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Excess and deficient summer monsoon rainfall over Orissa in relation to low pressure systems

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सार – इस शोध पत्र में उड़ीसा में अधिक और कम मानसून वर्षा के महीनों (जून–सितम्बर) के दौरान उड़ीसा और उड़ीसा के समुद्र के निकटवर्ती क्षेत्रों तथा भू क्षेत्रों में विकसित कम, अवदाब और चक्रवाती तूफान सहित निम्न दाब प्रणालियों (एल. पी. एस.) की बारंबारता, तीव्रता, इसकी गति, घटना का स्थान आदि जैसे विभिन्न अभिलक्षणों का पता लगाने के लिए अध्ययन किया गया है। यह अध्ययन 20 वर्षों (1980–1999) के आँकड़ों पर आधारित है। इस अध्ययन का प्रमुख उद्देश्य उड़ीसा में अत्यधिक मानसून वर्षा की गतिविधि में एल. पी. एस. के योगदान का पता लगाना है।

विभिन्न क्षेत्रों में एल. पी. एस. के बनने की आवृत्ति की अपेक्षा एल. पी. एस. के दिनों की संख्या से उड़ीसा में अधिक और कम वर्षा को बेहतर ढ़ग से समझा जा सकता है। जून माह के दौरान उड़ीसा में हुई अत्यधिक वर्षा का एल. पी. एस. के दिनों की संख्या के साथ विशेष रूप से संबंध नहीं है। बंगाल की खाड़ी के उत्तर पश्चिमी (एन. डब्ल्यू.) भागों और पश्चिमी बंगाल के गांगेय क्षेत्रों (जी. डब्ल्यू. बी.) में एल. पी. एस के दिनों की सामान्य संख्या की अपेक्षा उल्लेखनीय रूप से कम दिनों तथा आन्ध्र प्रदेश के उत्तरी तट (एन. सी. ए. पी.) से दूर पश्चिमी मध्य खाडी (डब्ल्यू. सी.) में एल. पी. एस. के दिनों की अवधि संख्या से जून माह के दौरान उड़ीसा में वर्षा कम हुई। जबकि उत्तर पश्चिमी खाड़ी और उड़ीसा और एल. पी. एस. दिनों के सामान्य संख्या की अपेक्षा उल्लेखनीय रूप से अधिक संख्या के कारण जुलाई माह में अत्यधिक वर्षा हुई जो अगस्त माह में हुई अत्यधिक वर्षा से संबद्ध एन. सी. ए. पी. से दूर उत्तर पश्चिमी खाड़ी में एल. पी. एस. दिनों की सामान्य संख्या से कम है बंगाल की खाड़ी से उड़ीसा में एल. पी. एस. के बारंबार होने वाली गति के कम होने से जुलाई और अगस्त दोनों माहों में उड़ीसा में वर्षा कम हुई। उत्तर पश्चिमी खाड़ी में एल. पी. एस. दिनों की सामान्य संख्या की अपेक्षा उल्लेखनीय रूप से अधिक कम दिनों से सितम्बर माह में उड़ीसा में अधिक/कम वर्षा हुई।

ABSTRACT. A study has been undertaken to find out different characteristics like frequency, intensity, movement, region of occurrence etc. of low pressure systems (LPS) including low, depression and cyclonic storm etc. developing over Orissa and neighbouring sea and land regions during excess and deficient monsoon rainfall months (June – September) over Orissa. The study is based on data of 20 years (1980-1999). The principal objective of this study is to find out the contribution of LPS to extreme monsoon rainfall activity over Orissa.

The number of LPS days rather than frequency of formation of LPS over different regions better explain the excess and deficient rainfall over Orissa. The excess rainfall over Orissa during June is not significantly related with the number of LPS days. Significantly less than normal number of LPS days over northwest (NW) Bay of Bengal and Gangetic West Bengal (GWB) and higher number of LPS days over west central (WC) Bay off north coastal Andhra Pradesh (NCAP) cause deficient rainfall over Orissa during June. While significantly higher than normal number of LPS days over NW Bay and Orissa leads to excess rainfall during July, less than normal number of LPS days over WC Bay off NCAP is associated with excess rainfall during August. The less number of LPS days over Orissa due to less frequent movement of LPS across Orissa from the Bay of Bengal leads to deficient rainfall over Orissa during both July and August. Significantly higher/less than normal number of LPS days over NW Bay leads to excess/deficient rainfall over Orissa during September.

Key words – Excess rainfall, Deficient rainfall, Monsoon, Orissa, Low pressure system.

1. Introduction

Indian summer monsoon is the major source of water (about 70-90%) for most parts of the country (Mooley *et al.*, 1981). Hence large scale failure of monsoon upsets the economy and leads to suffering of masses. However, Indian summer monsoon circulation shows large scale variability in different space and time scales leading to excess and deficient rainfall over different regions (Parthasarathy, 1984; Mooley and Parthasarathy, 1984;

TABLE 1

The frequency distribution of excess, deficient and normal monsoon rainfall months over Orissa during 1980-1999

Rainfall category	June	July	August	September
Excess rainfall	8	3	7	3
Deficient rainfall	5	10	5	6
Normal rainfall	7	7	8	11

Gregory and Parthasarathy, 1986 and Parthasarathy *et al.*, 1987). Indian summer monsoon rainfall (ISMR) largely depends on the westward moving low pressure systems (LPS) like low, depression, deep depression and cyclonic storm etc. developing over the Bay of Bengal and their life time as the LPSs are the major rain bearing systems (Rao, 1976; Sikka, 1980; Mooley and Parthasarathy, 1983; Mooley and Shukla, 1989; Jadhav, 2002, Mohapatra and Mohanty, 2004 and Mohapatra, 2008). Sikka (1980) has first examined the relation between LPS / LPS days and rainfall over India based on data of five years of excess and deficient monsoon rainfall. He has suggested that number of LPS days over Indian region within a season could discriminate between good and drought monsoon season. This suggestion has been later followed by Mooley and Shukla (1989); Jadhav (2002); Sikka (2006) and Mohapatra (2008). Mooley and Shukla (1989) have shown that the number of LPS days over Indian region is more significantly related than the frequency of LPS with ISMR and specifically so with central India rainfall. According to them, the life of LPS is longer in excess years than in deficient years of ISMR with frequency of such LPS being more in excess years. Sikka (2006) has further extended the studies of Mooley and Shukla (1989) by considering the data upto 2003. He has concluded that number of LPS days cannot be used to discriminate between incidence of a drought and excess monsoon season for all India and three homogeneous regions as suggested by Mooley and Shukla (1989). Jadhav (2002), Mohapatra and Mohanty (2004) and Mohapatra (2008) have shown that rainfall over smaller regions like meteorological sub-divisions of India may be significantly related with the number of LPS days. However, studies are limited on the behaviour of LPS leading to excess/deficient monsoon rainfall over different meteorological sub-divisions of India.

According to Prasad and Singh (1988), Gregory (1989) and Mazumdar (1998), monsoon rainfall over Orissa does not behave in the same way as the ISMR. Orissa gets about 115 cm of rainfall (India Meteorological Department, 2002) during summer monsoon season (June-September), which is about 80% of the average annual rainfall. According to Rao *et al.*,(1970) and Mohapatra (2007), Orissa gets rainfall during monsoon season by three types of synoptic systems, *viz*., (*i*) monsoon trough in normal position, (*ii*) LPS / cyclonic circulation developing over the Bay of Bengal, (*iii*) low level north-south trough in the low level westerlies approaching Orissa from the west during all India weak monsoon condition. Orissa lies close to the south of the mean position of monsoon trough in July, according to India Meteorological Department (1971). The maximum rainfall occurs to the south of the monsoon trough (Pathan, 1993) and the line of maximum rainfall passes through Orissa. Also the monsoon rainfall variability over Orissa is largely governed by the frequency, intensity, movement and life time of the LPS developing over the Bay of Bengal (Mohapatra and Mohanty, 2004 & Mohapatra, 2007). According to Mohapatra and Mohanty (2004), the seasonal monsoon rainfall over Orissa is more dependent on the LPS days over NW Bay of Bengal and Orissa. Higher number of LPS days over these two regions causes higher rainfall over Orissa and *vice versa*. The higher number of LPS days over the regions to the north/ south of Orissa like WC Bay and Bangladesh adversely affects the seasonal rainfall over Orissa. Though the seasonal rainfall over Orissa remains near normal in most of the years (Parthasarathy *et al.*, 1987), there is large variation in monthly rainfall leading to flood and droughts in sub-seasonal scale (Mohapatra and Mohanty, 2006). However, the studies are limited on the behaviour of the LPS leading to excess and deficient monsoon rainfall over Orissa.

Considering all the above, a study has been undertaken to find out the characteristics of LPS like average frequency of formation of LPS, their movement and number of LPS days over different geographical locations influencing rainfall over Orissa during excess and deficient monsoon rainfall months (June–September). The principal objective of this study is to find out the contribution of LPS to the extreme rainfall variability of monsoon rainfall over Orissa in sub-seasonal scale. This study will help in monitoring excess and deficient monthly monsoon rainfall over Orissa. It will also help in short range prediction of rainfall over Orissa with knowledge of location, movement and intensity of LPS.

2. Data and methodology

The monthly rainfall departures from normal (long period average) over Orissa during monsoon months for the period of 1980-1999 are collected from Meteorological Centre, India Meteorological Department (IMD), Bhubaneswar. The departure is defined as (actual rainfall – normal rainfall)/ normal rainfall. The monthly rainfall over Orissa are calculated by IMD based on the

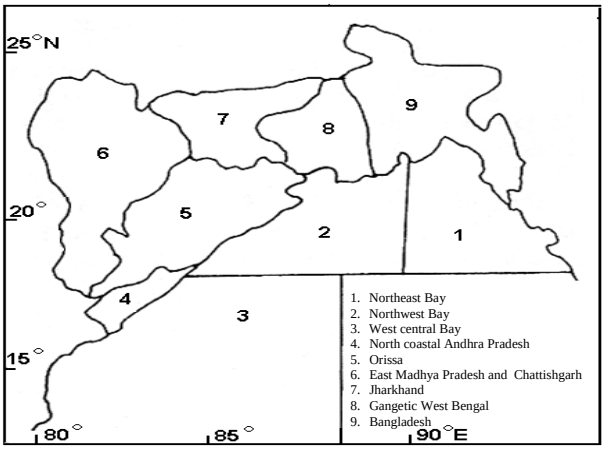


Fig.1. Regions of low pressure systems under consideration

average of daily rainfall recorded at about 75 almost uniformly distributed rain gauge stations in Orissa under district-wise rainfall monitoring scheme (DRMS). The frequencies of excess and deficient rainfall months have been determined by the criteria adopted by IMD and these frequencies are presented in Table 1. As per IMD criteria, if the actual rainfall in a month is higher than the long period average by 20% or more, it is called as an excess month. If the actual rainfall in a month is less than the long period average by 20% or more, it is called as a deficient month.

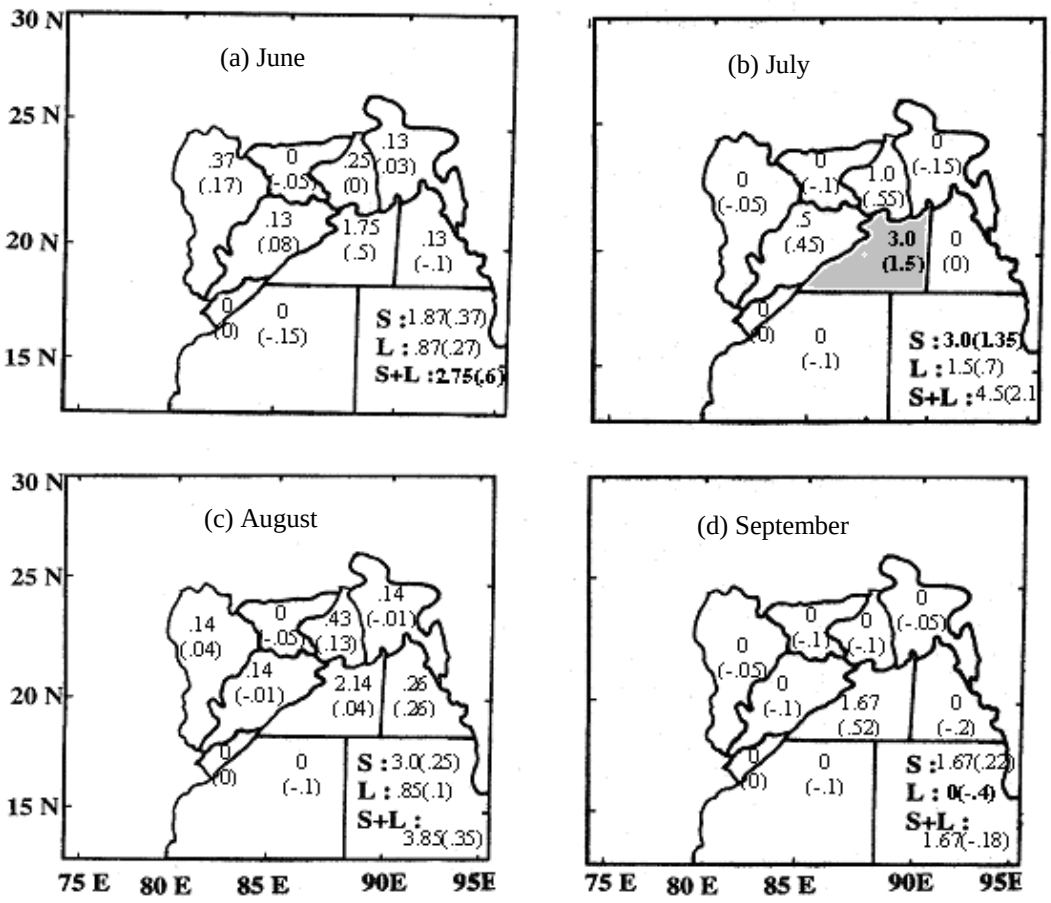
The data for 20 years (1980-1999) on LPS over Orissa and neighbourhood during monsoon season (June-September) are collected from the weather reports published by IMD. The LPS over Orissa and neighbouring regions like west central (WC) Bay of Bengal off north coastal Andhra Pradesh (NCAP), northwest (NW) Bay of Bengal, northeast (NE) Bay of Bengal, Gangetic West Bengal (GWB), Bangladesh (BDS), Jharkhand (JKD), east Madhya Pradesh and Chhatishgarh (EMPC) and NCAP are considered (Fig. 1), as these systems generally affect the monsoon rainfall over Orissa. (Mohapatra, 2007). Moreover, the selected regions over the sea are same as the regions classified by IMD for weather and climate monitoring. The selected land regions of India are the meteorological subdivisions of India according to classification of IMD except EMPC and NCAP. The EMPC considered in the study represents old meteorological sub-division of east Madhya Pradesh, which has been subdivided recently into two different meteorological subdivisions, *viz*., east Madhya Pradesh and Chattishgarh. The NCAP is the northern part of coastal Andhra Pradesh, a meteorological subdivision of India according classification of IMD. A day has been considered as an LPS day over a region, if the system is detected over the same region in the synoptic weather chart based on 0300 UTC observations. In addition, the first day of formation of the LPS over any region has also been considered as an LPS day for that region if the system is detected either at 0300 UTC or 1200 UTC observations. The simultaneous occurrence of the LPS over two different regions *e.g*., LPS over NW Bay and LPS over EMPC, though rare cases, is taken care by considering the day of occurrence as LPS day for both the regions.

TABLE 2

The mean rainfall departures over Orissa during excess rainfall months, deficient rainfall months and whole period under consideration based on data of 1980-1999

Period	Mean departure (%)		
	Excess Period	Deficient period	Whole period
June	40	-38	5
July	27	-31	-14
August	43	-33	6
September	37	-45	-6

The mean departures of rainfall from long period average during excess rainfall months, deficient rainfall months and whole period are calculated and analysed. The average numbers of LPS and LPS days over different regions under consideration during excess and deficient months are found out. The differences of average numbers of LPS / LPS days during excess and deficient monsoon months from the long period average based on data of 1980-1999 are calculated. The significance of the difference of number of LPS / LPS days from their respective long period averages are tested at 95% level of confidence using Students 't' test (Udny Yule and Kendall, 1997) . Also the same test is applied to find out the significant difference in number of LPS / LPS days during excess and deficient rainfall months. To find out the characteristics of movement of LPS in excess and deficient rainfall months, the tracks of movement of depressions and cyclones (cyclonic disturbances) developing over the regions under consideration are prepared separately for excess and deficient monsoon months. Similarly, the monsoon lows developing over the Bay of Bengal and crossing different coastal regions are found out separately for all excess and deficient monsoon months. The movement of lows developing over the land surface under consideration (land lows) are also analysed and discussed for composite excess and deficient monsoon rainfall months over Orissa.



S : Total sea surface under consideration L : Total land surface under consideration
S + L : Total sea and land surface under consideration

The difference (E-N) in average frequency during excess period (E) and whole period (N) is shown in parenthesis. Frequencies significantly different at 5% level from the normal frequencies based on whole period data are highlighted and their regions of occurrence are shaded.

Figs. 2(a-d). Mean frequencies of LPS formed over different regions under consideration during excess rainfall months over Orissa. (a) June, (b) July, (c) August and (d) September

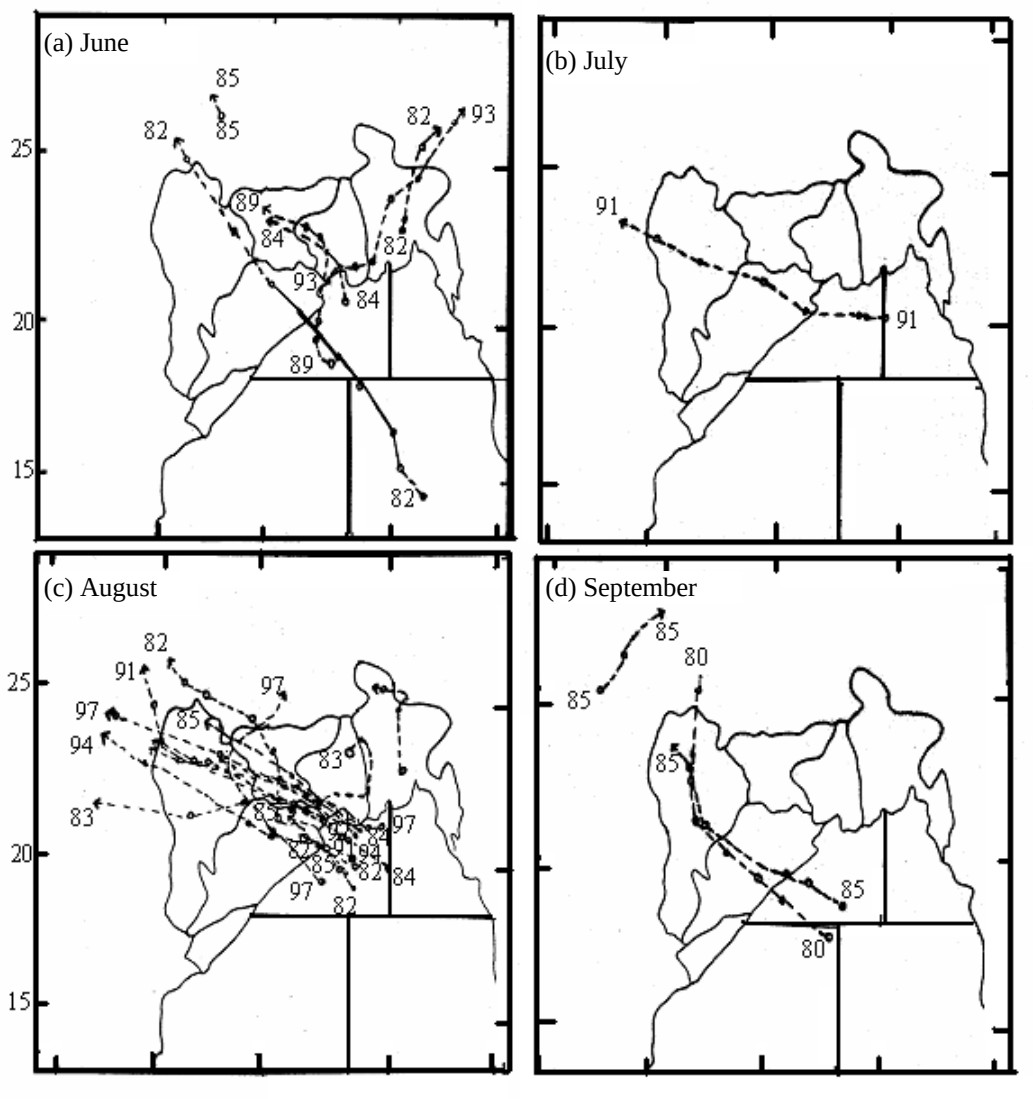
TABLE 3

Extreme rainfall departure (%) over Orissa during 1980-1999 for different summer monsoon months

Period	Extremely excess rainfall departure (year)	Extremely deficient rainfall departure (year)
June	64 (1980)	-55 (1987)
July	27 (1994)	-47 (1982)
August	60 (1983)	-47 (1998)
September	44 (1985)	-57 (1996)

3. Results and discussion

The mean departures of rainfall from long period averages during excess rainfall period, deficient rainfall period and whole period are shown in Table 2. Among different months, the rainfall in July is most contrasting in nature during 1980-1999 with significantly below average rainfall (-14%). It may be due to the fact that the rainfall over Orissa in July depends mostly on the number of LPS developing over the NW Bay. There has been significantly less number of LPS days, especially the cyclonic



O : Position of the system at 0300 UTC + : Position of the system at 1200 UTC
------ Depression, ——: Cyclonic storm, —— : Severe cyclonic storm
⟶ Direction of movement/ Region of dissipation

The figures in the beginning/end of the tracks indicate year of occurrence of the system

Figs. 3(a-d). Tracks of cyclonic storms and depressions developing over the Bay of Bengal during excess monsoon rainfall months over Orissa. (a) June, (b) July, (c) August and (d) September

disturbance days over the NW Bay during July in 1980-1999 than the long period average (Mohapatra and Mohanty, 2006). Considering the extreme rainfall departures (Table 3), the extreme variability of rainfall over Orissa is highest in June. It may be due to the fact that (*i*) the onset of monsoon over Indian region including Orissa takes place during June and (*ii*) the location and intensity of monsoon trough and hence the frequency and region of occurrence of LPS are highly variable during onset phase.

The characteristics of excess rainfall in relation to frequency of formation of LPS, movement of LPS and number of LPS days over different regions under consideration are analysed and discussed in Sec. 3.1, 3.2 and 3.3 respectively. The characteristics of deficient rainfall in relation to frequency of formation of LPS, movement of LPS and number of LPS days are presented and analysed in Sec. 3.4, 3.5 and 3.6 respectively. The comparison of frequencies of LPS and number of LPS

TABLE 4

Frequency distribution of monsoon lows developing over the Bay of Bengal and crossing different coastal regions during excess rainfall months over a period of 20 years (1980-1999)

Period	Region of formation	Subsequent location over Bay	Coastal region crossed by monsoon low				
			NCAP	Orissa	GWB	Bangladesh	Total
June	NE Bay	-	0	0	1	0	1
	NW Bay	-	0	3	6	1	10
	WC Bay	NW Bay	0	1	0	0	1
	Total (%)		0 (0)	4 (33)	7 (58)	1 (8)	12 (100)
July	NE Bay	-	0	0	0	0	0
	NW Bay	-	0	6	0	0	6
	WC Bay	-	0	0	0	0	0
	Total (%)		0 (0)	6 (100)	0 (0)	0 (0)	6 (100)
August	NE Bay	-	0	0	0	0	0
	NW Bay	-	0	7	4	0	11
	WC Bay	-	1	0	0	0	1
	Total (%)		1 (8)	7 (58)	4 (33)	0 (0)	12 (100)
September	NE Bay	-	0	0	0	0	0
	NW Bay	-	0	4	2	0	6
	Total (%)		0 (0)	4 (67)	2 (33)	0 (0)	6 (100)

TABLE 5

Movement of land lows over the regions under consideration during excess rainfall months based on data of 1980-1999

Period	Region of formation	Subsequent location	Direction of movement	Frequency
June	GWB	JKD	Westerly	2
July	GWB	JKD	Westerly	1
	GWB	Orissa	Westerly	1
August	BDS	GWB	Westerly	1
September	-	-	-	-
Total				5

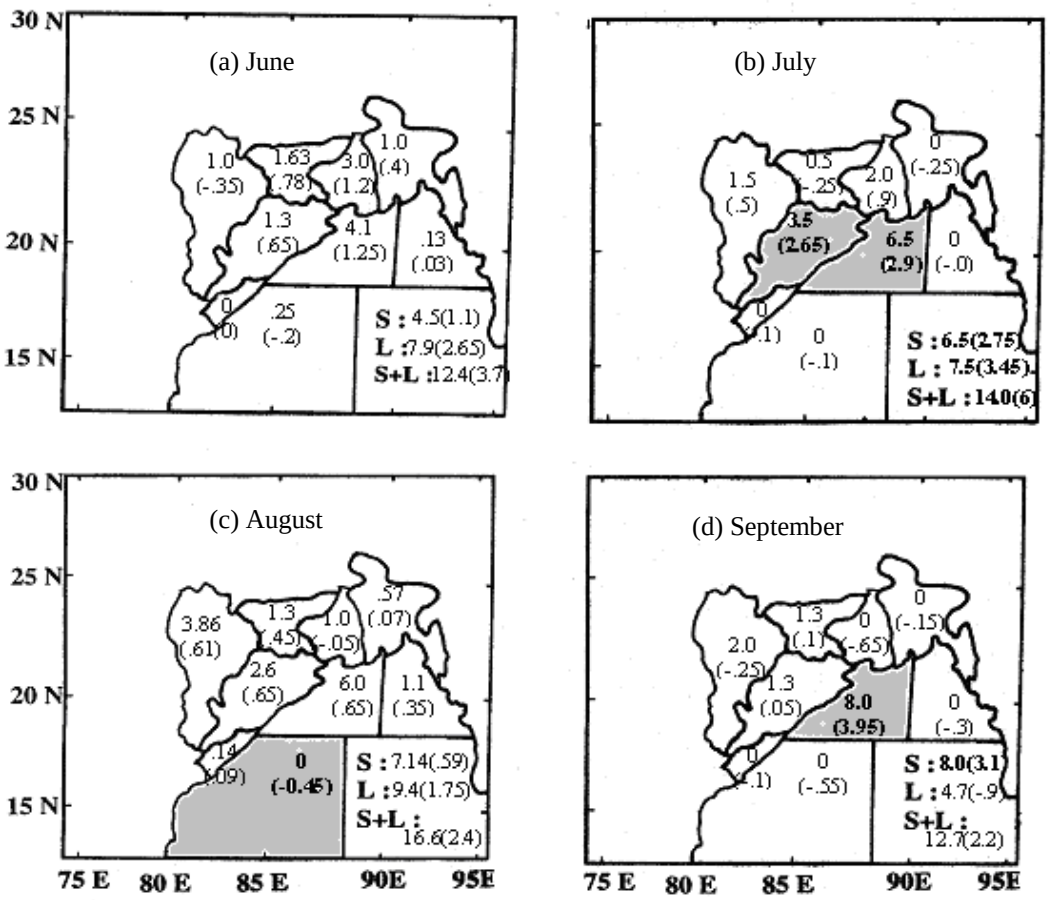
days during excess and deficient rainfall months are analysed and discussed in Sec. 3.7

3.1. *Excess rainfall and frequency of formation of LPS*

The mean frequencies of formation of LPS over different regions under consideration during excess rainfall periods and their departures from normal are shown in Fig. 2. The significantly higher frequency of LPS over the NW Bay in July leads to excess rainfall over Orissa. It may be due to the fact that southwest sector of westward moving LPS gets higher rainfall (Rajamani and Rao, 1981) and most parts of Orissa lie in the southwest sector of LPS over the NW Bay. There is no significant difference in frequency of LPS over different regions under consideration during all other monsoon months indicating the limitation of the frequency of LPS to explain the excess rainfall over Orissa.

3.2. *Excess rainfall and movement of LPS*

The characteristics of the normal movement of the lows and cyclonic disturbances over the regions under consideration have been discussed by Mohapatra and Mohanty (2005), based on the data over the same period (1980-1999). The tracks of movement of cyclonic disturbances during all excess rainfall months are shown in Fig. 3. Most of the cyclonic disturbances developing over the Bay of Bengal move in a northwesterly direction across north Orissa and adjoining GWB during excess June. In association with the cyclonic disturbances over the NW Bay/north Orissa/GWB, the zone of maximum rainfall (left forward sector of cyclonic disturbance) lies over Orissa. No cyclonic disturbance has crossed south Orissa coast or south of it during excess June. The cyclonic disturbances follow mostly west-northwesterly



S : Total sea surface under consideration L : Total land surface under consideration
S + L : Total sea and land surface under consideration

The difference (E-N) in average number of LPS days during excess period (E) and whole period (N) is shown in parenthesis.

Number of LPS days significantly different at 5% level from the normal number of LPS days based on whole period data is highlighted and its region of occurrence is shaded.

Figs. 4(a-d). Mean number of LPS days over different regions under consideration during excess rainfall months over Orissa. (a) June, (b) July, (c) August and (d) September

track across Orissa during excess July and August. The zone of maximum rainfall lies over Orissa with this type of tracks. Like June, no cyclonic disturbance has crossed south Orissa coast or south of it during excess July and August. During excess September, the systems over the NW Bay of Bengal move in northwesterly direction across central/south Orissa. In this month, though some of the cyclonic disturbances take northerly/northeasterly track, they do so after entering EMPC and hence do not adversely affect the rainfall over Orissa. No cyclonic disturbance has moved across NCAP during excess September.

Considering the movement of lows developing over the Bay regions under consideration during excess rainfall months (Table 4), most of the lows developing over the NW Bay move across GWB followed by Orissa in June, across Orissa in July and across Orissa followed by GWB in August and September. The lows over the Bay of Bengal rarely move across NCAP/BDS during excess months. The lows over NCAP/BDS are not favourable for rainfall over Orissa as most parts of Orissa do not lie in the left forward sector of the systems located over these regions. Also the monsoon trough shifts southward with low over NCAP/WC Bay and northward with low over

TABLE 6

Frequency distribution of monsoon lows developing over the Bay of Bengal and crossing different coastal regions during deficient rainfall months over a period of 20 years (1980-1999)

Period	Region of formation	Subsequent location over Bay	Coastal region crossed by monsoon low				
			NCAP	Orissa	GWB	Bangladesh	Total
June	NE Bay	-	0	0	0	0	0
	NW Bay	-	0	1	1	0	2
	WC Bay	-	0	0	0	0	0
	Total (%)		0 (0)	1 (50)	1 (50)	0 (0)	2 (100)
July	NE Bay	-	0	0	0	0	0
	NW Bay	-	0	1	3	0	4
	WC Bay	-	4	0	0	0	4
	Total (%)		4 (50)	1 (13)	3 (37)	0 (0)	8 (100)
August	NE Bay	-	0	0	0	0	0
	NW Bay	-	0	3	1	0	4
	NW Bay	WC Bay	1	0	0	0	1
	WC Bay	-	1	0	0	0	1
	Total (%)		2 (33)	3 (50)	1 (17)	0 (0)	6 (100)
September	NE Bay	-	0	0	0	2	2
	NE Bay	NW bay	0	1	0	0	1
	NW Bay	-	0	0	2	0	2
	WC Bay	-	4	0	0	0	4
	Total (%)		4 (44)	1 (11)	2 (22)	2 (22)	9 (100)

BDS causing shift of maximum rainfall zone away from Orissa.

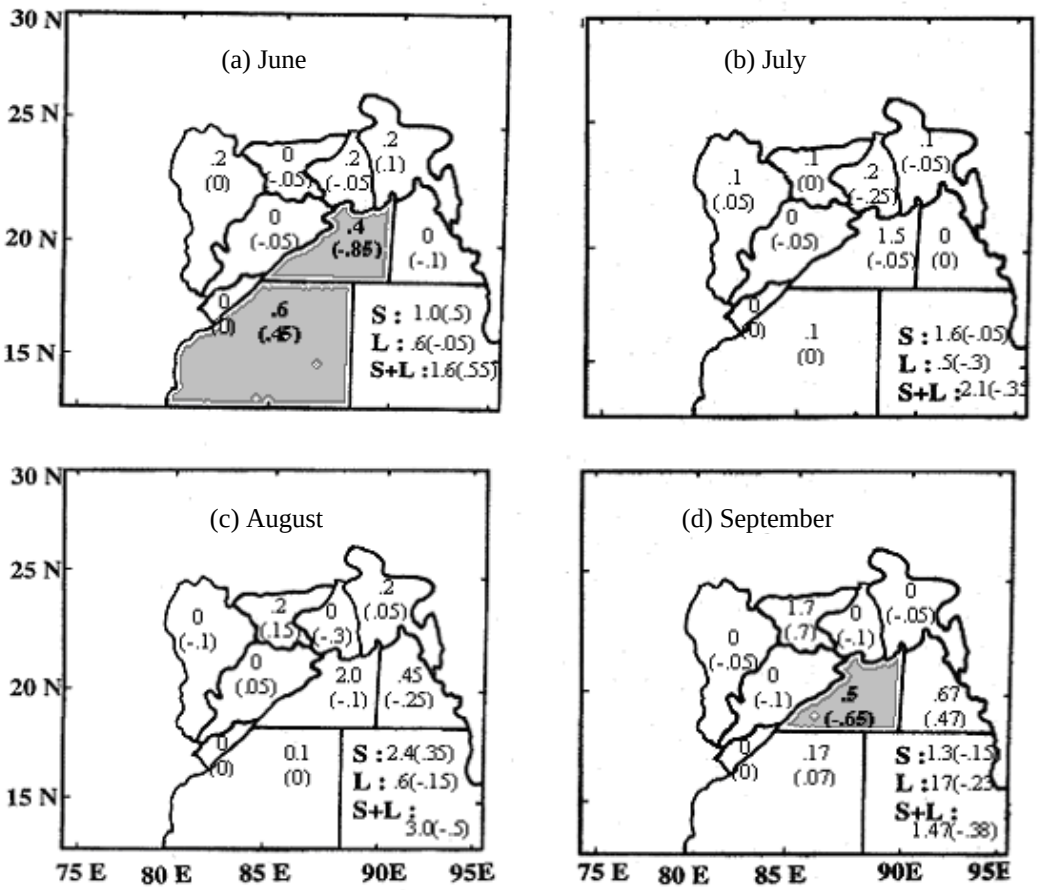
Considering the land lows developing over different regions and their subsequent movement during excess rainfall months (Table 5), these are very less in number. They mostly develop over GWB/BDS and move westwards/ northwestwards along the monsoon trough.

3.3. *Excess rainfall and number of LPS days*

During July, the higher number of LPS days over NW Bay and Orissa leads to excess rainfall over Orissa (Fig. 4) due to the reasons as discussed in previous section. The number of LPS days over WC Bay is significantly less during excess August (the month of maximum number of LPS days). The number of LPS days over NW Bay is significantly higher than normal during excess September. Comparing Fig. 2 and Fig. 4, excess rainfall over Orissa is better explained by the number of LPS days, for all the months except June. Like the frequency of LPS, the number of LPS days could not explain the excess rainfall in June.

3.4. *Deficient rainfall and frequency of formation of LPS*

The mean frequencies of formation of LPS over different regions under consideration during deficient monsoon rainfall months are shown in Fig. 5. It indicates that the decrease in frequency of formation of LPS over NW Bay accompanied with increase in LPS over WC Bay leads to deficient rainfall over Orissa during June. There is no significant difference in frequencies of formation of LPS over different regions under consideration during July and August compared to normal frequencies of formation indicating the limitation of the frequency of LPS to explain the deficient rainfall over Orissa during main monsoon months. It may be due to the fact that Orissa can get rainfall due to small scale systems like cyclonic circulations over NW Bay, GWB and Orissa compensating the deficiency due to less frequency of



S : Total sea surface under consideration L : Total land surface under consideration
S + L : Total sea and land surface under consideration

The difference (D-N) in average frequency of LPS during deficient period (D) and whole period (N) is shown in parenthesis. Frequencies significantly different at 5% level from the normal frequencies based on whole period data are highlighted and their regions of occurrence are shaded.

Figs. 5. (a-d). Mean frequencies of LPS formed over different regions under consideration during deficient rainfall months over Orissa. (a) June, (b) July, (c) August and (d) September

formation of LPS during these months. Orissa can get more rainfall also with less frequency of LPS, if the LPSs persist for longer period over the NW Bay and Orissa during these months. According to Mohapatra (2007), the cyclonic circulations extending upto mid-tropospheric levels over Orissa and adjoining region contribute significantly (about 15%) to the seasonal rainfall over Orissa. There is decrease in frequency of formation of LPS over NW Bay during deficient September over Orissa.

3.5. *Deficient rainfall and movement of LPS*

From Fig. 6, the cyclonic disturbances either move over the southern latitude while moving northwestwards and cross extreme south Orissa/NCAP or they move northeastwards and cross BDS coast during deficient June and July. During deficient August, the systems either cross extreme south Orissa coast or follow a relatively northerly track from the north Bay of Bengal to northern part of EMPC across GWB and JKD. During the period under study, no cyclonic disturbance has crossed north Orissa coast in deficient June, July and August. With such type of tracks over relatively northerly/ southerly latitude, most parts of Orissa do not lie in the left forward sector (sector of maximum rainfall due to maximum low level convergence and upward vertical motion) and hence gets deficient rainfall. During deficient September, the cyclonic disturbances over the Bay of Bengal either move over the regions to the north/south of Orissa or move faster across Orissa yielding less rainfall over Orissa.

TABLE 7

Movement of land lows over the region under consideration during deficient rainfall months based on data of 1980-1999

Period	Region of formation	Subsequent location	Direction of movement	Frequency
June	GWB	JKD	Westerly	2
	GWB	Bangladesh	Easterly	1
July	GWB	JKD	Westerly	2
	GWB	Orissa	Westerly	1
	Orissa	EMPC	Westerly	1
	JKD	GWB	Easterly	1
	Bihar	JKD	Southerly	1
	BDS	JKD, EMPC	Westerly	1
August	BDS	GWB, JKD, EMPC	Westerly	1
	JKD	EMPC	Westerly	1
	Orissa	EMPC	Westerly	1
	Bihar	SHWB	Easterly	1
September	JKD	Bihar	Northerly	1
		Total		15

From Table 6, about 50%, 33% and 67% of the total lows developing over the Bay of Bengal move across NCAP/BDS during deficient July, August and September respectively. Hence, like the cyclonic disturbances, the lows over the Bay of Bengal have a tendency to follow the track either to the south or to the north of Orissa during these deficient months.

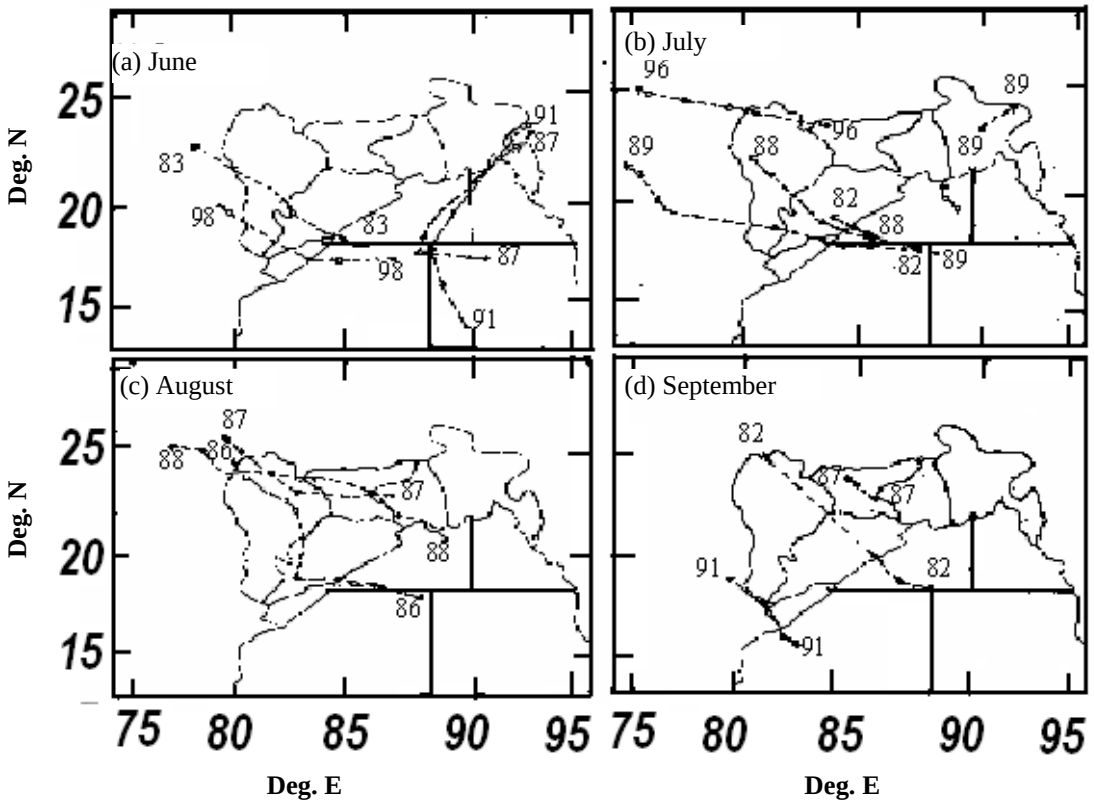
Comparing Tables 5 and 7, the number of land lows is more in deficiency months then in corresponding excess months. During deficient rainfall months, some of the land lows (Table 7) move northwards/ eastwards under the influence of the extratropical westerly trough and hence do not yield good rainfall over Orissa. According to Rao (1976), the lows develop over northern latitude like over JKD, Bihar and east Uttar Pradesh and move eastwards in association with the extra-tropical westerly trough during weak monsoon conditions.

3.6. *Deficient rainfall and number of LPS days*

The less than normal number of LPS days over the NW Bay and GWB and higher number of LPS days over WC Bay lead to deficient rainfall over Orissa during June (Fig. 7). With the LPS over WC Bay, the monsoon trough shifts markedly southward against its normal position through GWB during June. As a result, there is marked deviation in the monsoon flow pattern with LPS over WC Bay during this month. Also, most parts of Orissa do not lie in the southwest sector of the westward moving LPS over WC Bay as discussed earlier. The difference of LPS days is not significant, though there is decrease in number of LPS days over the NW Bay during deficient July and August. However, there is significant decrease in number of LPS days over Orissa during both these months. Hence, even with no significant difference in LPS days over NW Bay, less frequent movement of LPS across Orissa leads to deficient rainfall over Orissa during July and August. The deficient rainfall in September is associated with significant decrease in LPS days over NW Bay. Comparing Figs. 5 and 7, the number of LPS days better explains the deficient rainfall over Orissa rather than the frequency of LPS.

3.7. *Comparison of frequencies of LPS and LPS days formed during excess and deficient months*

The difference (E-D) in frequency of LPS formed over different regions under consideration during excess (E) and deficient (D) rainfall months are shown in Fig. 8. The frequency of LPS over NW Bay is significantly



O : Position of the system at 0300 UTC + : Position of the system at 1200 UTC

---- Depression, ——— : Cyclonic storm, ——— : Severe cyclonic storm

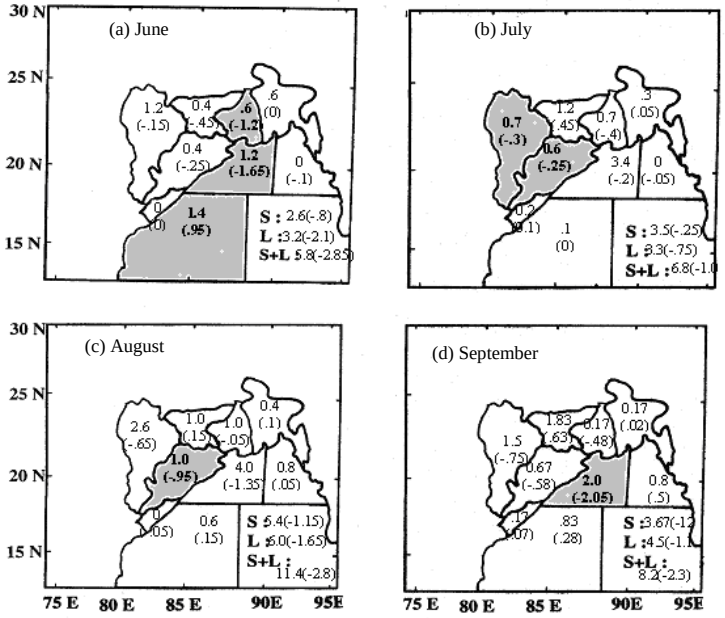
⟶ Direction of movement/ Region of dissipation

The figures in the begining/ end of the tracks indicate year of occurrence of the system

Figs. 6(a-d). Tracks of cyclonic storms and depressions developing over the Bay of Bengal during years of deficient monsoon rainfall months over Orissa. (a) June, (b) July, (c) August and (d) September

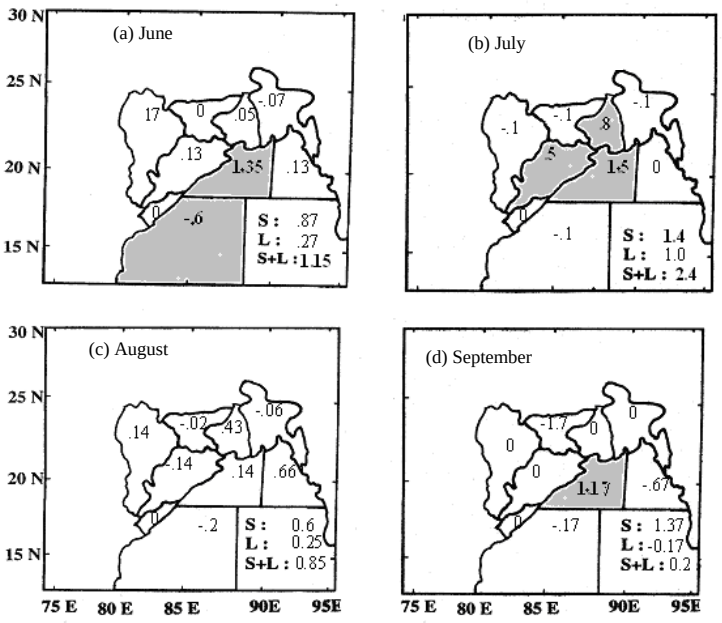
higher during all excess rainfall months except August compared to that during deficient rainfall months. In addition, the frequency of LPS over WC Bay is significantly less during excess June than during deficient June.

Comparison of number of LPS days during excess and deficient months (Fig. 9) indicates that the number of LPS days is significantly higher over NW Bay and GWB during excess June; over NW Bay, GWB and Orissa during excess July; over Orissa during excess August and over NW Bay during excess September. Such type of distribution of LPS days is possible only if there is frequent development and persistence of LPS over NW Bay and they subsequently lie over GWB during excess June and Orissa during excess July and August. These systems persist for a number of days over NW Bay during September. The number of LPS days over WC Bay off NCAP is significantly less during excess June than during deficient June. Examining the composites of 5 good and 5 bad monsoon years over India as a whole during July and August, Sikka (1980) has found that good and bad monsoon years over India as a whole are a priori not distinguishable from the number of cyclonic disturbances and cyclonic disturbance days over India. Also the tracks of cyclonic disturbances in the two categories of years are collectively similar. Considering the lows, he has found that the composite of good monsoon years is characterised by higher number of lows and low days than that during bad monsoon years. According to Sikka (2006), neither the number of LPS nor the number of LPS days in a season can be used to clearly discriminate between the



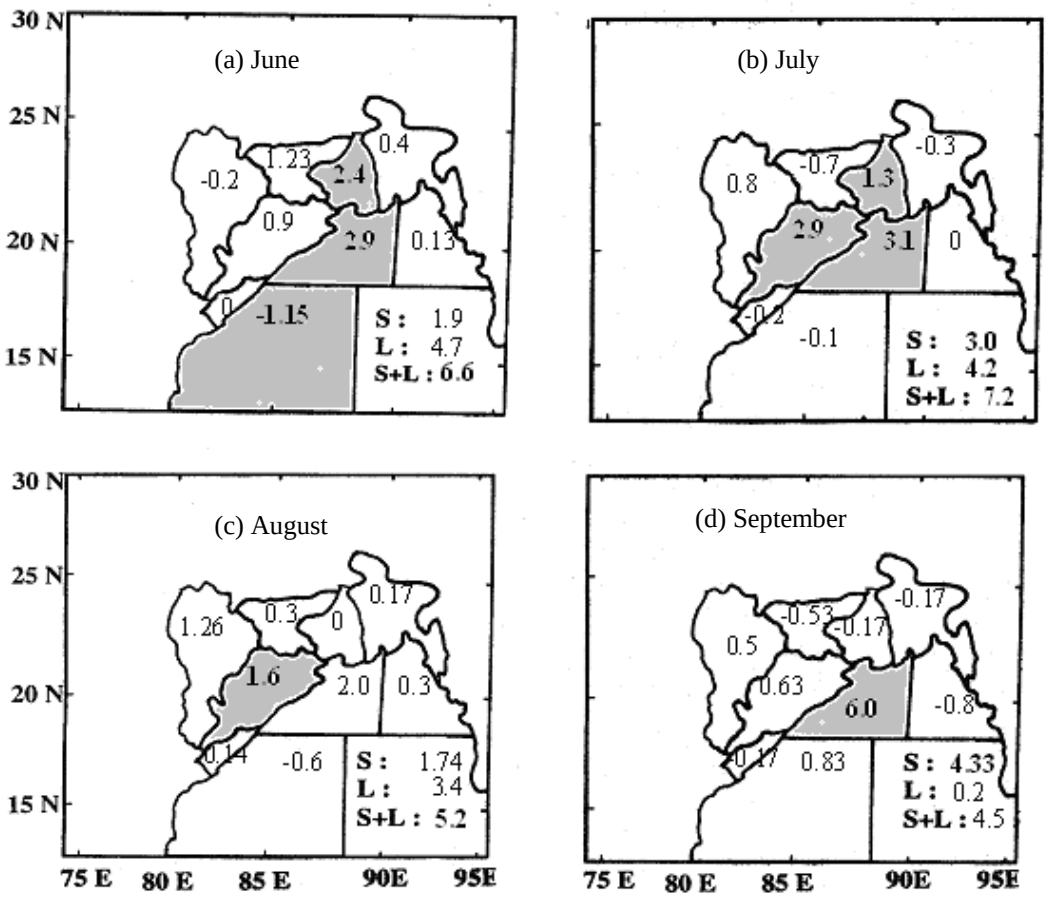
S : Total sea surface under consideration : Total land surface under consideration
S + L : Total sea and land surface under consideration
The difference (D-N) in number of LPS days during deficient period (D) and whole period (N) is shown in parenthesis. Number of LPS days significantly different at 5% level from the normal number of LPS days based on whole period data is highlighted and its region of occurrence is shaded.

Figs. 7(a-d). Mean number of LPS days over different regions under consideration during deficient rainfall months over Orissa. (a) June, (b) July, (c) August and (d) September



S : Total sea surface under consideration L: Total land surface under consideration
S+ L : Total sea and land surface under consideration
Difference (E-D) in frequencies of LPS during excess (E) and deficient (D) rainfall months is shown in parenthesis. Frequencies significantly different at 5% level are highlighted and their regions of occurrence are shaded.

Figs. 8(a-d). Difference (E-D) in frequencies of LPS formed over different regions under considerations during excess (E) and deficient (D) rainfall months. (a) June, (b) July, (c) August and (d) September



S : Total sea surface under consideration L : Total land surface under consideration
S + L : Total sea and land surface under consideration

Difference (E-D) in number of LPS days during excess (E) and deficient (D) rainfall months is shown in parenthesis. Number of LPS days significantly different at 5% level is highlighted and its region of occurrence is shaded.

Figs. 9(a-d). Difference (E-D) in number of LPS days over different regions under consideration during excess (E) and deficient (D) rainfall months. (a) June, (b) July, (c) August and (d) September

incidence of a drought or an excess monsoon season for either India or three homogeneous regions of India along which the LPSs move. Comprising these results with that of the present study, it can be concluded that the monsoon rainfall over Orissa is more sensitive than the ISMR to the LPS days.

4. Conclusions

The following broad conclusions are drawn from the above results and discussion

(*i*) The number of LPS days rather than frequency of formation of LPS over different regions better explain the excess and deficient rainfall over Orissa.

(*ii*) The excess rainfall over Orissa during June is not significantly related with the number of LPS days. Significantly less than normal number of LPS days over NW Bay and GWB and higher number of LPS days over WC Bay off NCAP cause deficient rainfall over Orissa during June. While significantly higher than normal number of LPS days over NW Bay and Orissa leads to excess rainfall over Orissa during July, less than normal number of LPS days over WC Bay off NCAP is associated with excess rainfall over Orissa during August. The less number of LPS days over Orissa due to less frequent movement of LPS across Orissa from the Bay of Bengal leads to deficient rainfall over Orissa during both July and August. Significantly higher/less than normal

number of LPS days over NW Bay leads to excess/deficient rainfall over Orissa during September.

(*iii*) The LPS predominantly moves from NW Bay to EMPC across Orissa during all the excess rainfall months except June when they mostly move across GWB followed by Orissa. More number of LPS either moves over northerly latitude across BDS or over southerly latitude across NCAP during all deficient monsoon months.

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