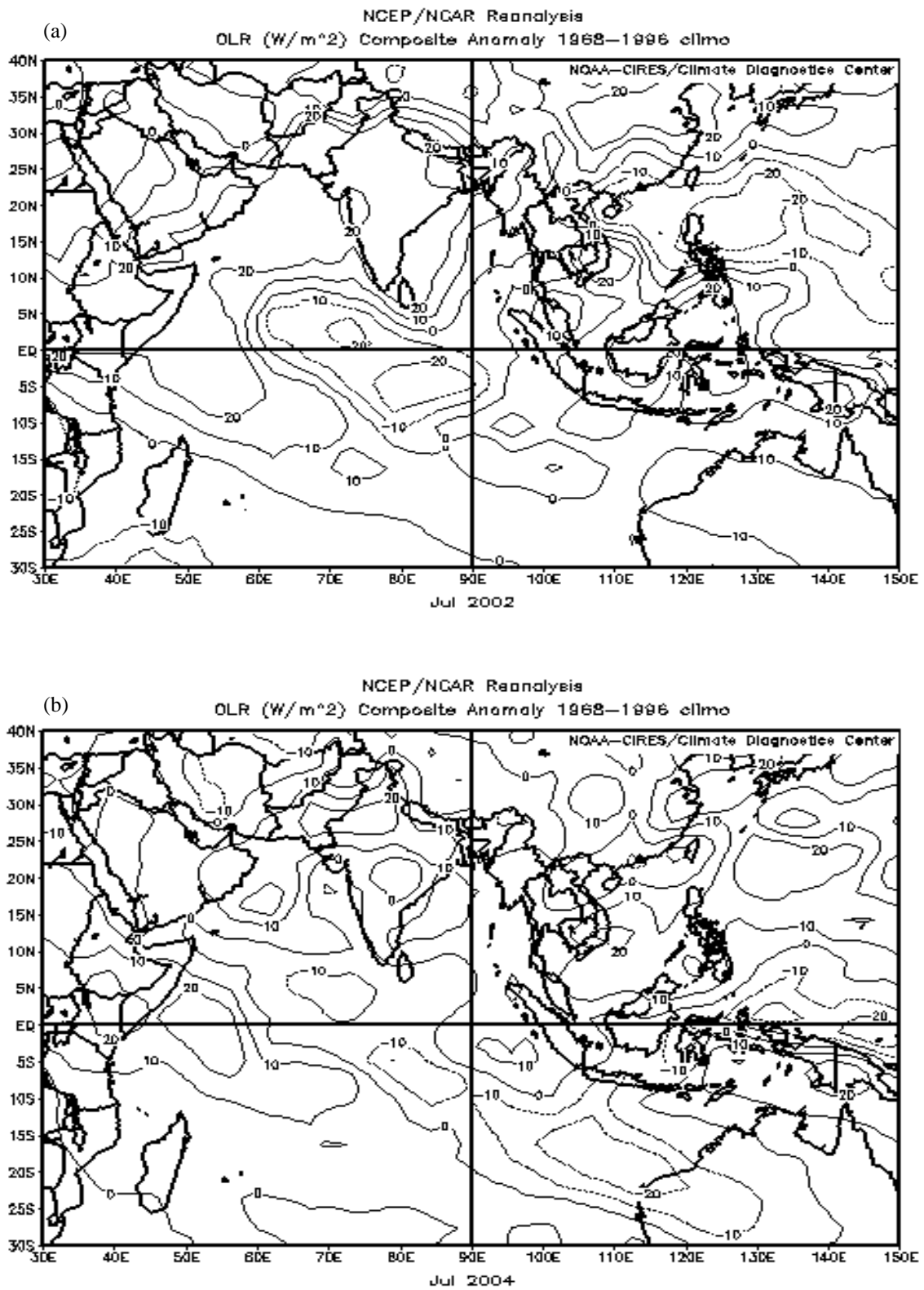
4.4. Impact of ENSO and Equatorial Indian Ocean Oscillation (EQUINOO)

El-Nino-Southern Oscillation (ENSO) strongly influences ISMR (Walker, 1924; Rasmusson and Carpenter, 1983; Keladis and Diaz, 1989 and Mooley and Paolino, 1989) However, ISMR became normal in 1997 even though, it was the year when most intense El-Nino of the last century prevailed. Later study by Krishna Kumar *et al.*, (1999) have found that such relationship is not stable and having a secular variation with epoch of strong/weak correlation coefficients (CC) with time. With the occurrence of two deficient monsoons in 2002 and 2004, it is necessary to find latest trend of their CC with updated data. Fig. 6(a) shows the 21-years running CC of ISMR with SST anomalies of different sectors of equatorial Pacific region. It shows weakening of CCs have been started in the beginning of 1980 for all Nino regions and continued till 1990. However, it recovered in the last few years for all sectors except Nino 1+2. In case of Nino 1+2, the CC has continued to be weakened un-interruptly since 1980 and become insignificant at present. The comparison of latest 21-year CCs shows that highest CC observed between ISMR and Nino 3.4 followed by Nino 4 and Nino 3. CC of ISMR with SOI plotted in Fig. 6(b) also shows though it was weakened similarly from the 1980; it recovered in 1990 like CC with Nino 3.4.

We have also listed monthly SST anomalies over different Nino regions for latest six drought years in Table 3. It shows that except 1979, anomalies in El-Nino years before 2002, were higher than normal in all regions in the monsoon season confirming dominant role of El-Nino in causing drought over India in these years. The El-Nino of drought 2002 and in 2004 showed an anomalous behavior in that it was weakened over Nino 1+2 or the area east off Peru coast during monsoon season but strengthened over western and central Pacific Ocean. One

can also confirm this by considering intensity of SST anomalies from Table 3. It shows that though, SST of Nino 4 in 2002 was warmer by $.5^\circ \text{C}$ compared to 2004 before July, SST anomalies in remaining months became same with anomalies 1 to 1.5°C in both the years. However, SST in Nino 3.4 in 2002 remained warmer by 0.5°C to 1°C compared to 2004 from June till December. In Nino 1+2, while all other deficient years are accompanied with warm SST anomalies over this region in monsoon, it is interesting to note persistence cooling in all months of monsoon of 2002 and 2004 with highest cooling of -1°C or more in June-August 2004. Monthly SOI data also shows though its values were negative during both years from June onwards, their values were with in -0.5 hPa in monsoon 2004 which are very less while in 2002 their negative values were stronger with values varying between -1 to -2.5 hPa .

The dominant classical mechanism through which El-Nino interacts with monsoon circulation and caused drought over India is by shifting of rising branch of Walker circulation towards central/eastern Pacific from its normal position of Indian region due to which significantly higher than normal convection occurred over the former region and the later region became deficient. To confirm whether ENSO has been affected ISMR through such mechanism in July 2002 and 2004, we have studied velocity potential and divergence anomalies at 200 hPa, OLR anomalies, frequency of typhoon, circulation and surface pressure anomalies over Indo-Pacific region for July 2002 and 2004. We have summarized their basic difference in Table 4. It shows presence of negative velocity potential anomalies with contour values upto -4 to -6 in July 2002 over Central Pacific with $+7$ over peninsular India in contrast to values of 4 and 0-1 in the respective regions in July 2004. Hence in 2002, raising branch of Walker circulation had shifted towards central/eastern Pacific from its normal position



Figs. 7(a&b). OLR anomalies in Wm^{-2} over Indo-Pacific region (a) July 2002 and (b) July 2004

with descending branch over Indian region while this did not happen in 2004. Subsequently, this is confirmed by the presence of corresponding significant below normal OLR anomalies, surface pressure anomalies and very higher number of typhoon and their days in July 2002 compared to July 2004 in Table 4. Hence, the shifting of such east-west Walker circulation was more predominantly seen in 2002 compared to 2004 in both intensity field and spatial extent. Also the daily analysis of cloud pictures from INSAT shows the whole cloud system from equatorial Indian Ocean had a tendency to move towards northwestern Pacific Ocean during the month of July 2002 but not in the month of July 2004. Hence, though role of El-Nino has been considered as a main cause in 2002 drought, there are no clear signal from comparison in Tables 3 and 4, on the basis of which we can attribute the cause of deficient rainfall during 2004 as an effect of El-Nino.

The study by Gadgil *et al.* (2003) for earlier extreme years shows that drought/flood over India are associated with either ENSO or EQUINOO or both. They have considered OLR anomalies over central Pacific (averaged over 160° E - 150° W, 5° S - 5° N) *i.e.*, CPOLR to represent ENSO and OLR anomalies/zonal wind anomalies over equatorial Indian Ocean to represent EQUINOO over Indian Ocean. It has also been stated that if drought/flood occurs due to later mechanism then a see-saw type of OLR anomalies are observed between the western and eastern equatorial Indian Ocean regions. To find whether CPOLR and EQUINOO is responsible for occurrence of deficient ISMR in the monsoon of 2004 as it was found by Gadgil *et al.* (2003) for earlier drought years including 2002, we have referred OLR anomalies of July over these regions from Fig. 7 and evolution of equatorial zonal wind anomalies over Indian Ocean with longitude from April till July for both 2002 and 2004 (Zonal wind anomalies figure has not been given because of want of space). Main differences between them are also listed in Table 4 for easy comparison. Since CPOLR was having negative OLR anomalies in July 2002 as in Fig. 7(a) and correspondingly from Table 4 while few contours of positive OLR anomalies of order of 10-30 Wm^{-2} was also observed over the same region in July 2004 as in Fig. 7(b). Hence, we also do not find any effect of CPOLR anomalies on ISMR in July, 2004 like it was found before for 2002 as an effect of ENSO.

From OLR pattern prevailed in Fig. 7(a) and correspondingly from Table 4, one may note in July 2002, EQUINOO mechanism was played equally strong role like ENSO in causing deficient ISMR because very high positive OLR anomalies over the western parts of equatorial Indian Ocean with the contour order up to 35 Wm^{-2} has been observed against to the high negative

OLR anomalies of -30 Wm^{-2} at its east. But, no such contrast anomalous OLR pattern was observed in July 2004 [Fig. 7(b)]. Rather, the high negative OLR anomalies are observed far from equator, which is over southeastern tropical Indian Ocean off northwest Australia.

Comparison of evolution of equatorial zonal wind anomalies from their Homoholer diagrams show prevailing of strong westerly anomalies dominating most parts of equatorial Indian Ocean in the first half of 2002 compared to that of 2004 for the same period. During June-July 2002, highest anomalies were occurred at two occasions. The first one was observed in 80° E - 95° E during 25th June - 10th July and the second one was in 70° E - 98° E during 10th - 20th July with both of their values reaching up to 8-11 m/s while in 2004, such anomalies were observed only once during 30th June - 8th July confined to 85° E - 95° E. Hence, EQUINOO has not been played any significant role in causing deficient ISMR in 2004 as was for ISMR of 2002.

5. Conclusion

Though monsoon advanced on 18 May over Kerala in 2004 which is much earlier than 2002 when advance was on 29 May, further progress up to central India were within normal dates in both seasons. While ISMR in respective June was good, occurrence of few longest stagnations resulted very long delay in their further advance and thus dates of monsoon covering entire India were 18 July in 2004, 3 days later than normal and 15th August, in 2002 with a record delay. July suffered the most in both the seasons with a record lowest ISMR in 2002. Both the July have prolonged break monsoon with longest record break monsoon/ dry spells in 2002. Both seasons were unanticipated until July end in respective years.

Not a single depression formed for the first time in the history in 2002 while their frequency was less than half of normal in 2004. Though, such less number of depressions formation have been a part of their decreasing climatic trend in decadal time scale which have been going on since 1970, not more number of lows were formed in 2002 and 2004 as was happening in earlier normal ISMR years to compensate the shortage in rainfall arising due to absence of depressions. Most of these lows were also quite feeble, short lived and followed shorter tracks.

Results show intraseasonal features developed in both the season were highly unfavourable leading to deficient ISMR including semi-permanent features. Day to day analysis of circulation and OLR anomalies over Indo-

Pacific region shows though, most of the dry spells were also associated with occurrence of SHET or EQUINOO in 2002, but no such strong interaction was found in 2004. Study also shows very high typhoon formation and their recurvature with significantly higher than normal convection over northwest Pacific are associated with record lowest ISMR in July, 2002 in contrast to occurrence of deficient ISMR in July, 2004 which has been associated with few typhoon formation and less convection. Similarly in July, 2002, Indian region was under the subsidence branch of Walker circulation with ascending branch over the western Pacific. In contrast to July 2004, when subsidence was over large part of western Pacific and adjoining Indian region. In 1997, ISMR escaped the effect of intense El-Nino of century during the season because of Indian region did not happen to fall in such subsidence region as had happened in July 2004. Hence, though role of El-Nino and Equatorial Indian Ocean Oscillation or EQUINOO have been considered as the main cause in drought of 2002, there is no clear signal on the basis of which we can attribute the cause of deficient ISMR in the monsoon of 2004 as an effect of ENSO OR EQUINOO or both as established by Gadgil *et al.*, (2003) for other earlier drought/flood years. However, study of monthly regional circulation features and day to day evolution of components of synoptic and semi-permanent systems shows that lack of day to day development of favourable regional intraseasonal features *e.g.* monsoon disturbances and semi-permanent systems, presence of very weak low level jet, penetration of strong mid-latitude westerlies etc. during monsoon months are main possible causes resulting deficient ISMR in both seasons of 2002 and 2004 as established by Jenamani and Dash (2005) for other earlier drought/flood years associated with ENSO or without ENSO. Incidentally, occurrence of both the deficient monsoons over India were coincided with nearly same oceanic conditions over the Pacific *i.e.*, warming of $+5^{\circ}\text{C}$ to $+1.3^{\circ}\text{C}$ over central and western Pacific with cooling of -0.7°C to -1.5°C over Eastern equatorial Pacific Ocean which were never observed before when ISMR was deficient in the history of recorded data.

References

- Dash, S. K., Jenamani, Rajendra Kumar and Shekhar, M. S., 2004, "On decreasing frequency of monsoon depressions over the Indian region", *Current Science*, 1404-1411.
- De, U. S., Prasad, O. and Vaidya, D. V., 1995, "The influence of Southern Hemisphere Equatorial Trough on rainfall during southwest Monsoon", *Theor. Appl. Climatol.*, **52**, 177-181.
- Desai, D. S. and Kulkarni, B., 2001, "Hiatus in northern limit of monsoon and its impact on monsoon", Proc. of TROPMET-2001, National symposium, 111-133.
- Gadgil, S., Srinivasan, J., Nanjundiah, R. S., Kumar, K. K., Munot, A. A. and Rupa Kumar, K., 2002, "On forecasting the Indian summer monsoon: the intriguing season of 2002", *Current Science*, **48**, 4, 25 August, 394-403.
- Gadgil, S., Vinayachandran, P. N. and Francis, P. A., 2003, "Droughts of the Indian Summer Monsoon: Role of Clouds over the Indian Ocean", *Current Science*, **85**, 12, 25 December, 1713-1719.
- Jenamani, Rajendra Kumar and Desai, D. S., 1999, "Monsoon variability in recent years from synoptic disturbances and semi-permanent systems", *Mausam*, **50**, 135-144.
- Jenamani, Rajendra Kumar and Thapliyal, V., 1999, "Characteristics of break monsoon", Proc. of TROPMET-1999, National symposium, 99-103.
- Jenamani, Rajendra Kumar and Dash, S. K., 2001, "Interdecadal variation of some characteristics of monsoon disturbances and their relationships with rainfall and other tropical features", *Int. J. Climatol.*, **21**, 759-771.
- Jenamani, Rajendra Kumar, 2001, "Mathematical modelling of weather systems during Indian summer monsoon", Ph. D. Dissertation, Utkal University, Bhubaneswar.
- Jenamani, Rajendra Kumar, 2004, "Comments on periodicity in the frequency of Indian monsoon cyclonic disturbances and storms", *Mausam*, **55**, 1, 189-194.
- Jenamani, Rajendra Kumar and Dash, S. K., 2005, "A Study on the Role of Synoptic and Semi-permanent Features of Indian Summer Monsoon on its Rainfall Variations during Different Phases of El-Nino", *Mausam*, **56**, 4, 825-840.
- Kalsi, S. R., Hatwar, H. R., Jayanti, J. N., Subramanian, S. K., Shyamala, B., Rajeevan, M. and Jenamani, R. K., 2004, "Various aspects of unusual behaviour of monsoon-2002", India Meteorological Report No 2004/2.
- Keladis, G. N. and Diaz, H. F., 1989, "Global climatic anomalies associated with extremes in the southern oscillation", *J. Climate*, **2**, 1069-1090.
- Krishna Kumar, K., Balagi, Rajagopal and Kane, M. A., 1999, "On the weakening of relationship between the Indian monsoon and El-Nino", *Science*, **284**, 25 June.
- Mooley, D. A. and Paolino, D. A., 1989, "The response of the Indian monsoon associated with the change in sea surface temperature over the eastern south equatorial Pacific", *Mausam*, **40**, 369-380.
- Rao, Y. P., 1976, "Southwest Monsoon" Met. Monograph, India Meteorological Department, Synoptic Meteorology, No.1/1976.
- Ramamurthy, K., 1969, "Some aspects of the break in the Indian Southwest monsoon during July and August", FMU Rep. IV. **18**, India Meteorological Department, New Delhi.
- Rasmusson, E. M. and Carpenter, T. H., 1983, "The relationship between eastern equatorial Pacific Sea surface temperatures and rainfall over India and Sri Lanka", *Mon. Wea. Rev.*, **111**, 517-528.

- Raman, C. R. V. and Rao, Y. P. 1981, "Blocking highs over Asia and monsoon droughts over India", *Nature*, **289**, 221-223.
- Raman, C. R. V., 1955, "Breaks in the Indian southwest monsoon and typhoons in southwest Pacific", *Current Science*, **24**, 219-220.
- Sikka, D. R. and Gadgil, S., 1980, "On the maximum cloud zone and the ITCZ over Indian longitudinal during the southwest monsoon", *Mon. Wea. Rev.*, **108**, 1840-1853.
- Singh, O. P., 2001, "Long term trends in the frequency of monsoonal cyclonic disturbances over the north Indian Ocean", *Mausam*, **52**, 4, 655-668.
- Thapliyal, V., 1997, "Preliminary and Final Long Range Forecast for seasonal monsoon rainfall over India", *J. of Arid Env.*, **36**, 385-403.
- Walker, G. T., 1924, "Correlation in seasonal variation of weather", IX, A further study of world weather, *Memoirs of India Meteorological Department*, **24**, 275-332.
-