

Evolution of convection anomalies over the Indo-Pacific region in relation to Indian monsoon rainfall

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सार – इस शोध-पत्र में भारत की ग्रीष्मकालीन मानसून वर्षा (आई. एस. एम. आर.) और प्रशांत महासागर के भारतीय क्षेत्र में शीत ऋतु से मानसून पूर्व ऋतु तक की संवहनीय गतिविधियों के विकास के मध्य संबंधों का पता लगाने का प्रयास किया गया है। इस अध्ययन में राष्ट्रीय महासागरीय और वायुमंडलीय प्रशासन (एन. ओ. ऐ. ऐ.) के ध्रुव कक्षीय अंतरिक्ष यान से प्राप्त हुए जनवरी 1975 से मई 2004 तक के निर्गामी दीर्घ तरंग विकिरण (ओ. एल. आर.) के मासिक औसत आँकड़ों का उपयोग किया गया है। यह देखा गया है कि अधिक आई. एस. एम. आर. वाले वर्षों में नकारात्मक ओ. एल. आर. (संवहन) विसंगतियाँ प्रशांत महासागर के पश्चिमी क्षेत्र पश्चिम उत्तर दिशा में जनवरी से धीरे-धीरे सुदृढ़ होने लगती हैं और मई माह तक दक्षिण पूर्व एशियाई क्षेत्र और पूर्वी भूमध्यरेखीय हिंद महासागर के समीपवर्ती क्षेत्रों में स्थापित हो जाती हैं। जिससे जनवरी में पश्चिमी प्रशांत महासागर में अनियमित आरोही गति (राइजिंग मोशन) के धीरे-धीरे प्रतिवर्तन से लेकर इसी क्षेत्र में अनियमित अवरोहण गति (सिंकिंग मोशन) तक का पता चला है। यद्यपि आई. एस. एम. आर. वर्षों में पश्चिमी प्रशांत महासागर क्षेत्र में जनवरी में स्थापित नकारात्मक ओ. एल. आर. विसंगतियाँ इस क्षेत्र में लगभग मई तक सक्रिय रहती हैं अतः इसके परिणामस्वरूप प्रशांत महासागर के पश्चिमी क्षेत्र में शीत ऋतु से मानसून पूर्व ऋतु तक आरोही गति लगातार बनी रहती है।

1979, 1982, 1987, 2002 और 2004 के न्यून वर्षा वाले वर्षों में फरवरी से मई तक पूर्वी हिंद महासागर और उसके समीपवर्ती दक्षिण पूर्व एशिया के क्षेत्रों की तुलना में पश्चिमी प्रशांत महासागर के 150° पूर्व में भी न्यून वर्षा वाले वर्षों की भाँति ओ. एल. आर. विसंगतियों के विकास से सामान्य की अपेक्षा तीव्र संवहनीय गतिविधि का पता चला है जबकि उसके परिणाम में तीव्र अंतः वार्षिक भिन्नता पाई गई है। जनवरी से मार्च तक की प्रशांत महासागर के पश्चिमी क्षेत्र की ओ. एल. आर. विसंगतियों की प्रवृत्ति में और मई में पश्चिमी भूमध्यरेखीय प्रशांत महासागर एवं पूर्वी हिंद महासागर तथा इसके निकटवर्ती दक्षिण पूर्वी एशियाई क्षेत्रों के बीच पाई गई। ओ. एल. आर. विसंगतियों की विभिन्नता के आई. एस. एम. आर. के साथ महत्वपूर्ण (95% स्तर) सहसंबंधों का पता चला है और अत्याधिक वर्षा वाले वर्षों में सामान्य समाश्रयण निदर्श का उपयोग करके इन दो पूर्वसूचकों द्वारा पूर्वानुमानित आई. एस. एम. आर. की तुलना में वास्तविक आई. एस. एम. आर. सहित महत्वपूर्ण सी. सी. (क्रमशः 95% और 99% स्तर) का पता चला है।

ABSTRACT. The present study is an attempt to explore a relationship between Indian Summer Monsoon Rainfall (ISMR) and the evolution of convective activity during winter to pre-monsoon seasons over the Indo-Pacific region. The monthly mean Outgoing Long-wave Radiation (OLR) data obtained from National Oceanic and Atmospheric Administration (NOAA) polar orbiting spacecraft are used in this study from January 1975 to May 2004. It is observed that the negative OLR (thus, convection) anomalies from January gradually strengthen in a west northwest direction from western Pacific region and got established over the southeast Asian region and adjoining eastern equatorial Indian Ocean by the month of May during excess ISMR years indicating a gradual reversal of anomalous rising motion over western Pacific in January to anomalous sinking motion in May over western Pacific region. However, during the deficient ISMR years the negative OLR anomalies established over the western Pacific region in January almost remain active over the same region till the month of May and consequently there is persistent presence of rising motion from northern winter to pre-monsoon seasons over the western Pacific.

Similar to the patterns during the deficient composite the evolution of OLR anomalies show stronger than normal convective activity over the western Pacific region east of 150° E compared to that of eastern Indian Ocean and adjoining southeast Asia from February to May during the deficient years of 1979, 1982, 1987, 2002, and 2004 though there exists strong interannual variability in its magnitude. The tendency of OLR anomalies over the western Pacific region from January to March and the difference of OLR anomalies between western equatorial Pacific and eastern Indian Ocean and adjoining southeast Asia regions in the month of May shows significant (95% level) correlation with ISMR and the predicted ISMR with these two predictors using simple regression model shows significant correlations (95% and 99% level respectively) with actual ISMR for the extreme years.

Key words – Indian Summer Monsoon Rainfall (ISMR), Outgoing Long-wave Radiation (OLR), Convection, Long range forecast.

1. Introduction

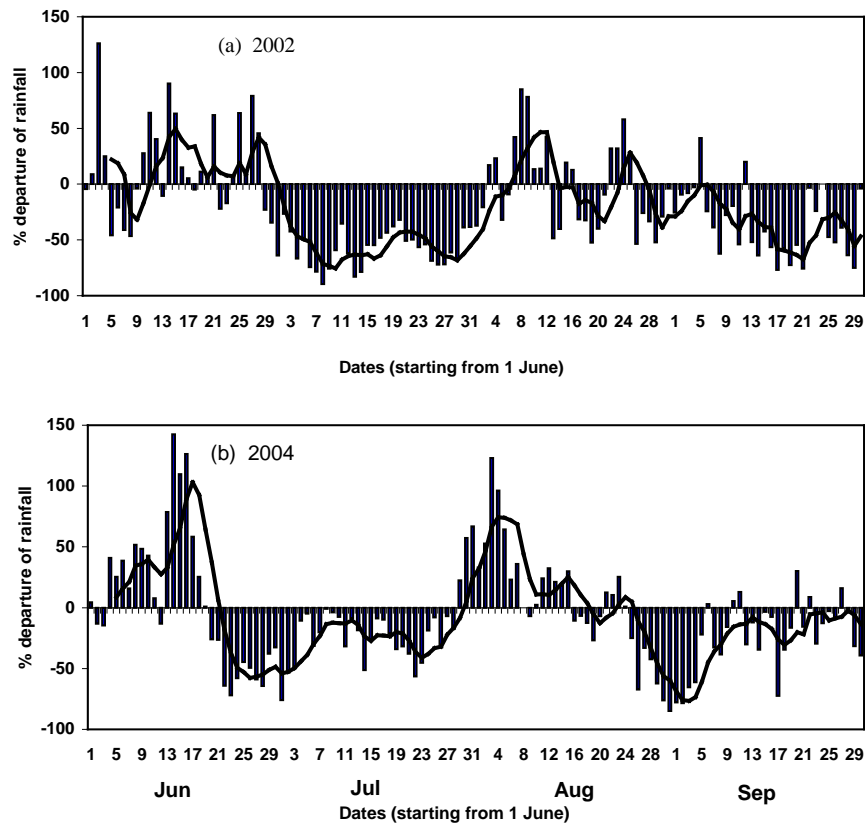
Being an agricultural country, the success or failure of the crops over India is always viewed with the greatest concern and these problems are closely linked with the behaviour of the summer monsoon rains from June to September (JJAS) as it contributes more than 80% of the annual total rainfall. Mean monsoon rainfall over the entire country as a whole during JJAS is 88 cm, as per India Meteorological Department (IMD), with a coefficient of variation of 10%. There are year-to-year variations of the monsoon with respect to the amount of monsoon rains and its distribution in different parts of the country. This interannual variability of Indian Summer Monsoon Rainfall (ISMR) occasionally causes large-scale droughts over different parts of the country, resulting in a significant reduction in agricultural output. The country has experienced such drought conditions over many of its parts during two recent years of 2002 and 2004, in which the seasonal rainfall departure over the country during JJAS was -19% and -13% respectively. The daily all India rainfall departure (%) from 1st June to 30th September for 2002 and 2004 is shown in Figs. 1(a&b). With the early onset of monsoon during 2004, the rainfall activity was very good during the first half of June and subsequently the subdued rainfall activity started and it continued almost till the last week of July [Fig. 1(b)]. However, it may be mentioned here that although the rainfall was below normal on most of the days during July 2004, the negative departures were less compared to that of corresponding departure during 2002 as shown in Fig. 1(a). The month of September also got large negative departure during many days of 2004.

This year-to-year fluctuation has greatest impact on our economy. Forecasting of the monsoon rainfall at least a season in advance, assumes profound importance for policy-making and planning of mitigatory efforts. This had been felt since long back when the forecasting of ISMR was started more than a century ago (Blanford, 1884) by using Himalayan snow cover. Since then, many statistical models based on empirical relationships among various predictors determined through the analysis of linear correlation with ISMR are being used for the prediction of ISMR (Shukla, and Paolino, 1983; Krishnakumar *et al.*, 1995; Thapliyal, 1997; Rajeevan *et al.*, 1998; Pattanaik, 2001; Sahai *et al.*, 2003; Rajeevan *et al.*, 2003 *etc.*). Sikka (1980), Shukla and Paolino (1983) and many others have found that among the various predictors, ENSO (El Nino-Southern Oscillation) has a ubiquitous influence on the monsoon circulation, which can play a dominant role in the forecast of ISMR. However, the search of new predictors is a greatest challenging job in view of weakening correlations of most of the predictors with ISMR in recent times

(Krishnakumar *et al.*, 1999 ; Chang *et al.*, 2001). Ramage (1983) has pointed out that the relationship between ISMR and some of the parameters (predictors) either ceased to exist or showed considerable decline with passage of time. Thus, most of the models could not predict the ISMR reasonably well for the recent two drought years of 2002 and 2004. Hence, the long range forecasting of ISMR remains a significant challenging job to the meteorological community. Many studies have been performed to understand the causes of the failure of monsoon 2002 (Sikka, 2003; Kalsi *et al.*, 2004, Srivastava *et al.*, 2004). In order to understand the role of many ocean-atmospheric processes associated with Indian summer monsoon, several previous field experiments (IIOE-1963-65, ISMEX-1973, MONEX-1977, MONEX-1979, BOBMEX-1999 and ARMEX-2002-03) have been conducted (Sikka, 2005). Though, these experiments have contributed to our knowledge of the large-scale features of the Indian summer monsoon, still a detailed analysis of the observational data (not only from the surface and upper air observations but also the satellite derived products) is required to further understand the complex nature of Indian summer monsoon. The present study is an attempt to find out any precursory patterns which can be used as the predictors for long range forecast of monsoon rainfall over India considering the abnormal behaviour of recent two deficient years of 2002 and 2004 and the failure to forecast the same.

2. Data and methodology

The OLR data measured from Advanced Very High Resolution Radiometers aboard National Oceanic and Atmospheric Administration (NOAA) polar orbiting spacecraft down loaded from the Web site at <http://www.cdc.noaa.gov/> are used in this study from January 1975 to May 2004, excluding the calendar year 1978 (when there was failure in satellite). The seasonal rainfall over the country during JJAS is obtained from the rainfall series prepared by IMD during the same period. To study the east-west circulation features, the monthly mean vertical velocity (ω) and velocity potential data obtained from the National Centre for Environmental Prediction (NCEP) reanalysis (Kalnay *et al.*, 1996) are also used in the present study. The monthly composite OLR anomalies are prepared and analysed from January to May (winter to pre-monsoon) before ensuing excess years and deficient years. The excess (deficient) years are identified when the percentage departure of ISMR for a given year is \geq (\leq) one standard deviation. Under this classification during 1975 to 2004, the 4 excess years identified are 1975, 1983, 1988 & 1994 and the 6 deficient years identified are 1979, 1982, 1986, 1987, 2002 and 2004. 1976 and 1997 were El Nino years but the ISMR was near normal.



Figs. 1(a&b). % departure of all India daily rainfall for the country as a whole from 1 June to 30 September for (a) 2002 and (b) 2004. The moving averages of 5 days mean are superposed

3. Results and discussions

3.1. Monthly mean OLR cycle

The OLR (a proxy for deep convection) is being used widely for the monsoon research (Webster; 1995; Krishnan *et al.*, 2000, Gadgil *et al.*, 2004 and Pattanaik *et al.*, 2005). Recent study by Pattanaik *et al.*, (2005) have found that the convective activity increases over Arabian Sea, Bay of Bengal and Indian land mass particularly to the south of 25° N during the early onset year of 2004, whereas, during late onset year of 2003, the convective activity over the Arabian Sea is quite less. Gadgil *et al.*, (2004) have suggested a possible link between the variation of deep convection over the equatorial Indian Ocean and ISMR by examining the OLR data over the Indian Ocean. Before analysing the OLR anomalies during excess and deficient year, it is necessary to examine the evolution of long-term mean OLR patterns. Fig. 2 shows the long-term OLR mean (1979-2003) from

January to October. It is seen from Fig. 2 that the locus of OLR minima (and, thus convection) moves northwards from the warm pool region to Southeast Asia from boreal winter to summer. It is also seen that between March and April, the magnitude of OLR along the equator begins to increase suggesting a weakening of convection. By May and June the monsoon heating is rapidly increased by the growth of convection to the north of the equator. The locus of OLR minima covers most parts of India during the active monsoon phase of July and August. During September the southward retreat of OLR minima begins and by October the OLR patterns indicate an increase in value over the India region, indicating withdrawal of monsoon. Thus, from the OLR cycle, it is seen that the minima in OLR (correlated with maximum convection) exists in the eastern Indian Ocean and the western Pacific Ocean and through spring and early summer, the locus of minima OLR moves northward to the East and South Asia with very rapid change. Webster (1995) has also shown that during March to May, the heat sources and sinks over

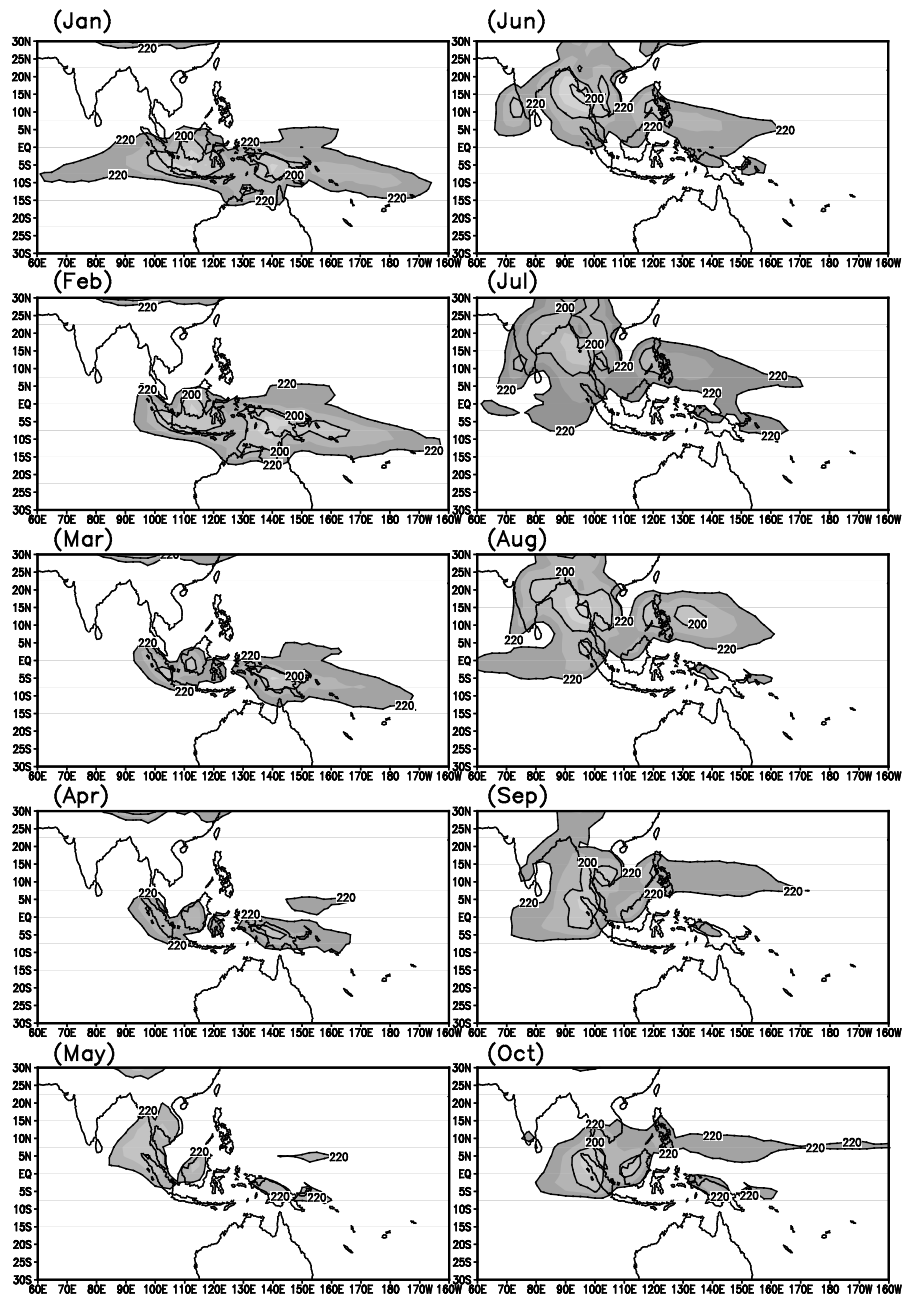


Fig. 2. Monthly long-term mean Outgoing Longwave Radiation (OLR) prepared from January to October. The shaded regions are OLR with value less than 220 watts/m^2

the western Pacific Ocean and the eastern Indian Ocean are undergoing their strongest and most rapid change and this heating tends to develop a strong asymmetric component as the locus of maximum heating moves northwards towards South Asia.

3.2. Evolution of convection anomalies during excess and deficient years

From the annual cycle of large-scale heat sources and sinks Webster (1995) had shown that with the

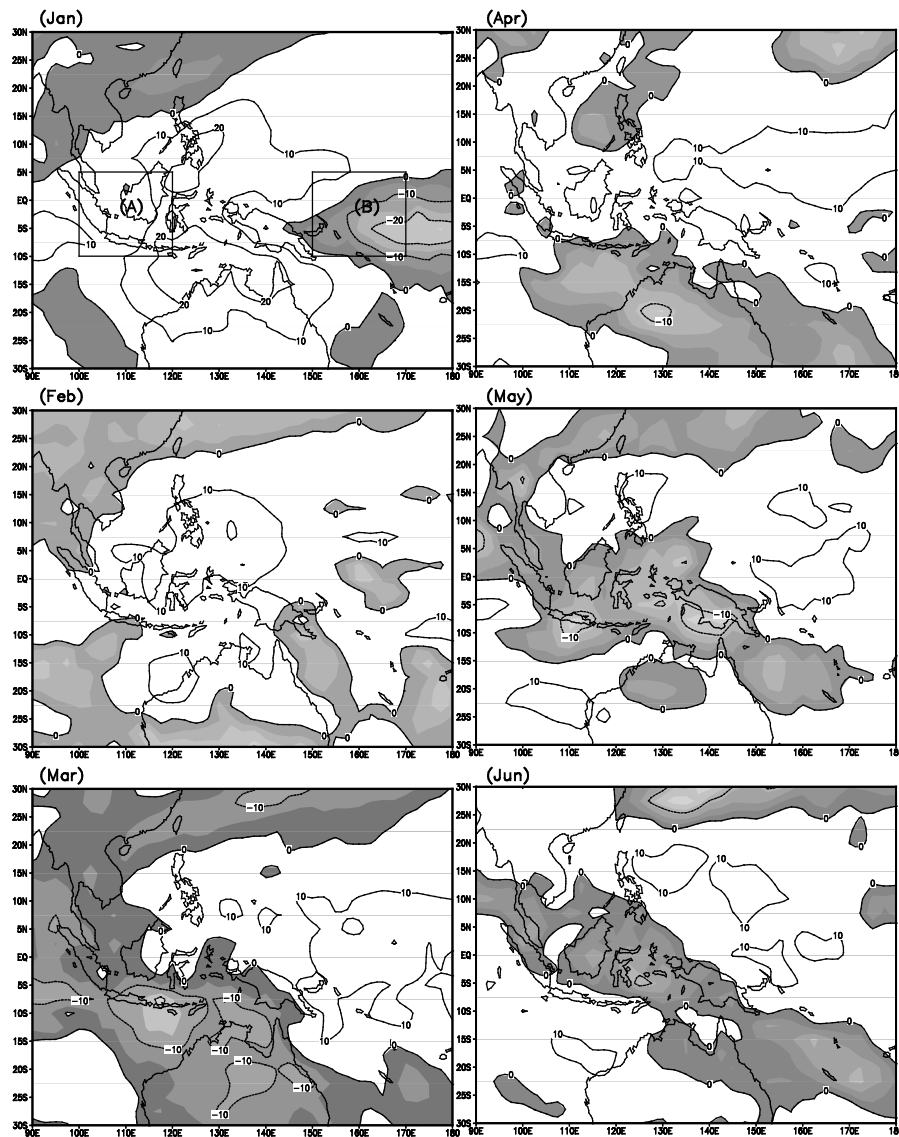


Fig. 3. Monthly composite OLR anomalies from January to June for the 4 excess ISMR years with negative values shaded

evolving summer monsoon over South Asia during late spring the summer monsoon is in its strongest growing phase. Again as there is a considerable variability in the phase and amplitude of each monsoon year (Webster and Yang, 1992), it is very essential to examine the evolution of convection patterns during different years. In order to use this as a precursor for the prediction of ISMR, the composite OLR anomalies has to be analysed just before the commencement of monsoon. The composite OLR anomalies from January to June during 4 excess ISMR years and 6 deficient ISMR years as defined earlier are

shown in Fig. 3 and Fig. 4 respectively. Here in Fig. 3 and Fig. 4 we have included the month of June in order to see the continuity of the patterns from winter to the beginning of southwest monsoon over India, though the features during June are not used as predictive feature for ISMR. It is seen that the OLR anomalies from January to June over the western equatorial Pacific (WEP) and eastern Indian Ocean and adjoining southeast Asia (EIOSA) show contrasting evolution before ensuing excess ISMR years and deficient ISMR years (Fig. 3 & Fig. 4). Prior to the excess ISMR years the composite anomalies during

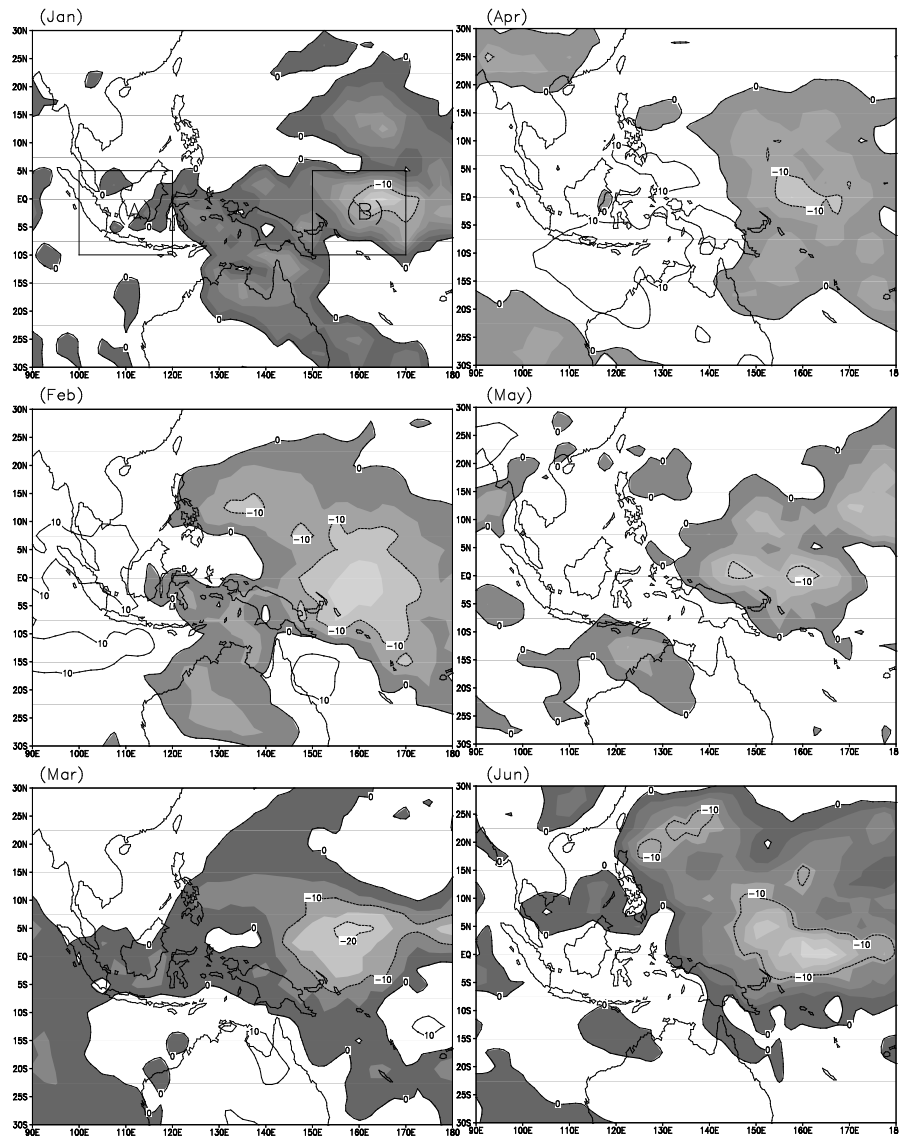
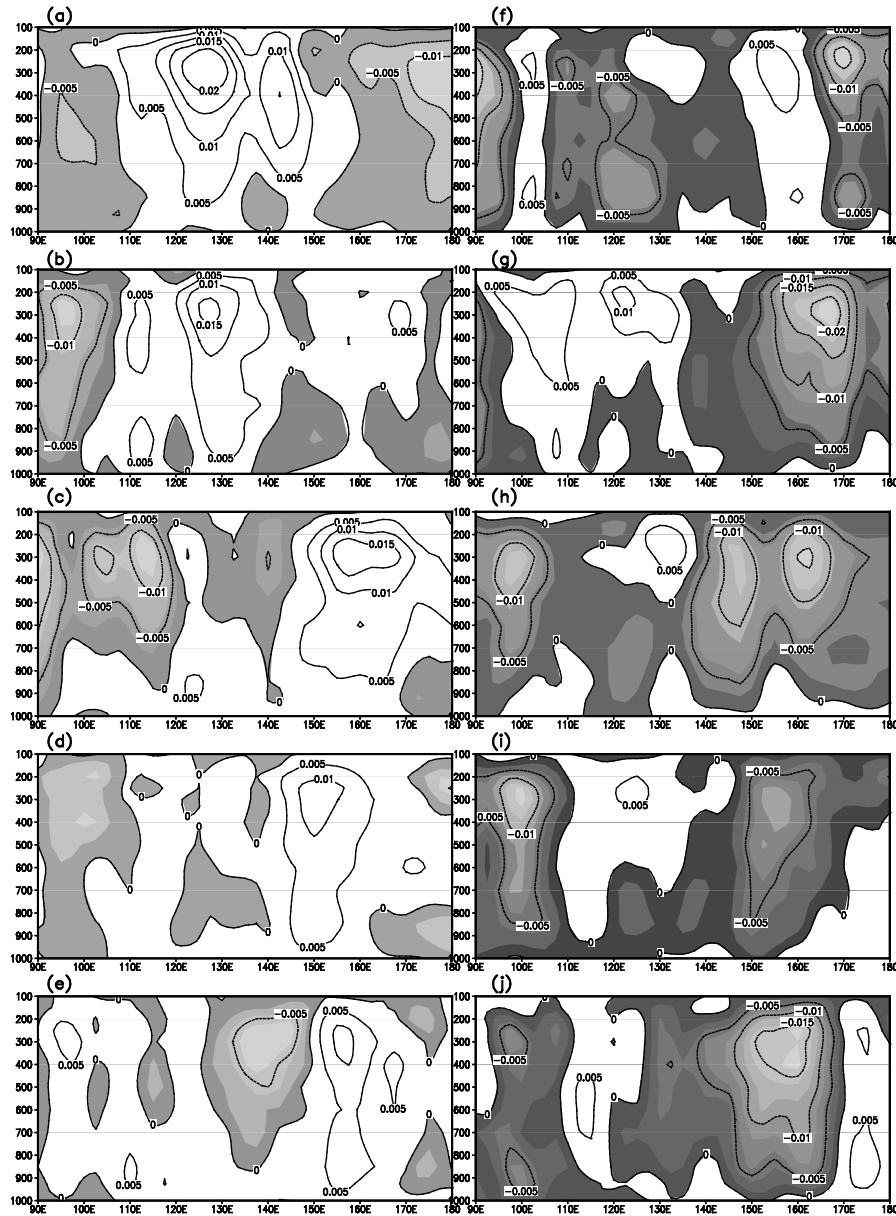


Fig. 4. Monthly composite OLR anomalies from January to June for the 6 deficient ISMR years with negative values shaded

January (Fig. 3) show negative anomalies associated with stronger than normal convective activity over the 'WEP' region (identified as box 'B' bounded by $150^{\circ}\text{E} - 170^{\circ}\text{E} : 10^{\circ}\text{S} - 5^{\circ}\text{N}$) and positive anomalies associated with weaker than normal convective activity over the 'EIOSA' region (identified as box 'A', bounded by $100^{\circ}\text{E} - 120^{\circ}\text{E} : 10^{\circ}\text{S} - 5^{\circ}\text{N}$). It is also seen from Fig. 3 that the reversal of patterns occurred gradually during subsequent months from February to May and also continued in June with negative OLR anomalies over the 'WEP' region became positive (decrease in convective activity) and the positive

OLR anomalies over 'EIOSA' region became negative (increase in convective activity). On the other hand, during the deficient years though the similar patterns of OLR anomalies are seen in January (Fig. 4), its magnitude is very less both in western (box 'A') and eastern sector (box 'B') compared to that of corresponding excess composites for January (Fig. 3). Also during the deficient composites the convective activity over the 'WEP' region increases further with increase in negative anomalies to the east of 150°E during subsequent months from February to June (Fig. 4), which disappeared during the

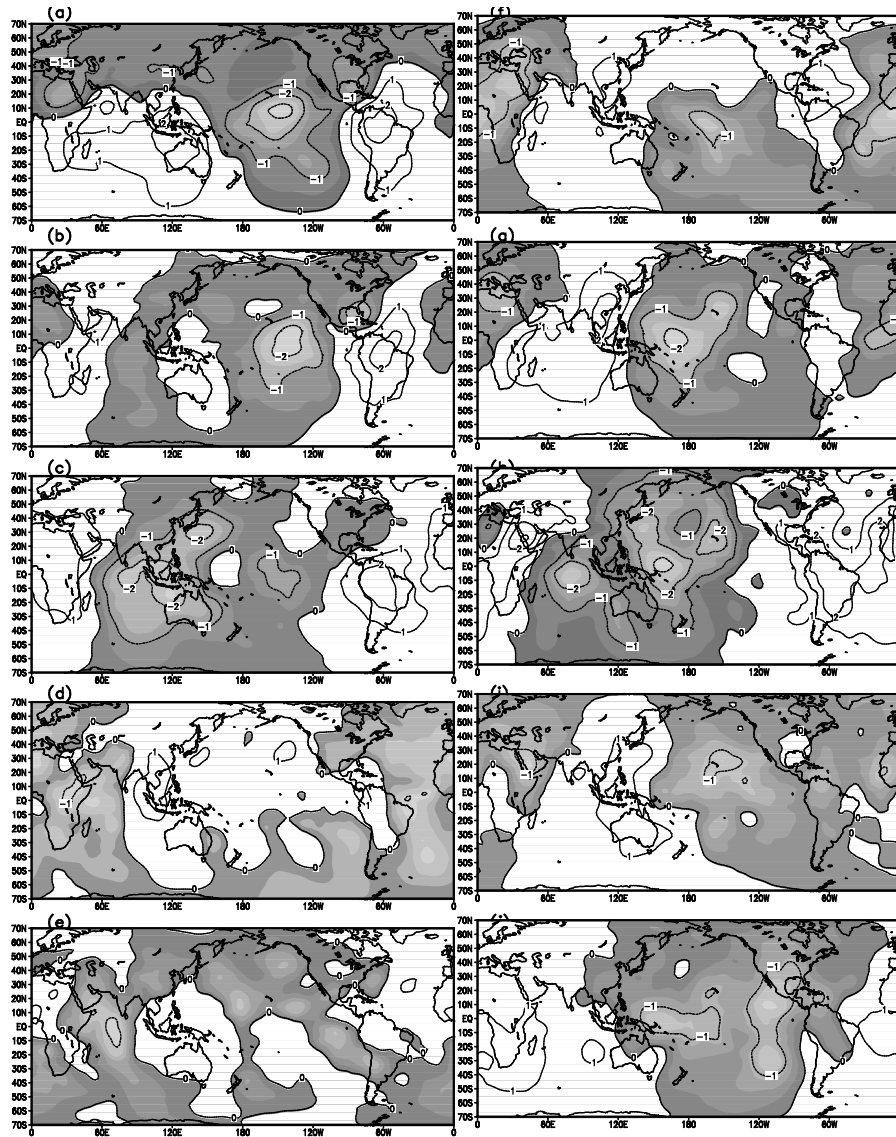


Figs. 5(a-j). Longitude-height plot of vertical velocity (ω) in Pa/sec averaged over the latitudes from 10° S to 5° N from January to May ('a' to 'e' before excess ISMR years) and ('f' to 'j' before deficient ISMR years). Rising motion shaded

excess years as it moves northwestward with the establishment of monsoon over east Asia and Southeast Asia. Thus, the convection anomalies established over the western Pacific region during the northern winter (January) almost remain active over the region till the month of May during deficient years, whereas during the excess years the convection anomalies from winter moves in a westnorthwest direction and got established over the southeast Asia region by the month of May.

3.3. Evolution of vertical velocity and divergent circulation during excess and deficient years

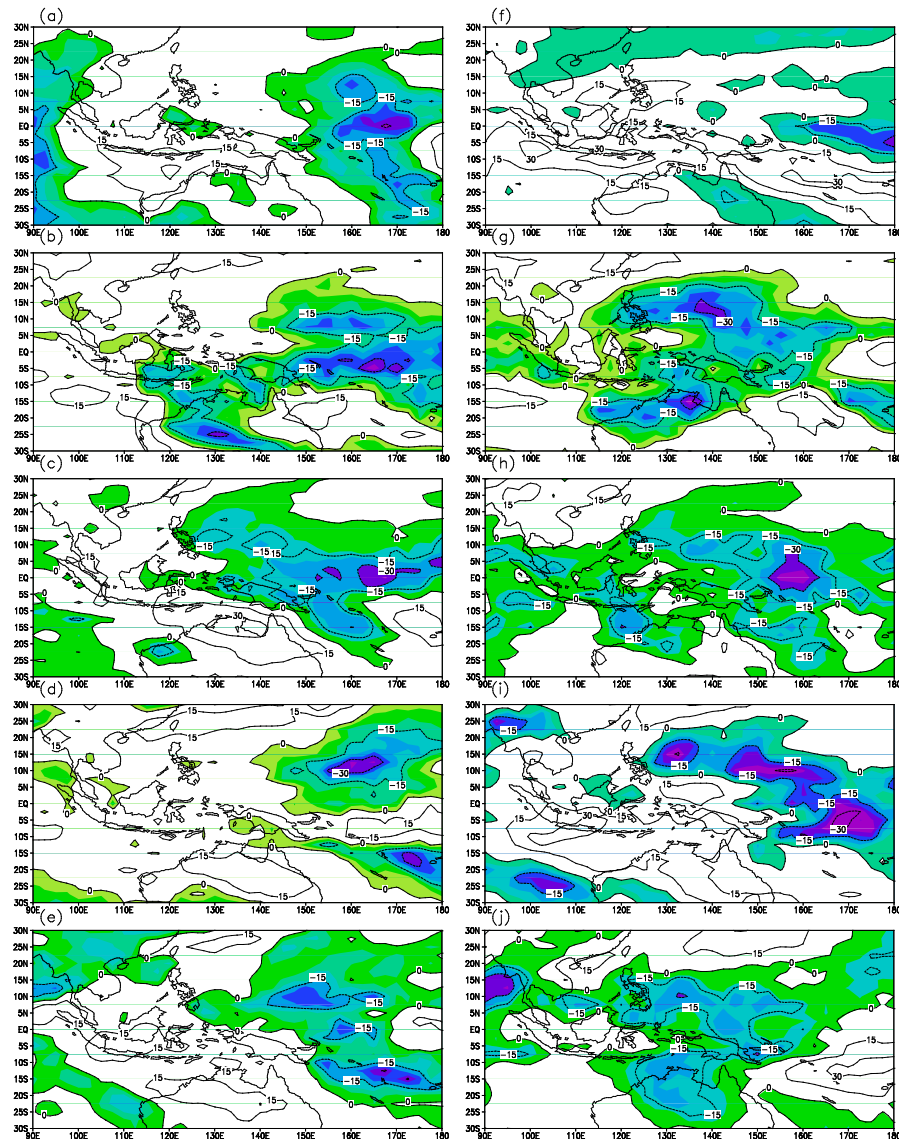
Fig. 5 shows the longitude-height plot of vertical velocity (ω) anomaly averaged between 10° S - 5° N from January to May. It is seen from Fig. 5 that in association with the migration of convection anomalies discussed above, the longitude-height plot of vertical velocity shows persistent presence of large scale



Figs. 6(a-j). Monthly composite anomalies of velocity potential from January to May at 200 hPa (respectively from 'a' to 'e' before excess ISMR years and (respectively from 'f' to 'j' before deficient ISMR years). The contour interval is $1 \times 10^6 \text{ m}^2 \text{ sec}^{-1}$ and the negative (outflow) regions are shaded

anomalous upward motion over the western equatorial Pacific between 150° E to 170° E (WEP region) from January to May during deficient years [Figs. 5(f-j)], whereas during the excess years [Figs. 5(a-e)] the anomalous rising motion observed to the east of 150° E in winter [Fig. 5(a)] is replaced subsequently by anomalous sinking motion during May [Fig. 5(e)] with anomalous increase of convective activity over the eastern Indian Ocean and adjoining southeast Asia (EIOSA) as shown in Fig. 3. The monthly evolution of 200 hPa composite velocity potential anomalies during excess and deficient

years (Fig. 6) also show persistent presence of anomalous rising motion over 'WEP' region during deficient years [Figs. 6(f-j)], whereas during the excess years the centre of rising motion shifted from 'WEP' region in winter to the 'EIOSA' region in the month of May [Figs. 6(a-e)]. Thus, the east-west oscillation of the anomalous Walker circulation between 'WEP' and 'EIOSA' regions with persistent presence of rising motion over 'WEP' region from northern winter to Pre-monsoon season can give possible indication for the ensuing weak monsoon conditions over India.

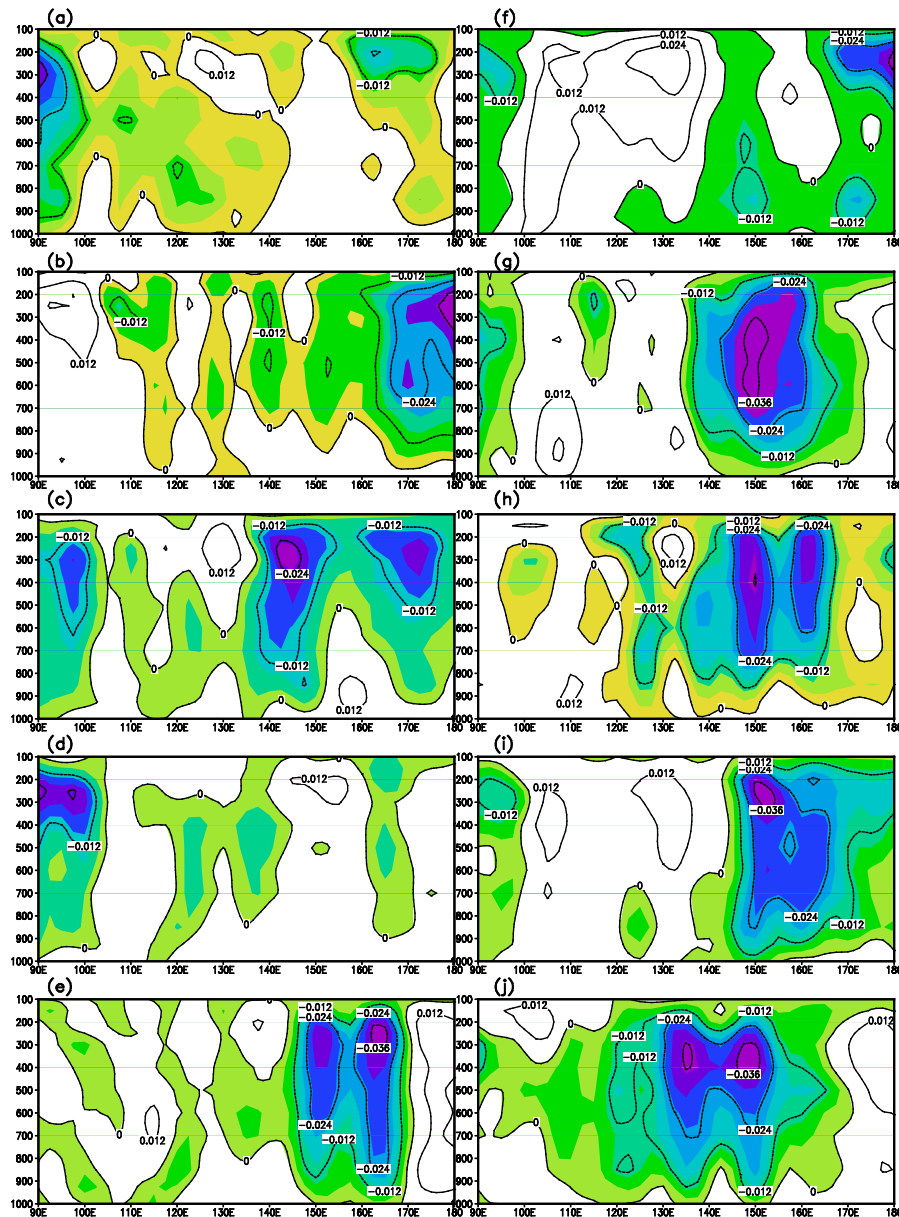


Figs. 7(a-j). Monthly OLR anomalies from January to May for 2002 (respectively from 'a' to 'e') and 2004 (respectively from 'f' to 'j')

3.4. Evolution of OLR and Omega anomaly during 2002, 2004 and other deficient years

In order to examine the evolution of OLR anomalies and the east west Walker circulation from winter to pre-monsoon seasons during recent two deficient years of 2002 and 2004, the monthly OLR anomalies are plotted from January to May for the year 2002 and 2004 in Fig. 7. It is observed from Figs. 7(a-e) that during 2002, the strong negative OLR anomalies were prevailing east of 150° E through January to May, a feature similar to the evolution of composite OLR anomalies during deficient

ISMR years as shown in Fig. 4. It is also observed that over the 'EIOSA' region the OLR anomalies are positive from January to May, which indicate weaker convective activity during 2002. Associated with the convection anomalies stronger anomalous rising motion also prevailed east of 150° E from January to the month of May [Figs. 8(a-e)] before the deficient monsoon of 2002. Similar to 2002, during the monsoon season of 2004 also stronger than normal convective activity prevailed over the 'WEP' region compared to that of 'EIOSA' region from January to May [Figs. 7(f-j)], which is also identical to the evolution of composite OLR anomalies during the



Figs. 8(a-j). Longitude-height plot of vertical velocity (ω) in Pa/sec averaged over the latitudes from 10° S to 5° N from January to May for 2002 (respectively from 'a' to 'e') and for 2004 (respectively from 'f' to 'j')

deficient years as shown in Fig. 4. In association with the migration of convection anomalies, the corresponding longitude-height plot of vertical velocity (ω) anomaly averaged between 10° S - 5° N from January to May during 2004 [Figs. 8(f-j)] show persistent presence of large scale upward motion between 150° E to 170° E (box 'B') from January to May and sinking motion over the western region from 100° E to 120° E (box 'A'). Thus, the east-west oscillation of the anomalous Walker circulation

between 'WEP' region and 'EIOSA' region are changed in according with the evolution of OLR anomalies for the deficient monsoon years of 2002 and 2004. In order to see the interannual variability of the pattern of convective activity the OLR anomalies from January to May for other deficient years *viz.*, 1979, 1982, 1986 and 1987 are also examined (Fig. not shown). It is also observed that stronger than normal convective activity prevailed over the 'WEP' region compared to that of 'EIOSA' region

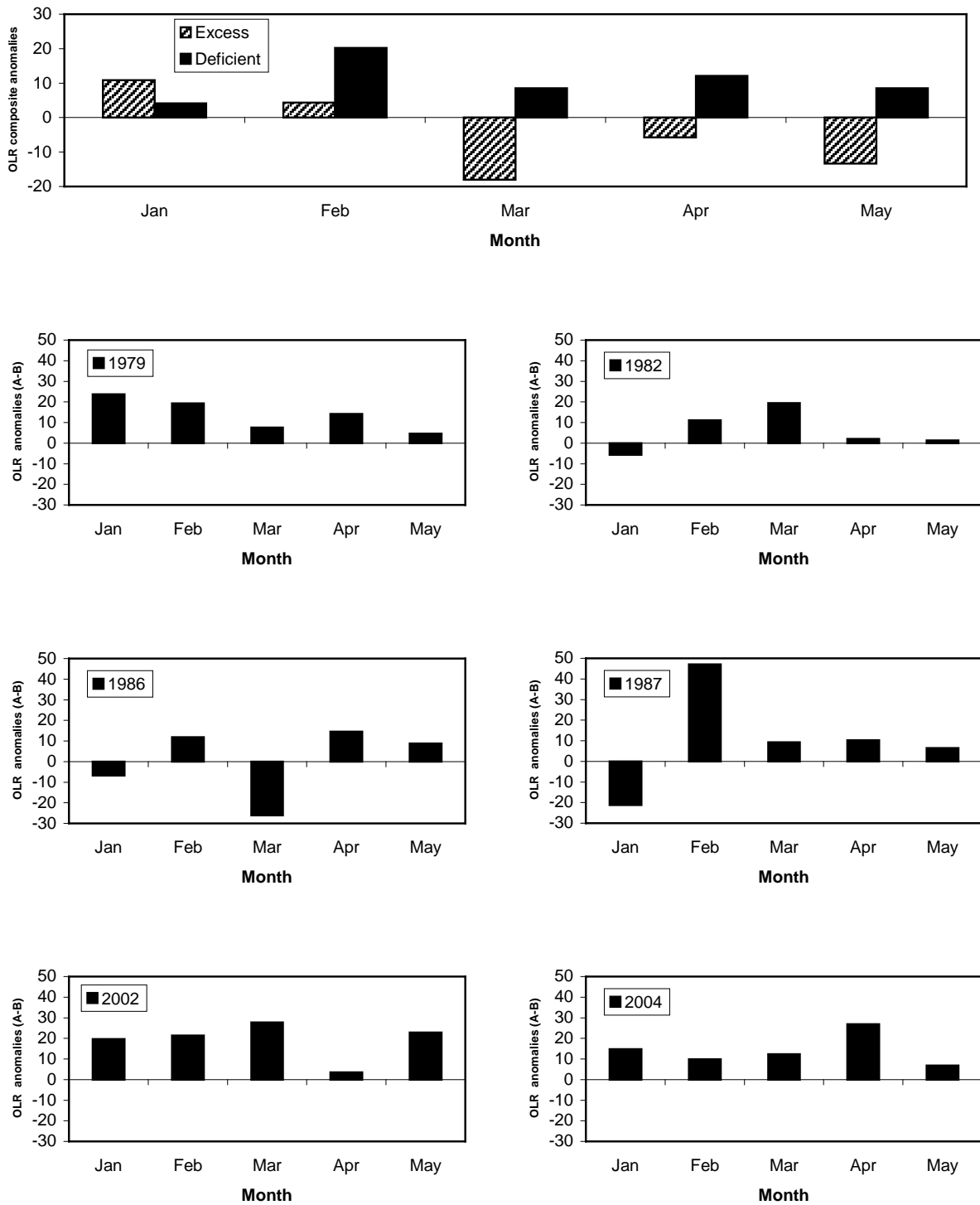


Fig. 9. The difference of OLR anomalies over the region 'A' (100° E - 120° E, 10° S - 5° N) and 'B' (150° E - 170° E, 10° S - 5° N). Composite anomalies for 4 excess and 6 deficient years & for individual deficient years as indicated

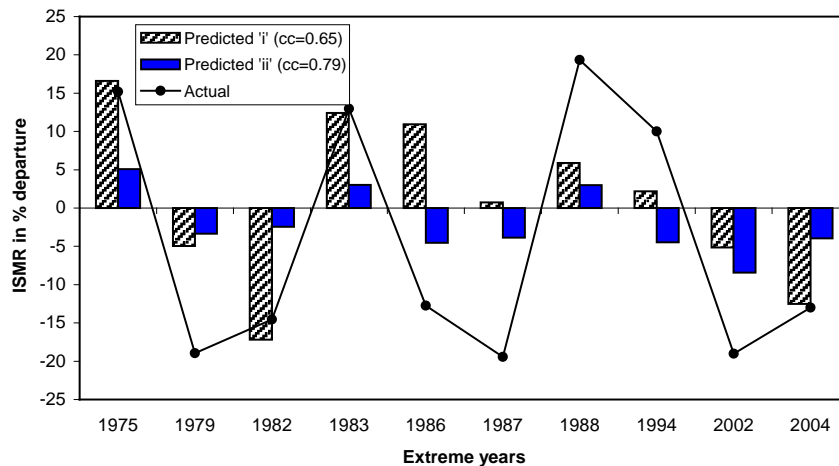


Fig. 10. Actual and predicted Indian summer monsoon rainfall with two parameters identified above during the 10 extreme years between 1975 to 2004

from January to May during 1979, 1982 and 1987. However, during the year 1986 (when the El Niño was in developing phase from January) the pattern of OLR anomalies show large band of convective activity extending from 'EIOSA' region to 'WEP' region during the month of January and March. Thus, it is seen from the present results that even during the El Niño linked deficient years of 1982, 1987, 2002 and 2004 the evolution of OLR anomalies are very much identical with stronger than normal convective activity prevailed over the 'WEP' region compared to that of 'EIOSA' region from January to May. Thus, it is suggested that during the El Niño linked years of 1982, 1987, 2002 and 2004 the warming of SSTs over the Western Pacific regions east of 150° E are associated with increase in convective activity over the region to the east of 150° E than that of west of 150° E during January to May.

In order to quantify the contrasting evolution of convective activity during the excess and deficient years from January to May as shown in Figs. 3 & 4 the OLR anomalies were calculated over the two regions identified in the boxes in Fig. 3 with western sector over the 'EIOSA' region ('A') bounded by 100° E - 120° E : 10° S - 5° N and the eastern sector over the 'WEP' region ('B') bounded by 150° E - 170° E : 10° S - 5° N. The strength of relative convective anomalies over these two regions are compared by taking the difference of OLR anomaly over the region ('A') and the OLR anomaly over the region ('B') from January to May during excess and deficient years. The OLR anomaly over 'A' - the OLR anomaly over 'B' for the individual deficient years and the

composite mean of these years from January to May is shown in Fig. 9. It is seen from the composite mean (Fig. 9; top) that there is a reversal in convection anomalies with change of sign from positive in winter (January-February) to negative in pre-monsoon (March-May) months during the excess composite years, which is associated with gradual decrease of convective activity over the 'WEP' region and increase of convective activity over the 'EIOSA' region. However, during the deficient years it remains positive from January to May without change of sign, which indicate persistent presence of stronger convective activity over the 'WEP' region compared to that of the 'EIOSA' region (Fig. 9; top). For the individual deficient years also (shown in Fig. 9) the patterns are closely matching with that of deficient composite anomalies for the deficient years 1979, 2002 and 2004 with all the values are on the positive side. The deficient years of 1982 and 1987 (El Niño years) also had similar patterns from February to May although it started from a weak negative value in January. Again during the deficient year of 1986, the negative value appeared in March did not persist in two subsequent months from April to May and it became positive like that of other deficient years. It is also seen from Fig. 9 that the magnitude of the difference from January to May is not identical during all the 6 deficient years with 2002 showing large positive difference from January to March and again in the month of May. However, the signal is weak in the month of May for the deficient years of 1979, 1982, 1987 and 2004. Again during the deficient years 1982, 1987, 2002 and 2004 the signal during March is stronger than that during the month of May. It is also observed that following the strong El Niño year of 1997

the year of 1998 also shows a exactly similar pattern like that of excess composites with positive values from January to May (Fig. not shown) although the El Nino was still active till the beginning of monsoon during 1998. Thus, the OLR anomalies from January to May during excess and deficient monsoon years show contrasting patterns with respect to its intensity and its movement from boreal winter to summer over western equatorial Pacific and eastern Indian Ocean and adjoining southeast Asia. During some occasions the signal is prominent in March and on some occasions it is prominent during May.

Considering the signal during the month of March and May, two predictors are identified based on the evolution of OLR anomalies from January to May. First the Correlation Coefficient (CC) is calculated with the tendency of OLR anomalies (OLRA) over the western Pacific region (box 'B') between January and March with ISMR for the period from 1975 to 2004, excluding the year 1978 and is found to be -0.4 . Similarly, another significant CC with ensuing ISMR is also found with the second predictor obtained by taking the difference of OLRA between the regions bounded by box 'A' and box 'B' in the month of May. The two linear regression equations based on these two parameters along with the CCs values are shown below.

<i>Parameters</i>	<i>Regression Eq.</i>	<i>CC</i>
(i) (January OLRA – : March OLRA) in box 'B',	$Y = -0.577 \times -1.2035$	-0.40
(ii) (OLRA in box 'A' : –OLRA in box 'B') in May	$y = -0.278 \times -2.0839$	-0.38

The above CCs are significant at 95% level. In order to consider the prospect of using the above two parameters in a simple linear regression model for the prediction of ISMR, the predicted ISMR based on the above two regression equations along with actual ISMR during the 10 extreme years are shown in Fig. 10. It is seen from Fig. 10 that the parameter 'i', which can be used in the month of April shows inverse relationship with ISMR during all the year except during 1994. Similarly, the parameter 'ii', which uses the OLR anomalies during the month of May shows opposite relation with ISMR on 80% occasions, out of 10 extreme years except on two occasions (1986 and 1987). Though the CCs explain only about 16% of variance for the whole period considered the CCs between predicted ISMR and actual ISMR with both the parameters increased to 0.65 and 0.79 (significant at 95% and 99% level) respectively with 10 extreme years only (Fig. 10). Thus, it is seen that the above two

parameters identified based on the OLR anomalies have some skills in capturing the sign of ISMR departure during most of the extreme years though the magnitudes are not matching perfectly.

4. Conclusions

Following conclusions may be drawn from the present study :

It is found that the convection anomalies from winter moves in a west northwest direction from western Pacific region and got established over the eastern Indian Ocean and adjoining southeast Asia region by the month of May before an ensuing excess ISMR year indicating a gradual reversal of anomalous rising motion over the western Pacific in January to anomalous sinking motion in May. However, during the deficient ISMR years the convection anomalies established over the equatorial western Pacific east of around 150° E during the northern winter (January) almost remain active over the same region till the month of May and consequently there is persistent presence of anomalous rising motion from January to May over the western Pacific region before deficient ISMR years. Similar to the patterns during the deficient composite the interannual variability of evolution of OLR anomalies show stronger than normal convective activity over the western Pacific region east of 150° E compared to that of eastern Indian Ocean and adjoining southeast Asia from February to May during the deficient years of 1979, 1982, 1987, 2002, and 2004 though there exists strong interannual variability in its magnitude.

The tendency of OLR anomalies over the western Pacific region bounded by 150° E - 170° E : 10° S - 5° N from January to March and the difference of OLR anomalies between the regions bounded by 100° E - 120° E : 10° S - 5° N & 150° E - 170° E : 10° S - 5° N in the month of May shows significant (95% level) correlation with ISMR and the predicted ISMR with these two predictors using simple regression model shows significant CCs (95% and 99% level respectively) with actual ISMR for the 10 extreme years.

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