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A diagnostic study of interannual variability of Indian summer monsoon using outgoing longwave radiation (OLR) data

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सार — 1979-92 के दौरान की अवधि में, एन.ओ.ए.ए. ध्रुवीय कक्षी उपग्रहों से प्राप्त मासिक बर्हिगामी दीर्घ तरंग विकिरण (ओ.एल.आर.) आंकड़ों के उपयोग से, अच्छे मानसून वर्षों (1983 और 1988), खराब मानसून वर्षों (ई.एन.एस.ओ. से संबंधित स्थिति के लिए 1982 और 1987 तथा ई.एन.एस.ओ. रहित स्थिति के लिए अलग से 1979 तथा 1986) तथा सामान्य मानसून वर्षों (1980, 1981, 1984, 1985, 1989, 1990, 1991 और 1992) के संबंध में मिश्रित ओ.एल.आर. असंगतियों की जाँच की गयी । 5° अक्षांश ग्रिड से 5° रेखांश पर 50° पू. तथा 130° प. रेखांशों (तिथि रेखा में से) के बीच बंधे भूमंडलीय उष्ण कटिबंध (30° उ. - 30° द.) के ऊपर अभिकलन किया गया ।

इन चारों स्थितियों में अप्रैल, सितंबर माह से मिश्रित बर्हिगामी दीर्घतरंग विकिरण असंगतियों के आवकाशिक वितरणों में महत्वपूर्ण भिन्नताएँ हैं, जो संगठित संवहनीय पद्धति में अवकाशिक तथा कालिक परिवर्तनों को सूचित करती हैं। अच्छे मानसून वर्षों के लिए इंडोनेशियन क्षेत्रों के ऊपर प्रस्थायित्व ऋणात्मक (निगेटिव्ह) असंगतियाँ दर्शाने वाली वर्धित संवहनीय क्रियाएं पायी गयी, जबकि तिथि रेखा के थोड़ा पश्चिम की ओर भूमध्य रेखीय प्रशांत महासागर के ऊपर बड़ी मात्रा में धनात्मक (पॉजिटिव्ह) असंगतियाँ दर्शाने वाली अवदाबित संवहनीय क्रियाएँ पायी गयी । खराब मानसून वर्षों के दौरान प्रशांत महासागर क्षेत्र (ई.एन.एस.ओ. स्थिति में) के ऊपर तथा भूमध्य रेखीय हिन्द महासागर (ई.एन.एस.ओ. रहित स्थिति में) के ऊपर सामान्य से ऊपर संवहनीयता पायी गयी । सामान्य मानसून वर्षा के दौरान बर्हिगामी दीर्घतरंग विकिरण असंगतियों की अवकाशिक पद्धतियां ठीक, अच्छे मानसून वर्षों के समान है, परंतु कमजोर असंगतियों के साथ । इन प्रेक्षणों को भारतीय उपमहाद्वीप के ऊपर और उत्तर हिन्द महासागर तथा प्रशांत महासागर के ऊपर उष्ण कटिबंधीय अभिसरण क्षेत्र (टी.सी.जैड.) के बीच सापेक्ष परस्पर क्रिया के माध्यम से समझाया जा सकता है । एल नीनो वर्षों के दौरान संवहनीय क्रिया का पूर्व की ओर हटाव, वॉकर परिसंचरण के हटाव/व्युत्क्रमण के कारण हो सकता है । मानसून पूर्व महिनों के दौरान बर्हिगामी दीर्घतरंग विकिरण असंगतियों के प्रबल चिह्न हैं, जो परवर्ती मानसून क्रिया की प्रकृति का अनुमान लगाने में उपयोगी हो सकती है ।

ABSTRACT. Using the monthly outgoing longwave radiation (OLR) data obtained from NOAA polar orbiting satellites, during the period 1979-92, composite OLR anomalies in respect of good monsoon years (1983 and 1988), bad monsoon years (1982 and 1987 for the case associated with ENSO and 1979 and 1986 separately for the case without ENSO) and normal monsoon years (1980, 1981, 1984, 1985, 1989, 1990, 1991 & 1992) were examined. The computation has been performed over the global tropics (30°N-30°S) bounded between the longitudes 50°E and 130°W (through date line) on 5° longitude × 5° latitude grid.

There are significant differences in the spatial distributions of composite OLR anomalies between these four cases from the month of April to September indicating spatial and temporal changes in the organized convective pattern. For the good monsoon years persistent negative anomalies indicating enhanced convective activity were observed over the Indonesian regions, whereas large positive anomalies indicating depressed convective activity were observed over equatorial Pacific just west of date line. During the bad monsoon years above normal convection was observed over Pacific region (ENSO case) and over equatorial Indian Ocean (Non ENSO case). During normal monsoon years, the spatial patterns of OLR anomalies were similar to that of good monsoon years, but with weaker anomalies. These observations can be explained through the relative interaction between tropical convergence zone (TCZ) over the Indian sub-continent and that over the north Indian Ocean and Pacific. The eastward shift of the convective activity during El-Nino years can be attributed to shift/reversal of Walker circulation. There are strong signals of OLR anomalies during premonsoon months which may be useful in inferring the nature of the subsequent monsoon activity.

Key words — Outgoing longwave radiation (OLR), Anomaly, Convective activity, Tropical convergence zone (TCZ), Good and bad monsoon years

1. Introduction

Monsoon is one of the most consistent global phenomena, which is affecting a large number of tropical countries where half of the total world population resides. Indian summer monsoon is the major source of water (about 70-90%) for most parts of the country. The country's agriculture, power generation and industrial production substantially depend on the monsoon rains. Large scale failures of the monsoon upset the country's economy and result in intense suffering of the masses. There has been a pressing need to indicate in advance the performance of the monsoon. Indian summer circulation and rainfall shows high variability in different space and time scales. The space scale varies between as small as a rainfall regime represented by rainfall recorded at a rainguage station to all India scale. The time scale varies from day, to interannual, to decades, centuries and even millenia.

Interannual variations of Indian monsoon rainfall is caused by many global and regional features, the most important global feature being El-Nino-Southern Oscillation (ENSO). Relationship between ENSO and Indian monsoon rainfall has been extensively studied (Sikka 1980, Angell 1981, Keshavamurty 1982, Rasmusson and Carpenter 1983, Shukla and Mooley 1987, Ropelewski and Halpert 1987, Parthasarathy and Sontakke 1988, Bhalme *et al.* 1990). The possible mechanisms which affect Indian monsoon are through reversal/eastward shift of Walker circulation (Krishnamurty *et al.* 1989), large scale intrusion of mid-latitude westerlies (Arkin 1982) and upper tropospheric circulation and thermal anomalies north of India (Krishnamurty *et al.* 1989, Rajeevan 1993 a). Krishnamurty *et al.* (1989) who studied the physical causes of the drought (1987) found that ENSO related shift in the convection (from west Pacific to east Pacific) was evident even before the monsoon season.

The purpose of the present study is to examine the spatial and temporal changes in convection patterns associated with the interannual variability of Indian summer monsoon by making use of long time series of monthly outgoing longwave radiation (OLR) data.

2. Data and methods of study

The monthly OLR data used in the study are obtained from Climate Analysis Centre (CAC) of NOAA, USA. These data are derived from NOAA polar orbiting satellites digitized on a global grid of $2.5^\circ \times 2.5^\circ$. We have used the data for the period 1979-92. These data were later smoothened to $5^\circ \times 5^\circ$ grid scale. Since we have used monthly data it effectively reduces the error, if any, that could arise due to the different equatorial crossing times of the polar satellites used to obtain the data. These data were also corrected for the possible instrument bias arising due to the use of different types of sensors in different satellites.

During the period 1979-92, two good monsoon (flood) years (1983, 1988) occurred over India (case A). There were also four large scale droughts, two (1982, 1987) associated with ENSO (case B) and two (1979, 1986) without ENSO (case C). The rest (case D) were normal monsoon years (1980, 1981, 1984, 1985, 1989, 1990, 1991 & 1992).

Therefore, to make the diagnostic study of these extreme years we have examined the composite OLR anomalies over the area of global tropics bounded between latitudes 30°N and 30°S and longitudes 50°E and 130°W (through the date line).

A year is said to be bad (good) monsoon year when the area weighted percentage rainfall departure from the long term normal for the whole season is 10% below (above) normal. Otherwise the year is said to be normal.

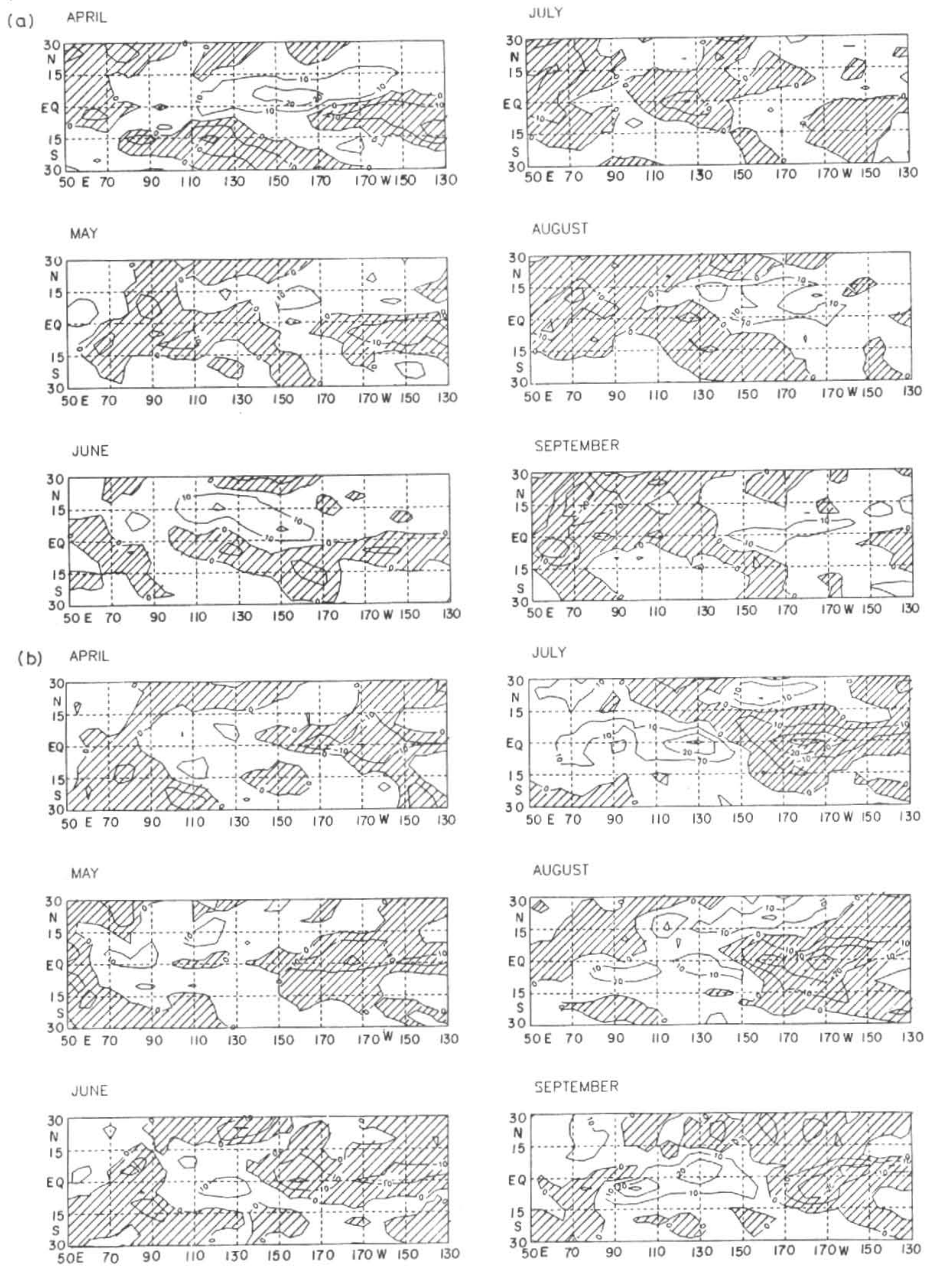
The OLR anomalies were computed from a base period of 10 years (1979-88). Composite anomaly charts were prepared for each of these cases by taking arithmetic mean of OLR anomalies at each grid point for the respective years. Anomaly charts were prepared for the months April to September.

3. Results

3.1. *Good monsoon years (1983 and 1988)*

Fig. 1a shows OLR composite anomalies for the excess monsoon years (1983 and 1988) for the months April to September.

The most significant feature observed in this case was the strong negative anomalies over the Indian subcontinent, South Indian Ocean and region extending from Indonesia to southwest Pacific Ocean indicating above normal convective activity over these regions. Strong positive anomalies indicating depressed convection were observed over the equatorial central Pacific Ocean. These negative anomalies over Indonesian region and positive anomalies over the



Figs. 1(a&b). Composite anomalous outgoing longwave radiation (Wm^{-2}) for (a) the good monsoon case (Case A) and (b) the bad monsoon case (Case B). Contour interval is 10 Wm^{-2}. Negative anomalies are indicated by hatched areas.

central Pacific region constitute a dipole like pattern of OLR anomalies (Lau and Chan 1983). This dipole-like pattern was persistent throughout the monsoon season and was noticed even prior to that.

During the month of April negative anomalies were observed over south Asian. region and over region extending from southeast Indian ocean to southwest Pacific.

During May, negative anomalies over the south Asian regions moved eastwards and combined with that over the south Indian ocean. By June negative anomalies were observed over the south Arabian sea and over central India. In July negative anomalies were comparatively stronger and extended over larger parts of Indian region, consistent with the active monsoon situations during these months. In the next two subsequent months these negative anomalies over the Indian and neighbouring monsoonal area persisted.

3.2. *Bad monsoon years of ENSO case (1982 and 1987)*

Fig. 1b shows composite OLR anomalies for the bad monsoon years (1982 and 1987) which were also ENSO years.

The main feature was the persistent negative anomalies over the equatorial central Pacific region and positive anomalies over the Indonesian and Indian regions during the monsoon and pre-monsoon months. This showed enhanced convective activity over the equatorial Pacific and below normal convective activity over the Indian and Indonesian regions. Thus the usual dipole-like pattern (negative anomalies over Indonesian region and positive anomalies over the equatorial central Pacific) during good monsoon years was found to be reversed during ENSO years.

During April, positive anomalies were observed over Indian region and negative anomalies over Bay of Bengal, south Indian ocean and some parts of east Asia. During May positive anomalies were seen over southeast Arabian Sea and Bay of Bengal in place of negative anomalies of April which now moved over the Indian land. During monsoon months persistent positive anomalies were seen over the Indian region showing below normal convective activity. Particularly in the month of July the positive anomalies were comparatively stronger.

3.3. *Bad monsoon years of non-ENSO case (1979 and 1986)*

During the period 1979-92 we had two bad monsoons (1979 and 1986) which were not ENSO years. However, 1986 cannot be completely treated under this category because the El-Nino event of 1986-87 was started during the second half of 1986, so instead of taking composite of 1979 and 1986, these years were treated and studied separately.

Fig. 2a shows the OLR anomalies for the year 1979.

The important feature is the persistent positive anomalies over the south Asian monsoon region throughout the monsoon and pre-monsoon seasons. Negative anomalies were observed over the north Indian ocean during the monsoon months except in August. During August negative anomalies were observed over south Indian ocean. The negative anomalies were also observed over east Asia in June and over northeast Pacific in July.

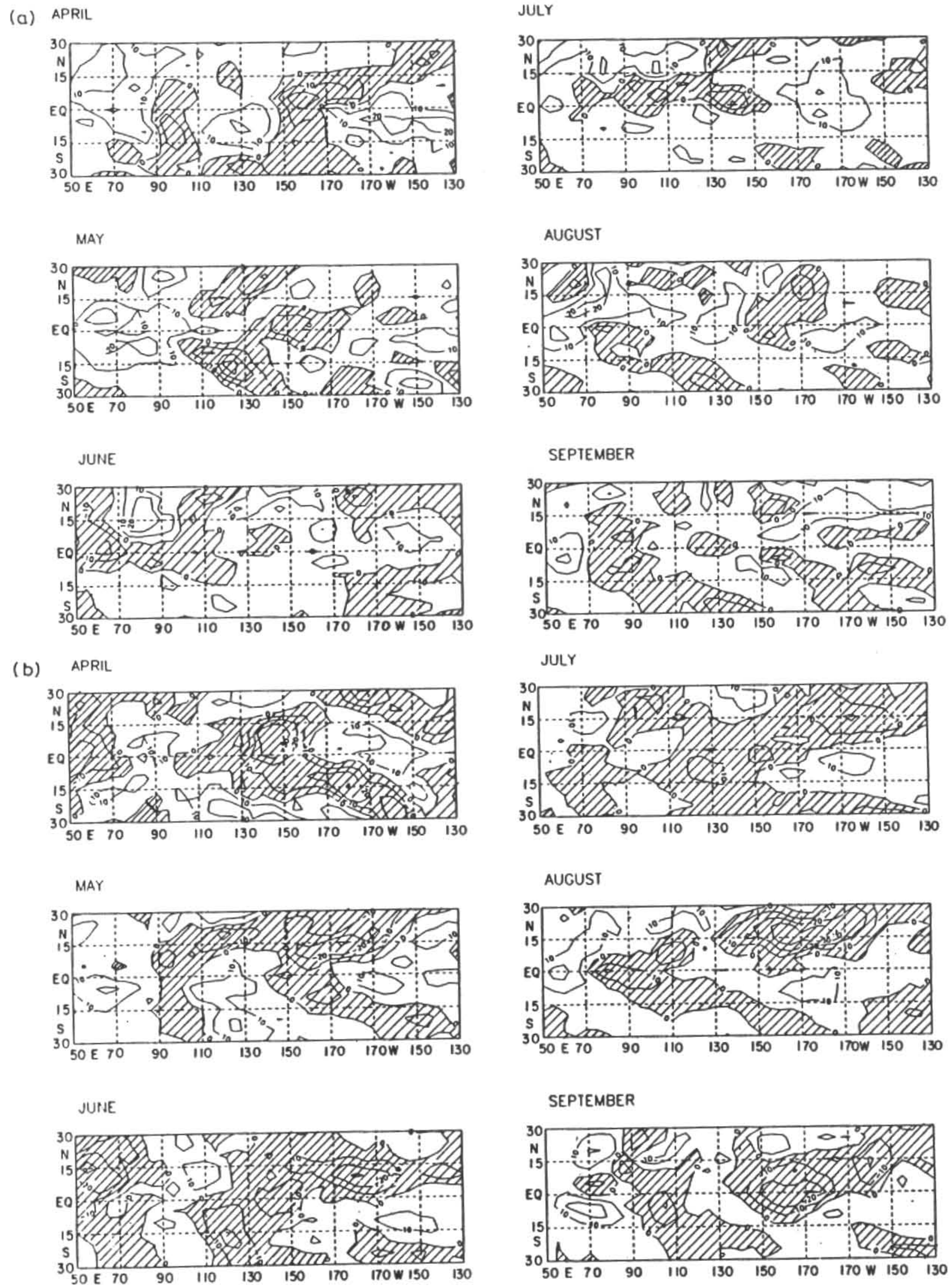
Fig. 2b shows the OLR anomalies for the year 1986. Except for April and June during all other months positive OLR anomalies were seen over the Indian region which means that June had above normal convection and it was supported by above normal (11%) rainfall activity over India during that month. However, the subsequent months were deficient. It was clearly evident from Fig. 2b that the negative OLR anomalies moved from west Pacific to equatorial Pacific from April to September in accordance with the typical El-Nino event, that was the process which started by mid 1986.

3.4. *Normal monsoon years (1980, 1981, 1984, 1989, 1990, 1991 and 1992)*

Fig. 3 shows composite OLR anomalies for the normal monsoon years.

The spatial patterns of OLR anomalies were almost similar to that of good monsoon case, but anomalies were comparatively weaker. Negative anomalies were observed over the Indian region, south Indian Ocean and region extending from Indonesia to southwest Pacific Ocean and positive anomalies were observed over equatorial central Pacific Ocean. This features persisted through the monsoon season.

In April, negative anomalies were observed over Bay of Bengal, equatorial region extending from



Figs. 2(a&b). Anomalous outgoing longwave radiation (Wm^{-2}) for the year (a) 1979 (Case C) and (b) 1986 (Case C). Contour interval is 10 Wm^{-2}. Negative anomalies are indicated by hatched

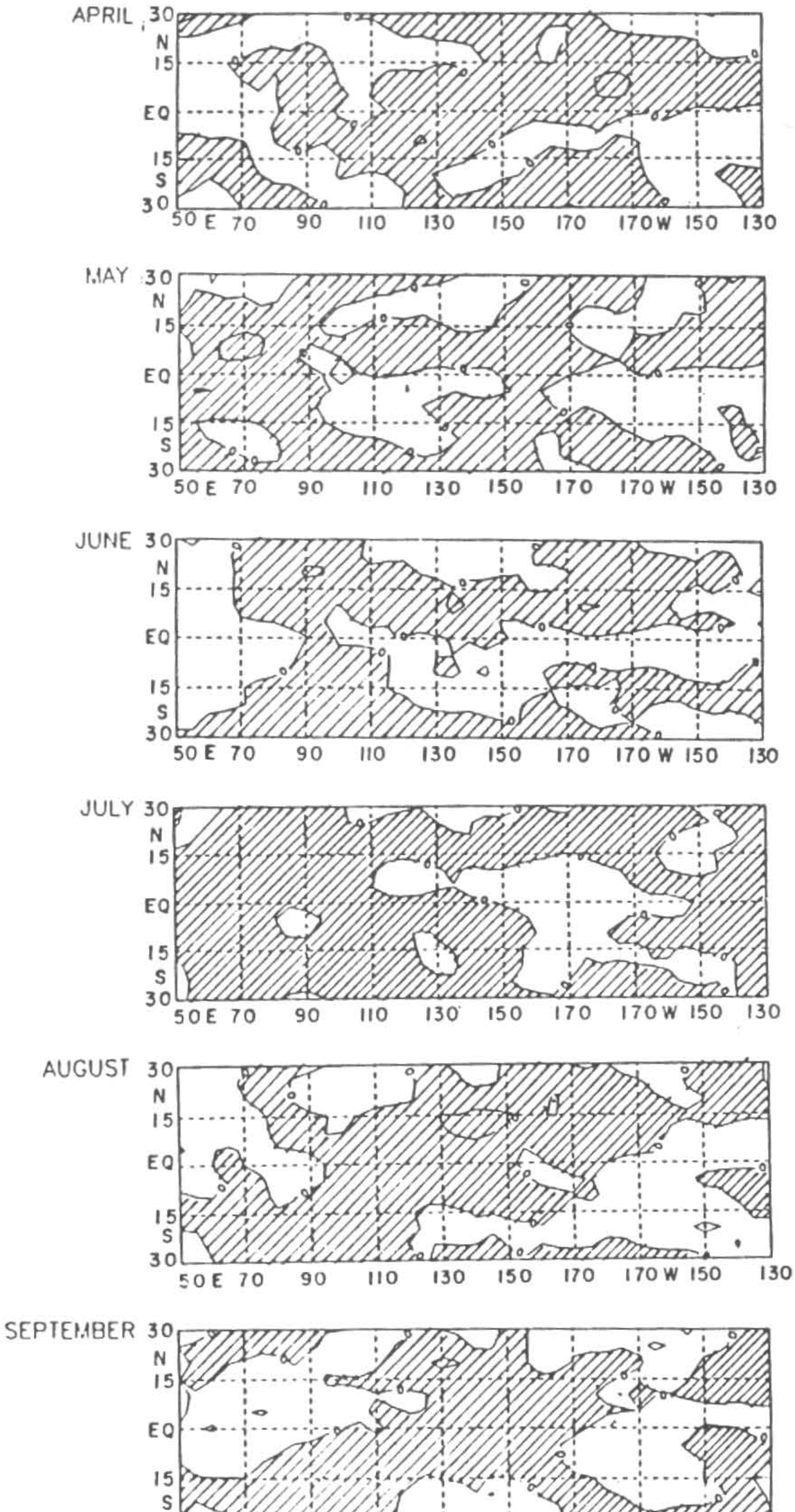


Fig. 3. Anomalous outgoing longwave radiation (Wm^{-2}) for the normal monsoon case (Case D). Contour interval is $10Wm^{-2}$. Negative anomalies are indicated by hatched areas.

TABLE 1

Number of depressions and lows during monsoon season from 1979 to 1992

Year	June		July		August		September		Total	
	Dep	Low	Dep	Low	Dep	Low	Dep	Low	Dep	Low
1979	3	0	1	1	2	2	1	3	7	6
1980	2	3	0	5	3	0	2	1	7	9
1981	1	0	0	5	3	1	3	1	7	7
1982	1	0	2	2	5	1	2	2	10	5
1983	2	0	0	4	1	4	1	4	4	12
1984	1	5	1	1	1	3	0	4	3	13
1985	0	3	0	1	4	2	2	2	6	8
1986	0	2	1	3	3	2	1	1	5	8
1987	1	2	0	2	1	3	2	2	4	9
1988	2	2	1	4	1	3	0	6	4	15
1989	3	1	1	3	1	4	0	4	5	12
1990	1	1	0	3	2	3	1	2	4	9
1991	1	1	1	2	1	5	1	2	4	10
1992	2	0	1	2	0	6	0	3	3	11

Dep – Depression

Indonesian region to west Pacific and some parts of east Asia. In the subsequent months these negative anomalies over the equatorial region slowly moved northward and persisted over the northwest Pacific throughout the monsoon season. Except for May and July weak positive anomalies were seen over the north Indian Ocean.

4. Discussions

In the previous section we have observed that there were significant differences in spatial and temporal OLR anomaly patterns between good monsoon years, bad monsoon years (El-Nino case), bad monsoon years (Non El-Nino case) and normal monsoon years.

During the bad monsoon years, it was observed that convection was more than normal over Pacific region (El-Nino case) as well as over equatorial Indian Ocean (*e.g.*, 1979). This eastward shift in strong convection from equatorial west Pacific to east Pacific was very much pronounced during El-Nino years; indicating the eastward shift of the ascending branch of Walker circulation. This eastward shift in convection pattern is very much clear in Fig. 4, which is the time - longitude plot of OLR anomalies averaged between 5^{o}S and 5^{o}N. The eastward shift was observed during 1982, 1987 and 1992 (El-Nino episodes). The figure also indicates a periodicity of four to five years between two successive El-Nino episodes. It is also important to notice that these eastward shifts were observed even prior to monsoon season; this signal could be useful in the prediction of Indian monsoon seasonal rainfall. However, a suitable Index indicating this eastward shift in Walker circulation by the month of April or May should be developed for inclusion in LRF empirical models.

The eastward shift in OLR anomalies indicates the reversal of dipole-like structure in OLR anomalies generally found in the equatorial Indian and Pacific regions. This reversal of dipole-like structure is an important mode of variation of OLR anomalies found in the tropics (Lau and Chan 1983).

It is generally assumed that interannual variation of Indian monsoon rainfall is associated with the spatial and temporal variations of continental tropical convergence zone (TCZ) over Indian region (Gadgil 1988, Sikka 1980). TCZ is a zone of large convergence and organized precipitation. The space time variations of TCZ over the Indian region are linked to the genesis, intensity and propagation of the monsoon disturbances embedded on it.

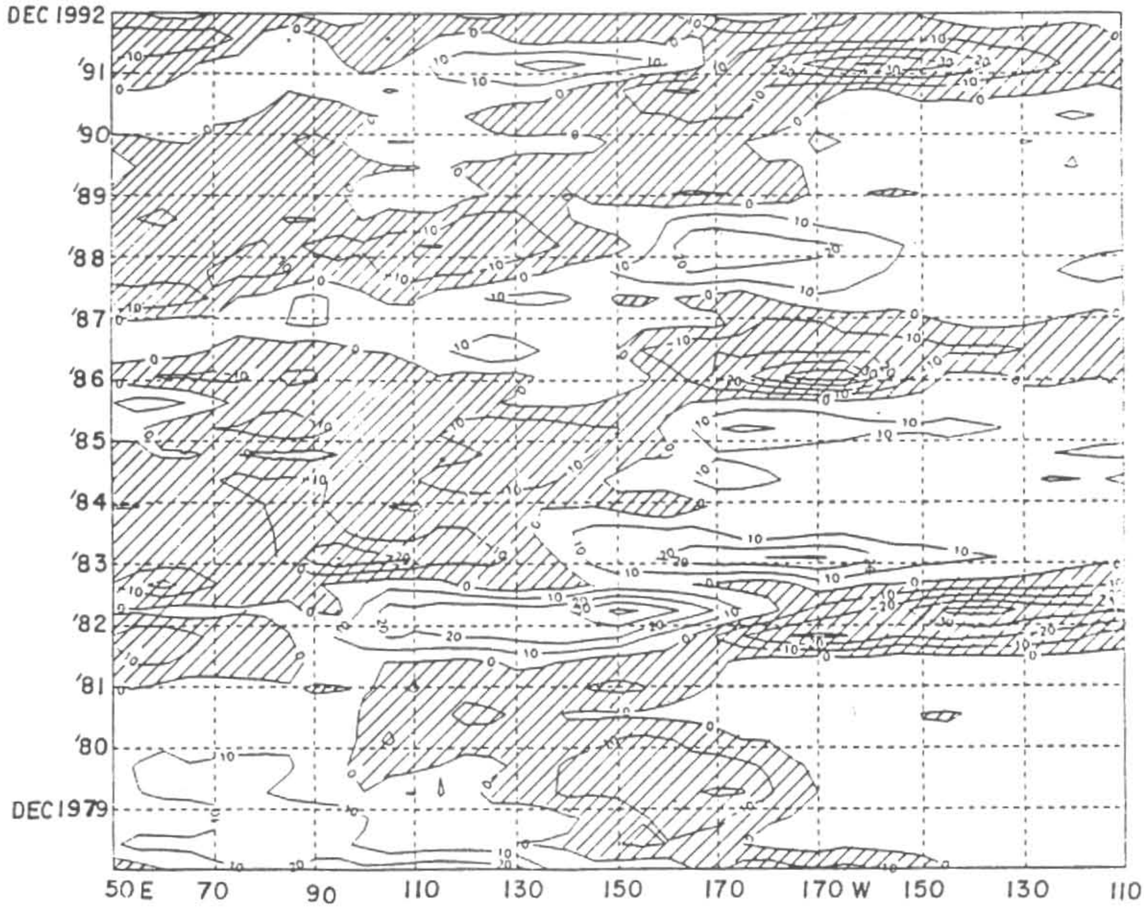


Fig. 4. Time-longitude section (5°N-5°S) of anomalous outgoing longwave radiation (Wm^{-2}). Contour interval is $10Wm^{-2}$. Negative anomalies are indicated by hatched areas.

Table 1 shows the number of depressions and lows during the monsoon season of 1979-92. It can be seen that the number of monsoonal lows were comparatively more during good monsoon years like 1983 and 1988. The persistent negative OLR anomalies over Indian region during the monsoon season of good monsoon years (Fig. 1a) are the indications of stronger continental TCZ and its associated stronger cyclogenesis.

However, continental TCZ over Indian region becomes weak during some years, in association with the stronger eastern end of the continental TCZ (over West Pacific) and stronger oceanic TCZ over Indian ocean.

There is an inverse relationship of intensity and duration of the active spells of the TCZ over the Indian monsoon zone to that of the active spells of TCZ over the eastern sector over west Pacific (Joseph 1990, Rajeevan 1993b) and TCZ over the Indian ocean (Gadgil 1988). These inverse relationships were evident in OLR anomaly charts discussed in the earlier sections. For example, during 1979, the negative anomalies over equatorial Indian Ocean (Fig. 2a) were indicating a stronger oceanic TCZ and depressed convective activity over Indian continental region (Fig. 2a). During good monsoon years (1983 and 1988) continental TCZ over Indian region was active as inferred from the persistent negative OLR anomalies (Fig. 1a). In 1986, on the other hand, eastern end of continental TCZ was active as indicated by negative anomalies. By mid 1986 the eastward shift of Walker circulation also resulted in below normal rainfall activity over India.

Weak but negative composite OLR anomalies over the monsoonal area for the normal monsoon case indicate that continental TCZ was equally active throughout the area. Weak positive anomalies over north Indian Ocean during some monsoon months also indicates that oceanic TCZ was comparatively inactive during those months.

It is also important to note that the selective mechanism which controls the activity of oceanic TCZ, continental TCZ over Indian region and eastern end of continental TCZ and their interactions is operative on intra-seasonal time scales also.

5. Conclusions

The following conclusions can be drawn from this study :

(*i*) There were significant differences in spatial and temporal OLR anomaly patterns between good and bad monsoon years indicating spatial and temporal changes in the organised convective patterns.

(*ii*) During the good monsoon years (1983 and 1988) continental TCZ over Indian region was active as indicated by strong and persistent negative OLR anomalies. Convection over central and east Pacific was below normal as indicated by positive anomalies.

(*iii*) During bad monsoon during El-Nino years (1982 and 1987) it was found that the ascending branch of Walker circulation shifted eastwards and convection was more than normal over central and east Pacific. The normal dipole-like structure of OLR anomaly pattern was found reversed. This eastward shift and reversal of dipole-like structure was evident even prior to monsoon season.

(*iv*) During bad monsoon in 1979, it was found that oceanic TCZ over equatorial Indian Ocean was active as indicated by persistent negative anomalies. Continental TCZ over the Indian region was however inactive.

(*v*) In the normal monsoon case continental TCZ was active throughout the monsoonal area but activity was comparatively weaker than that of the good monsoon case. The oceanic TCZ over Indian Ocean was found to be comparatively inactive during the normal monsoon.

(*vi*) The interactions between continental TCZ over Indian region, eastern end of continental TCZ over Pacific and oceanic TCZ over Indian region as proposed and documented by previous researchers were also evident in the OLR anomaly patterns discussed in this study.

More empirical and theoretical studies are required to establish the interactions between TCZ's mentioned in this study. Also attempts should be made to model, suitably, the eastward shift in convection pattern found during the bad monsoon years, in LRF models.

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