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Sub-divisional summer monsoon rainfall over India in relation to low pressure systems over the Bay of Bengal and adjoining land regions during 1982-1999

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सार – इस शोध पत्र में ग्रीष्मकालीन मानसून ऋतु (जून–सितम्बर) के दौरान भारत के विभिन्न मौसम विज्ञानिक उपखंडों की वर्षा सहित बंगाल की खाड़ी और निकटवर्ती भू क्षेत्रों में निम्न दाब प्रणाली (एल. पी. एस.) के संबंधें के विशिष्ट लक्षणों का पता लगाने के लिए अध्ययन आरम्भ किया गया है। इस उद्देश्य के लिए भारत के 35 मौसम विज्ञानिक उपखंडों की वर्षा और विभिन्न मानसून के महीनों में पश्चिमी मध्य (डब्ल्यू. सी.) खाडी, उत्तर पश्चिमी (एन. डब्ल्यू.) खाड़ी उत्तर पूर्वी (एन. ई.) खाड़ी, बंगलादेश (बी. डी. एस.), पश्चिमी बंगाल के गांगेय क्षेत्र (जी. डब्ल्यू. बी.), उड़ीसा, उत्तरी तटीय आंध्र प्रदेश (एन. सी. ए. पी.), पूर्वी मध्य प्रदेश और छत्तीसगढ़ (ई. एम. पी. सी.) और झारखंड में एल. पी. एस के दिनों तथा 18 वर्षों (1982-1999) से अधिक की अवधि के समूचे मौसम का विश्लेषण किया गया है। भारत में उपखंडवार मानसून वर्षा पर एल. पी. एस. के प्रभाव में प्रति माह अत्याधिक भिन्नता पाई गई है। तथापि विकसित सहसंबंधित मानचित्र सहित इस अध्ययन में प्रस्तुत किए गए परिणाम एल. पी. एस. के स्थान और संबंद्ध मानसून द्रोणी के आधार पर 24 घंटों की वर्षा का पूर्वानुमान लगाने में सहायक हो सकते हैं।

उत्तर पश्चिमी खाड़ी में एल. पी. एस. के निरंतर विकास और उसकी अवस्थिति पूर्वी मध्य भारत में मौसमी मानसून की अत्याधिक वर्षा के लिए अनुकूल पाई गई है। पश्चिमी मध्य खाड़ी में एल. पी. एस. के विकास और उसकी अवस्थिति उस क्षेत्र में मौसमी वर्षा को प्रतिकूल रूप से प्रभावित करती है। दूसरी ओर, पश्चिमी मध्य खाड़ी में एल. पी. एस. के निरंतर विकास और उसकी अवस्थिति तथा एन. सी. ए. पी., के पार इसकी उत्तरवर्ती पश्चिमाभिमुखी प्रवृति पश्चिमी तट को छोड़कर प्रायद्वीपीय क्षेत्र में अत्याधिक मौसमी वर्षा के लिए अनुकूल पाई गई है। ई. एम. पी. सी. में एल. पी. एस. की वृद्धि से उत्तर पश्चिमी भारत की मौसमी वर्षा में कमी आई है। पश्चिमी मध्य भारत, उत्तरपूर्वी भारत और पश्चिमी तट की मौसमी वर्षा का विचाराधीन क्षेत्रों में एल. पी. एस. दिनों की संख्या के साथ उल्लेखनीय संबंध नहीं पाया गया है।

ABSTRACT. A study is undertaken to find out characteristic features of relationship of the low pressure system (LPS) over the Bay of Bengal and adjoining land regions with the rainfall over different meteorological sub-divisions of India during summer monsoon season (June-September). For this purpose, rainfall over 35 meteorological sub-divisions in India and LPS days over west central (WC) Bay, northwest (NW) Bay, northeast (NE) Bay, Bangladesh (BDS), Gangetic West Bengal (GWB), Orissa, north coastal Andhra Pradesh (NCAP), east Madhya Pradesh and Chattisgarh (EMPC) and Jharkhand (JKD) during different monsoon months and the season as a whole over a period of 18 years (1982-1999) are analysed. There is large month to month variation in the impact of the LPS on the sub-divisional monsoon rainfall over India. However, the results presented in the study including developed correlation maps may be helpful to predict 24 hours rainfall based on the location of the LPS and associated monsoon trough.

The frequent development and persistence of LPS over NW Bay are favourable for higher seasonal monsoon rainfall over east central India. The development and persistence of LPS over WC Bay adversely affect the seasonal rainfall over this region. On the other hand, the frequent development and persistence of LPS over WC Bay and its subsequent westward movement across NCAP are favourable for higher seasonal rainfall over the peninsular region excluding west coast. The seasonal rainfall over northwest India decreases with increase in LPS days over EMPC. The seasonal rainfall over west central India, northeast India and west coast are not significantly related with the number of LPS days over the regions under consideration.

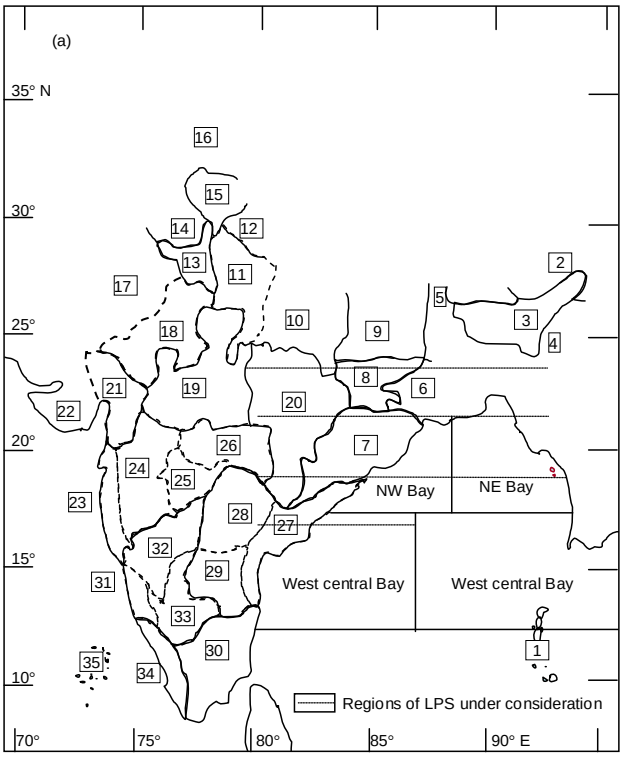
Key words – Low pressure system, Rainfall, Monsoon, Correlation.

1. Introduction

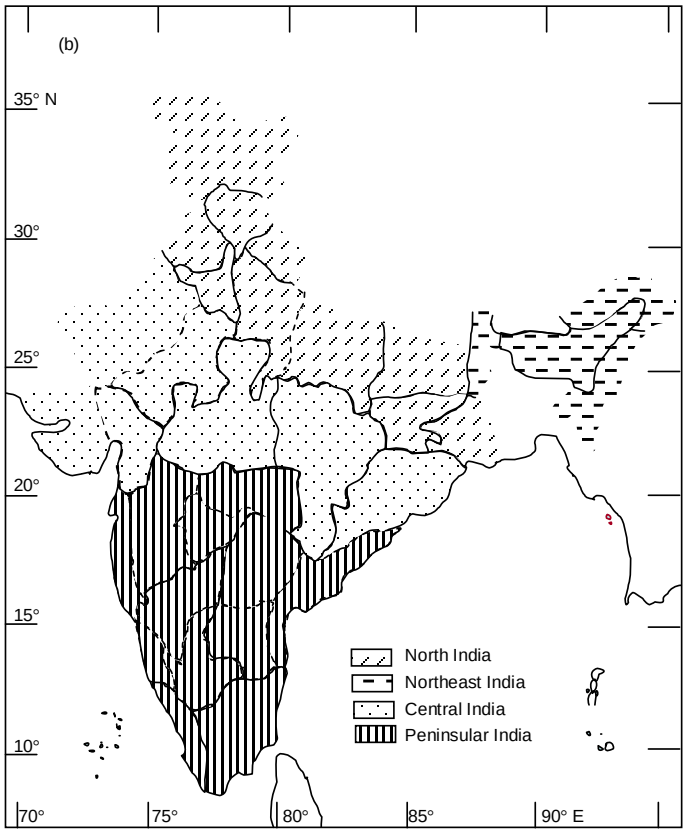
The main synoptic systems during summer monsoon season (June-September) which contribute to the rainfall over India are semi-permanent monsoon trough and the westward moving low pressure system (LPS) over the Bay of Bengal. The existence of a closed low pressure area formed due to a low, depression or cyclonic storm is termed as an LPS. The detailed definition of LPS, as per criteria of India Meteorological Department (IMD), is discussed by Mooley and Shukla (1989). Sikka (1980) has first examined the relation between LPS/LPS days and rainfall over India based on data of five years each of excess and deficient monsoon rainfall. He has suggested that number of LPS days over Indian region within a season could discriminate between a good and a drought monsoon season. This suggestion has been later followed by Mooley and Shukla (1989), Jadhav (2002) and Sikka (2006). Mooley and Shukla (1989) analyzing the data during 1888-1983 have found significant direct relationship between LPS days over Indian region including Bay of Bengal and Arabian Sea and central Indian rainfall during monsoon season. 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 can not be used to discriminate between incidence of a drought and excess monsoon season for all India and 3 homogeneous regions as suggested by Mooley and Shukla (1989). Sikka (2006) and Mooley and Shukla (1989) have further shown that the correlation between rainfall and LPS days over Indian region undergoes both regional and inter-epoch fluctuations. According to Jadhav (2002), when the LPS lies over the area of latitude 20° N- 25° N and longitude 80° E - 90° E, there is significant increase in the rainfall activity in the meteorological sub-divisions of central India (Orissa, east Madhya Pradesh & Chattisgarh, west Madhya Pradesh, east Rajasthan and Gujarat state) and northeast India and southeast peninsular India experience significant decrease in rainfall in the months of July and August. All the above studies indicate that the number of LPS days is more significantly related with the monsoon rainfall over smaller regions like meteorological sub-divisions and homogeneous regions traversed by the LPS. Also their relationship shows temporal variation. However, these studies deal with the detailed relationship between monsoon rainfall and LPS days over the specified grids in Indian region. On the other hand, the operational forecaster in IMD issues the rainfall forecast in relation to the location of LPS over different meteorological sub-divisions of India and adjoining specified sub-divisions of Bay of Bengal and Arabian Sea. Hence, the study of relationship between number of LPS days over IMD specified regions and rainfall over different sub-divisions based on data of recent years may be more useful for operational weather prediction.

The LPS either form over the Bay of Bengal or develop from the remnants of depressions/cyclonic storms which move from south China Sea to Bay of Bengal (Saha *et al*., 1981). According to Jadhav (2002) and Sikka (2006), a large majority of the LPS form over the Bay of Bengal to the north of 15° N and travel in the west-northwest direction yielding good amount of rainfall to their surrounding area. The characteristics of LPS over different grids of 4° latitude × 4° longitude in the region of 5° N - 35° N and 60° E - 100° E (henceforth called as Indian region) for the summer monsoon season (June-September) have been analysed in detail by Mooley and Shukla (1989) and Sikka (2006). According to Mooley and Shukla (1989), about 88% of the total LPS over Indian region form to the east of 80° E. According to Jadhav (2002), who has analysed the characteristics of LPS days over different grids (5° latitude × 5° longitude) based on data of 1891-1990 over the Indian region, most of the LPS days are observed in the area of latitude 15° N - 25° N and longitude 80° E - 95° E. This area includes mostly north coastal Andhra Pradesh (NCAP), east Madhya Pradesh and Chattisgarh (EMPC), Orissa, Jharkhand (JKD), Gangetic West Bengal (GWB), north Bay of Bengal, west central (WC) Bay and Bangladesh (BDS). The total numbers of LPS days over this area bounded by latitude 15° N - 25° N and longitude 80° E-95° E during June, July, August, September and season as a whole are about 66%, 65%, 64%, 61% and 65% of total numbers of LPS days over Indian region respectively. Mohapatra and Mohanty (2004) have analysed in detail the characteristics of LPS and LPS days over the meteorological sub-divisions of Orissa, GWB, EMPC, JKD, NCAP and neighbouring land and sea regions like Bangladesh, northwest (NW) Bay, northeast (NE) Bay and WC Bay of Bengal based on data of 20 years (1980-1999). About 8 LPS form and 16 LPS days occur over NW Bay alone during the season as a whole.

Heavy rainfall can occur upto 1000 km ahead of the centre of depression and 400 km to the left of depression track (Pisharoty and Asnani, 1957). According to Mukherjee and Shyamala (1978), the influence of depression causing rainfall extends beyond 500 km. Abbi *et al*., (1970) have found that the probability of heavy rainfall over Gujarat and north Konkan increases significantly as the depression reaches near 80° E. According to Kripalani and Singh (1986), the probability of occurrence of 24-hr rainfall, more than or equal to 2.5 mm exceeds 0.8 over an area lying ahead of the depression and varying in extent from 3° - 5° latitude and 5° - 10° longitude in length depending on the geographical position of the depression at the start of the 24-hr period. The average rain exceeds 2 cm over a rectangular belt of 3° - 4° latitude and 7° - 10° longitude lying to the left of depression track. All these studies indicate that the LPS



1. Andaman & Nicobar Islands
2. Arunachal Pradesh
3. Assam & Meghalaya
4. Naga., Mani., Mizo. and Tri.
5. Sub-Himalayan West Bengal & Sikkim
6. Gangetic West Bengal
7. Orissa
8. Jharkhand
9. Bihar
10. East Uttar Pradesh
11. West Uttar Pradesh
12. Uttarakhand
13. Haryana, Chandigarh & Delhi
14. Punjab
15. Himachal Pradesh
16. Jammu & Kashmir
17. West Rajasthan
18. East Rajasthan
19. West Madhya Pradesh
20. East Madhya Pradesh and Chattisgarh
21. Gujarat Region
22. Saurashtra & Kutch
23. Konkan & Goa
24. Madhya Maharashtra
25. Marathwada
26. Vidarbha
27. Coastal Andhra Pradesh
28. Telangana
29. Rayalaseema
30. Tamil Nadu & Pondicherry
31. Coastal Karnataka
32. North Interior Karnataka
33. South interior Karnataka
34. Kerala
35. Lakshadweep



Figs. 1(a&b). (a) Meteorological sub-divisions of India and (b) map showing different homogeneous regions of India

over the north Bay of Bengal and adjoining sub-divisions have large spatial impact on rainfall.

Considering the above, a study is undertaken to find out the relation of monsoon rainfall over different meteorological sub-divisions with the number of LPS days over the regions of NE Bay, NW Bay, WC Bay and adjoining meteorological sub-divisions of India and Bangladesh [Fig. 1(a)]. The LPS days over other regions are not considered as they are less in number and hence have least influence on monthly and seasonal rainfall. The principal objective of this study is to find out the contribution of LPS over the above regions to the spatio-temporal variability of summer monsoon rainfall over India. This study will help in operational short range forecasting of summer monsoon rainfall over different meteorological sub-divisions based on the location of LPS. It can also help in further studies for development of synoptic and statistical prediction models and interpretation of numerical weather prediction models guidance.

2. Data and methodology

The percentage departures of rainfall from long period average for different summer monsoon months and the season as a whole (June-September) over the period of 1982-1999 have been collected from the articles, 'weather' published by IMD (1983-2000) in the Journal, 'Mausam'. The data on LPS and its characteristics like intensity, movement and region of occurrence during different summer monsoon months and the season as a whole for the period of 1982-1999 have been collected from the weather reports published by 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 observation. 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 observation. The region with centre of LPS has been considered as region of LPS, *e.g*., the LPS over NW Bay and adjoining areas of NE Bay / Orissa has been considered as LPS over NW Bay. 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. The time series of the number of LPS days over different regions under consideration during 1982-1999 have been prepared for different summer monsoon months and the season as a whole.

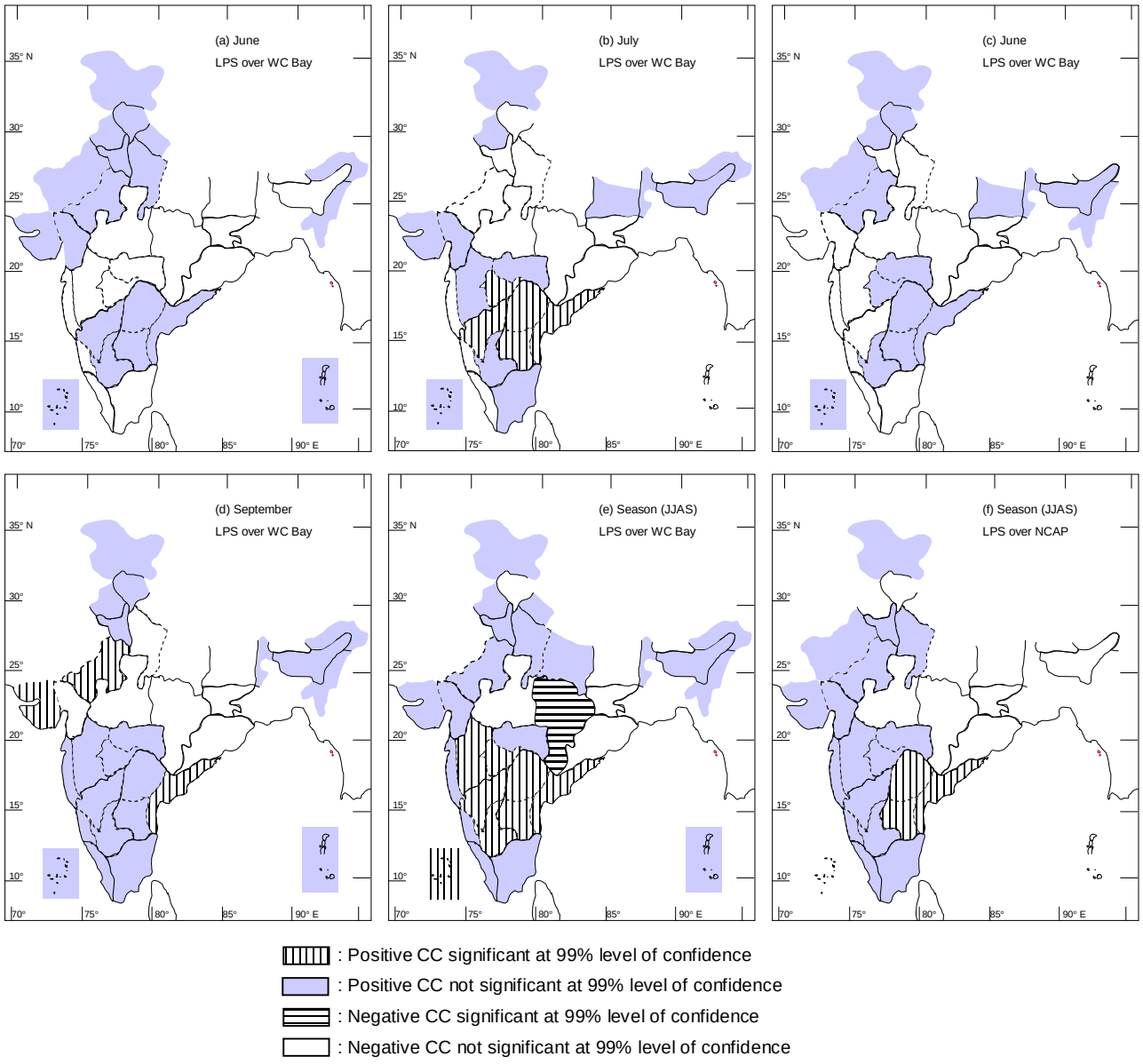
The average rainfall over different meteorological sub-divisions of India during the period under study is analysed. The linear correlation coefficients (CC) of rainfall departure over different meteorological sub-divisions of India with the number of LPS days over 9 different regions under consideration [Fig. 1(a)] during different monsoon months and the season as a whole are calculated. The CC values are tested for 99% level of confidence using Student's *t*-test. The significant relationships are brought out and analysed. In addition to above, the rainfall over broad homogeneous regions of India are analysed in relation to LPS. For this purpose, India has been considered to consist of four homogeneous regions, *viz*., (*i*) north India, (*ii*) northeast India, (*iii*) central India and (*iv*) peninsular India [Fig. 1(b)]. Further, the sub-divisions with S. No. (11-16) and S. No. (6, 8, 9, 10) of north India to the west and east of 80° E are considered as western and eastern parts of north India respectively. Similarly, the sub-divisions in central India lying to the east of 80° E, *viz*., EMPC and Orissa constitute east central India and west Madhya Pradesh, Gujarat and Rajasthan to the west of 80° E constitute west central India. The sub-divisions along the west coast and remaining sub-divisions of the peninsular India have been considered to constitute two separate sub-homogeneous regions of the peninsular India. The area weighted rainfall departures from long period average over different homogeneous regions are calculated and time series are prepared for different monsoon months and the season as a whole over the period of 1982-1999. The CCs between number of LPS days over different regions under consideration [Fig. 1(a)] and the rainfall over different homogeneous regions of India are also calculated and analysed.

3. Results and discussion

The average sub-divisional summer monsoon rainfall during the period under study is presented in Sec. 3.1. The correlations between sub-divisional rainfall and LPS days over 9 different regions under consideration are analysed and discussed in Sec. 3.2.

3.1. *Average sub-divisional rainfall*

The seasonal rainfall has been normal (rainfall departure from the long period average is within –19% to +19% of long period average) over all the meteorological sub-divisions of India (not shown). It may be due to the fact that there is no significant change in the number of LPS days over Indian region during the period under study compared to long period average (Jadhav and Munot, 2004 and Sikka, 2006), though the frequency of depressions and depression days have decreased significantly. Even the number of LPS days over Indian region has increased slightly during all the months and the season as a whole except July when it has remained almost same. The number of LPS days over the whole



Figs. 2(a-f). Correlation coefficients (CC) of rainfall over different meteorological sub-divisions of India with (a-e) number of LPS days over WC Bay and (f) number of LPS days over NCAP during summer monsoon season

region under consideration in this study also shows no significant change from the long period average (Mohapatra and Mohanty, 2004). The adverse impact due to decrease in frequency of depression and depression days has been compensated due to increase in low and low days.

The average rainfall in different monsoon months have been normal during the period under study over most of the sub-divisions except one or two sub-divisions in northwest and adjoining west-central India, south peninsula and northeast India (not shown). The rainfall has been excess (rainfall departure from the long period average ≥ 20%) over Punjab, Haryana, Chandigarh & Delhi, Rajasthan and interior Karnataka in June, west Rajasthan in July, Haryana, Chandigarh & Delhi, coastal Karnataka and Rayalaseema in August and Arunachal Pradesh in September. It has been deficient (rainfall

TABLE 1

Significant correlation coefficients (at 99% confidence level) of rainfall over different homogeneous regions of India with number of LPS days over different regions during summer monsoon season

Homogeneous region	Jun	Jul	Aug	Sep	Season
West central India	-	-	-	-	-
East central India	GWB (0.71)	GWB (0.55), Orissa (0.56)	Orissa (0.63)	-	NW Bay (0.54) WC Bay (-0.57)
North India (west of 80° E)	NE Bay (0.64)	-	-	-	EMPC (-0.51)
North India (east of 80° E)	NW Bay (0.74), NE Bay (0.61), GWB (0.63)	-	-	JKD (0.52)	-
Northeast India	-	Orissa (-0.64)	-	GWB (-0.53)	-
West coast	-	BDS (-0.65)	-	-	-
Peninsular India excluding west coast	EMPC (0.52)	WC Bay (0.60)	-	-	WC Bay (0.78), NCAP (0.55)

The correlation coefficients are shown inside the parentheses

departure from the long period average ≤ -20%) over Nagaland, Manipur, Mizoram & Tripura (NMMT) in June, Saurastra & Kutch and Uttarakhand in July and Vidarbha and Telangana in September.

3.2. *Sub-divisional rainfall in relation to LPS*

The CCs of sub-divisional rainfall with the number of LPS days over 9 different regions under consideration are presented and discussed in Sec. 3.2.1 to 3.2.8.

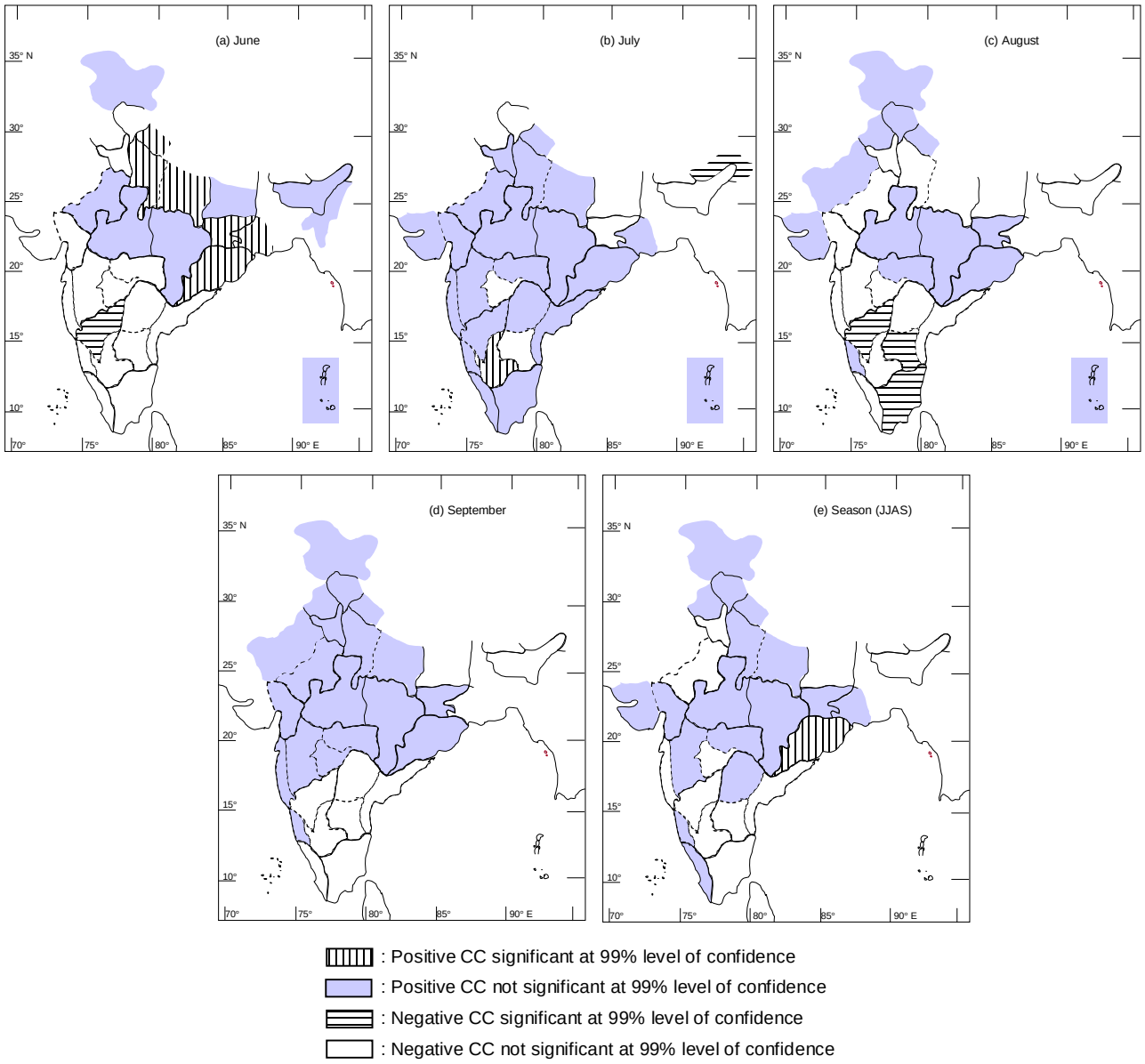
3.2.1. *Sub-divisional rainfall in relation to LPS over WC Bay and NCAP*

The relation between the sub-divisional rainfall and the number of LPS days over WC Bay is more significant during the monsoon season as a whole than during individual monsoon months [Figs. 2(a-f)]. The seasonal rainfall over Andhra Pradesh, interior Karnataka, Madhya Maharashtra and Marathawada in the south peninsula significantly increase with increase in LPS days over WC Bay as these regions lie in the southwest sector with the west-northwestward moving LPS over WC Bay (Rajamani and Rao, 1981). Considering individual months, direct influence of LPS over WC Bay is limited to rainfall over Andhra Pradesh, north interior Karnataka and Marathawada in July. Considering different homogeneous regions (Table 1), the rainfall over peninsular India excluding west coast increases with increase in LPS days over WC Bay during July and season as a whole. The seasonal rainfall over EMPC [Fig. 2] and east central India (Table 1) decrease with increase in LPS days over WC Bay, as the monsoon trough shifts southward with the LPS over WC Bay and the minimum rainfall zone lies to the north of the monsoon trough (Pathan, 1993).

Since the number of LPS days over NCAP in individual monsoon months are very less, only the LPS days during the season as a whole has been considered to find out their relationship with the sub-divisional rainfall. The seasonal rainfall over all the sub-divisions of Andhra Pradesh [Fig. 2(f)] significantly increases with the increase in number of LPS days over NCAP like that due to increase in LPS days over WC Bay. Considering different homogeneous regions (Table 1), the seasonal rainfall over the peninsular India excluding west coast significantly increases with the increase in number of LPS days over NCAP like that due to increase in LPS days over WC Bay.

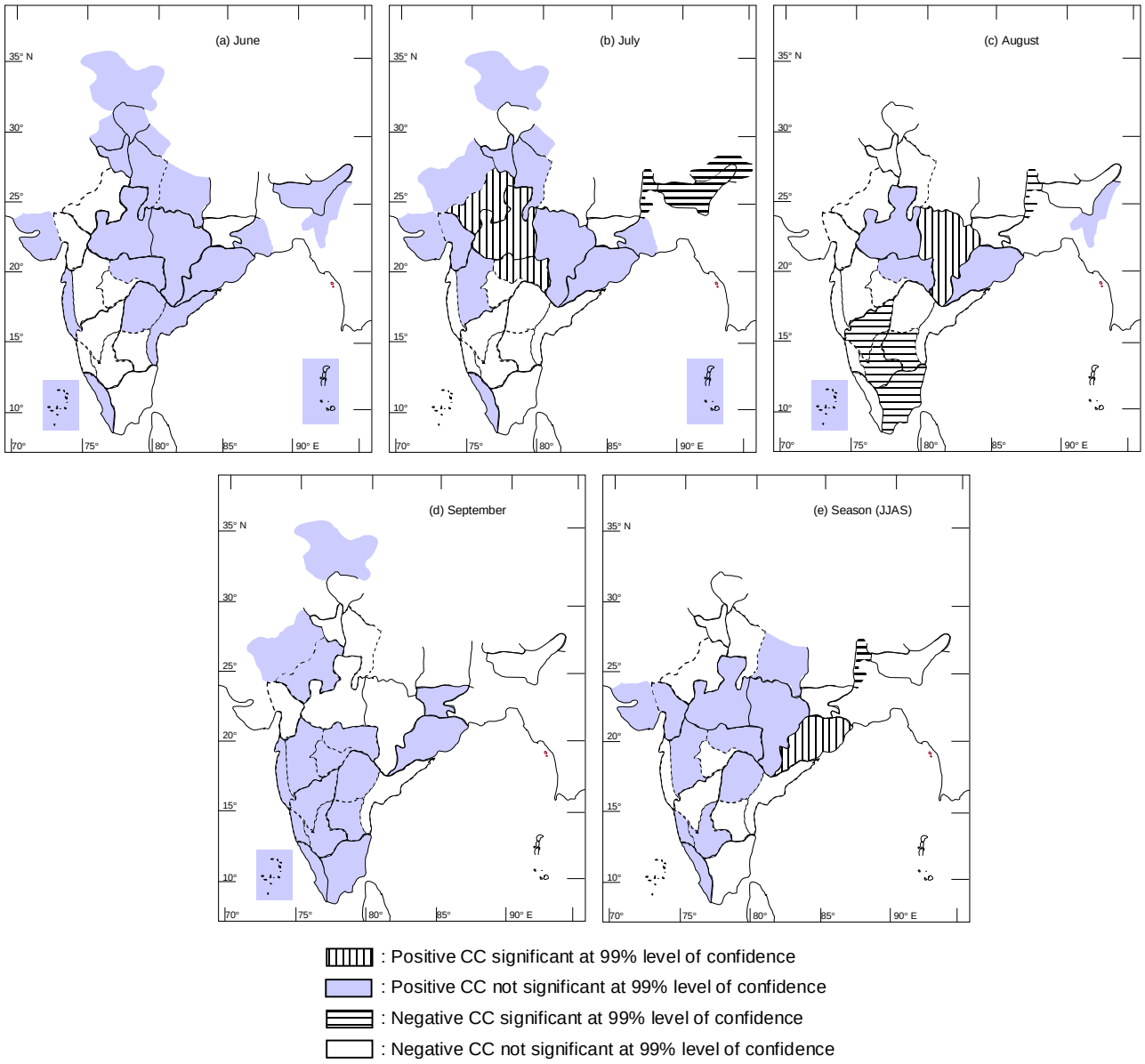
3.2.2. *Sub-divisional rainfall in relation to LPS over NW Bay*

The rainfall over GWB, Orissa and Jharkhand significantly increases in June with increase in LPS days over NW Bay [Figs. 3(a-e)]. It is due to the fact that the LPS over NW Bay mostly moves west-northwestwards along the monsoon trough across GWB-Jharkhand (Mohapatra and Mohanty, 2005) during this month, (*ii*) southwest sector of the LPS gets maximum rainfall (Rajamani and Rao, 1981) and most parts of GWB, Orissa and Jharkhand lie in the southwest sector of LPS over NW Bay. However, the seasonal rainfall over Orissa only increases with increase in number of LPS days over NW Bay confirming the earlier findings of Mohapatra and Mohanty (2004). Considering the homogeneous regions



Figs. 3(a-e). Correlation coefficients (CC) of rainfall over different meteorological sub-divisions of India with number of LPS days over NW Bay during summer monsoon season (a) June, (b) July, (c) August, (d) September and (e) Season (JJAS)

(Table 1), the rainfall over eastern part of north India during June and east central India during the season as a whole increase with increase in LPS days over NW Bay. The rainfall over Uttar Pradesh and Uttarakhand also increases in June with increase in LPS days over the NW Bay. Srinivasan *et al*., (1972) has shown that these regions can get good rainfall due to interaction of mid-latitude westerly systems affecting the region with the LPS over NW Bay. The rainfall over Arunachal Pradesh in July decreases with increase in LPS days over NW Bay [Figs. 3(a-e)]. The rainfall over some sub-divisions of south peninsula, *viz*., north interior Karnataka in June and north interior Karnataka, Rayalaseema and Tamil Nadu in August decreases with increase in LPS days over NW Bay. The contrasting nature of the seasonal rainfall distribution over northeast India and southeast peninsula

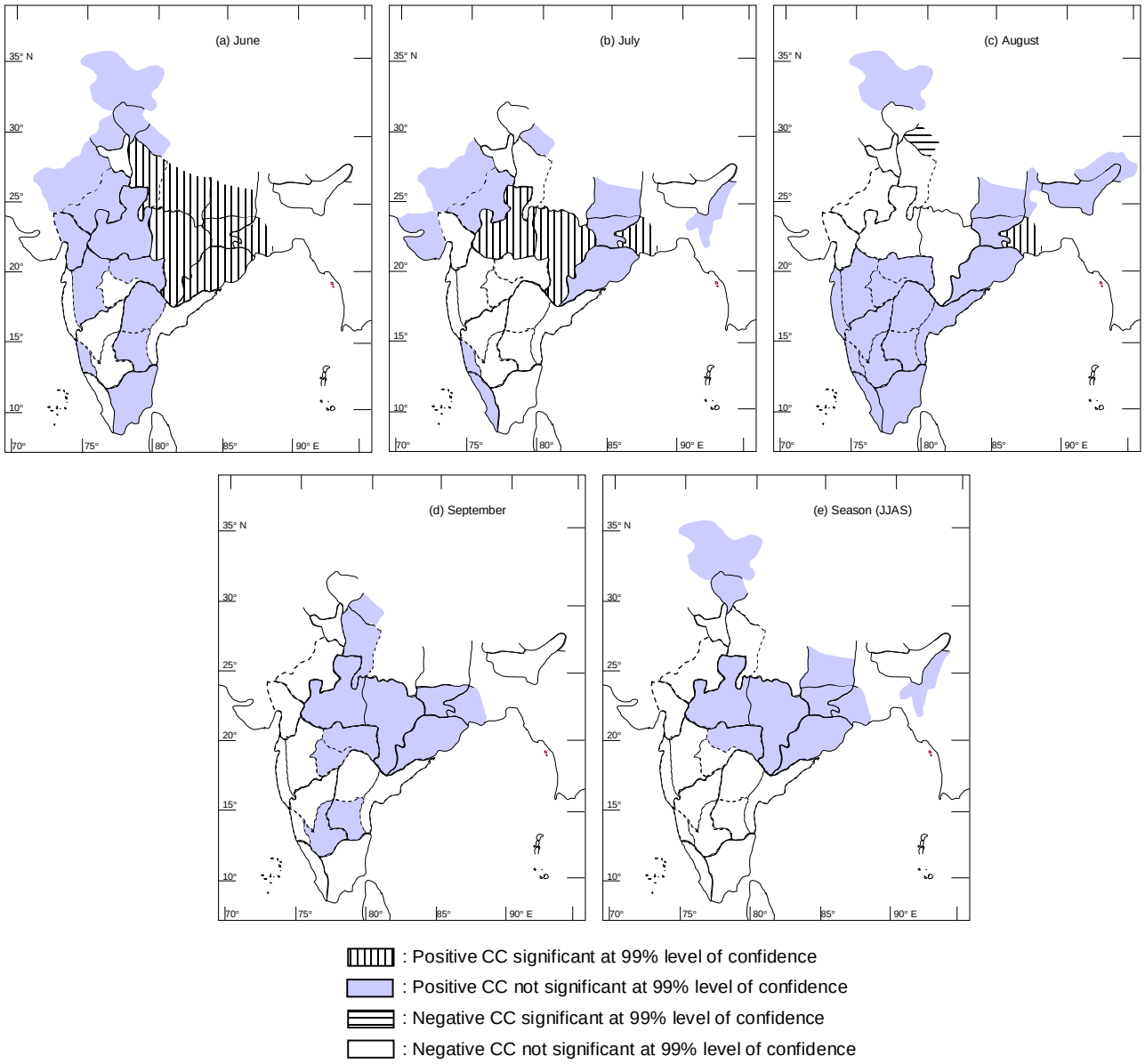


Figs. 4(a-e). Correlation coefficients (CC) of rainfall over different meteorological sub-divisions of India with number of LPS days over Orissa during summer monsoon season (a) June, (b) July, (c) August, (d) September and (e) Season (JJAS)

to that over central India has also been found out by previous studies of Bedi and Bindra (1980), Prasad and Singh (1988) and Gregory (1989).

3.2.3. *Sub-divisional rainfall in relation to LPS over Orissa*

The sub-divisional rainfall over Vidarbha, west Madhya Pradesh and east Rajasthan in July and EMPC in August increases with increase in number of LPS days over Orissa [Figs. 4(a-e)] as these sub-divisions lie in the left forward sector of mainly west-northwestward moving LPS over Orissa and left forward sector gets maximum rainfall (Rajamani and Rao, 1981). The seasonal rainfall over Orissa increases with increase in number of LPS days over Orissa. Considering the homogeneous regions (Table 1), the rainfall over the east central India increases in July and August with increase in LPS days over Orissa. The rainfall over some sub-divisions of peninsula, *viz*., Tamil Nadu, interior Karnataka and Rayalaseema are



Figs. 5(a-e). Correlation coefficients (CC) of rainfall over different meteorological sub-divisions of India with number of LPS days over GWB during summer monsoon season (a) June, (b) July, (c) August, (d) September and (e) Season

adversely affected during August due to increase in LPS days over Orissa like that due to increase in LPS days over the NW Bay. The rainfall over Arunachal Pradesh and Assam & Meghalaya in July and over sub-Himalayan West Bengal & Sikkim in July, August and season as a whole are adversely affected with increase in LPS days over Orissa. Considering homogeneous regions (Table 1), the rainfall decreases over northeast India in July with the increase in number of LPS days over Orissa. Hence, there is opposite type of rainfall distribution over some sub-divisions in northeast India in July and peninsular India excluding west coast in August compared to that over some of the sub-divisions in central India due to LPS over Orissa.

3.2.4. *Sub-divisional rainfall in relation to LPS over EMPC*

The correlation of the number of LPS days over EMPC with the rainfall is significant only for one or two sub-divisions in different monsoon months and the season as a whole (not shown). The rainfall over Vidarbha and

Marathawada in June and only Vidarbha in August increase with increase in LPS days over EMPC, as they lie in the southwest sector of this mainly west-northwestward moving LPS. Considering homogeneous regions (Table 1), the rainfall increases over peninsular India excluding west coast in June with increase in LPS days over EMPC. The rainfall increases over GWB in July and Jharkhand (JKD) in September with increase in LPS days over EMPC. The rainfall over Assam & Meghalaya in July, east Uttar Pradesh in August and Haryana, Chandigarh & Delhi during the season as a whole decrease with increase in LPS days over EMPC. It may be due to the fact that with the LPS over EMPC, the monsoon trough lies to the south of its normal position. The region of minimum rainfall lies about 2-3 degree latitude north of the axis of the mean sea level position of the monsoon trough (Pathan, 1993). Due to the above reasons, the seasonal rainfall decreases over western part of north India (northwest India) with increase in LPS days over EMPC (Table 1).

3.2.5. *Sub-divisional rainfall in relation to LPS over GWB*

The rainfall over the region extending from GWB-Orissa to EMPC - west Uttar Pradesh significantly increases with increase in LPS days over GWB during June [Figs. 5(a-e)] like that due to increase in LPS days over NW Bay [Figs. 3(a-e)]. The rainfall increases over GWB, EMPC and west Madhya Pradesh in July with increase in LPS days over GWB. Considering homogeneous regions (Table 1), the rainfall over eastern part of north India in June and east central India in June and July increase with increase in LPS days over GWB. The rainfall increases only over GWB with increase in LPS days over GWB during August. All the above results may be due to the fact that the monsoon trough passes through relatively northerly latitude during June and shifts southward as the season advances further. The number of LPS days over GWB is also maximum in June compared to other monsoon months (Mohapatra and Mohanty, 2004). The rainfall over northeast India in September decreases with increase in LPS days over GWB (Table 1).

3.2.6. *Sub-divisional rainfall in relation to LPS over Jharkhand (JKD)*

Considering the impact of LPS over JKD on sub-divisional rainfall (not shown), the rainfall over some sub-divisions in north India like west Uttar Pradesh and GWB increases in June with increase in LPS days over JKD. It may be due to the fact that with the LPS over JKD, the monsoon trough shifts relatively northward and hence the zone of maximum rainfall. The rainfall over Bihar increases during September with increase in LPS days over JKD. It may be due to the fact that in the month of September, the LPS over JKD moves on many occasions in a northeasterly direction (Rao, 1976) under interaction of upper tropospheric westerly trough. As a result, Bihar lies in the left forward sector and gets more rainfall. Considering the homogeneous regions (Table 1), the rainfall increases over eastern part of north India with increase in LPS days over JKD in September due to the above mentioned reason. Also, the occurrence of LPS over JKD is more frequent in September, compared to other monsoon months (Mohapatra and Mohanty, 2004). The correlation of LPS days over JKD with the rainfall is not significant during main monsoon months of July and August for any meteorological sub-division. However, the seasonal rainfall over east Uttar Pradesh decreases with increase in LPS days over JKD.

3.2.7. *Sub-divisional rainfall in relation to LPS over NE Bay*

The rainfall increases over JKD and Bihar during June (not shown) with increase in LPS days over NE Bay. It may be due to the fact that the LPS over NE Bay mainly moves across BDS during this month (Mohapatra and Mohanty, 2005). As a result, most parts of JKD and Bihar lie in the left forward sector to get more rainfall. Also, the number of LPS days over NE Bay is maximum in June and less in other months (Mohapatra and Mohanty, 2004). The rainfall also increases over Jammu & Kashmir, Uttarakhand and west Uttar Pradesh with increase in LPS days over the NE Bay in June. Srinivasan *et al*., (1972) has shown that some sub-divisions of northwest India may get good rainfall due to LPS over north Bay of Bengal, if there is interaction of the mid-latitude westerly systems over the region with the monsoon trough and the LPS. Considering homogeneous regions (Table 1), the rainfall also increases over both western and eastern parts of north India with increase in LPS days over NE Bay in June. The rainfall decreases over Marathwada in June and Orissa in September with increase in LPS days over the NE Bay. It increases over Andaman & Nicobar Islands and Tamil Nadu in July with increase in LPS days over NE Bay.

3.2.8. *Sub-divisional rainfall in relation to LPS over Bangladesh (BDS)*

The rainfall over GWB increases with increase in LPS days over BDS during June and July (not shown) as the LPS over BDS mostly moves west-northwestwards and most parts of GWB lie in the southwest sector and hence get more rainfall during these months. The rainfall significantly decreases over Konkan & Goa during July with the increase in LPS days over BDS. Considering homogeneous regions (Table 1), the rainfall also decreases over west coast in July with increase in LPS days over

BDS. It may be due to the fact that the monsoon trough shifts northward in association with the LPS over BDS. As a result, the strength of westerlies over the peninsular region decreases leading to less orographic interaction of Western Ghat and hence less rainfall over the west coast. The rainfall over Assam & Meghalaya significantly increases with increase in LPS days over BDS during September and season as a whole. It may be due to the northward location of associated monsoon trough and interaction of the basic monsoon flow with the LPS and orography of the region. In addition, the LPS over BDS very often moves northeastward under the influence of the upper tropospheric westerly trough in September (Rao, 1976). In this case, Assam & Meghalaya lies in the left forward sector to get more rainfall.

The structure of CC and their spatial distribution are different in different monsoon months as per expectation. It may be due to the fact that the CC mostly depends upon the characteristics like intensity and movement of LPS and the associated monsoon trough. For example, during monsoon advance period (month of June), the monsoon trough is not well established. Similarly, during the withdrawal phase of monsoon (month of September), the monsoon trough is ill defined. Hence, the structure and spatial distribution of CC in June and September are different from that in July and August. Also there is interaction of mid-latitude westerly trough with the LPS, mainly in September and June. The characteristics of LPS, formed at prior to break and the end of break could also be different.

4. Conclusions

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

(*i*) The average seasonal monsoon rainfall has been normal during 1982-1999 over all the meteorological sub-divisions of India.

(*ii*) There is large month to month variation in the impact of the LPS on the sub-divisional monsoon rainfall over India. However, the results presented in the study including the correlation maps may be helpful to predict 24 hours rainfall based on the location of the LPS and associated monsoon trough.

(*iii*) The frequent development and persistence of LPS over NW Bay are favourable for higher seasonal monsoon rainfall over east central India. The development and persistence of LPS over WC Bay adversely affect the seasonal rainfall over this region. On the other hand, the frequent development and persistence of LPS over WC Bay and its subsequent westward movement across NCAP are favourable for higher seasonal rainfall over the peninsular region excluding west coast. The seasonal rainfall over northwest India decreases with increase in LPS days over EMPC. The seasonal rainfall over other homogeneous regions are not significantly related with the number of LPS days over the regions under consideration.

(*iv*) Considering monthly rainfall, the higher number of LPS days over GWB in June, GWB/Orissa in July and Orissa in August causes higher rainfall over east central India. The rainfall over eastern part of north India increases with increase in LPS days over NW Bay, NE Bay and GWB in June and JKD in September. The rainfall over northwest India also increases with increase in LPS days over NE Bay in June. The rainfall over the peninsular India excluding west coast increases with increase in LPS days over EMPC in June and WC Bay in July. The rainfall over west coast decreases in July with increase in LPS days over Bangladesh. The rainfall over northeast India decreases with increase in LPS days over Orissa in July and GWB in September.

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