MAUSAM, **57**, 2 (April 2006), 329-362

Letters to the Editor

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ANALYSIS OF RAINFALL VARIABILITY OVER ANDHRA PRADESH IN RELATION TO CYCLONIC DISTURBANCES

1. The north coastal Andhra bordering south Orissa coast does get affected by cyclonic systems forming in Northwest Bay. Similarly, south coastal districts and adjoining Rayalaseema come under the influence of cyclonic systems forming over southwest Bay and adjoining west central Bay. As such, the entire coast of Andhra Pradesh is vulnerable to natural disasters arising due to depressions, cyclonic storms (CS) and severe cyclonic storms (SCS). The depressions are low-pressure systems with maximum sustained surface winds from 17 to 33 knots (61 kmph). It is well known fact that Cyclonic Disturbances (CDs) which include depressions, CSs and SCSs accompanied by very heavy rain, gales and storm surges cause severe damage to life and property over the Indian coastal regions every year. These systems initially form as a low-pressure area and intensify into depressions and occasionally into CSs. The CSs over north Indian Ocean generally form during pre-monsoon season (March to May) and post-monsoon season (October to December). Along the eastern coast of India, the state of AP has experienced disastrous affects of many such CSs in the past. The state consists of three meteorological sub-divisions *viz*., Coastal Andhra Pradesh (CAP), Telangana (TEL) and Rayalaseema (RAY) as shown in Fig. 1. These three sub-divisions also face floods in some years and droughts in other years. The extensive damage to life and property caused by Chirala cyclone of November 1977 will be remembered for a long time by people of the state. Raghavan and Rajesh (2003) have discussed trends in impact of CS over Andhra Pradesh. Again excess (deficient) rainfall in a year can cause floods (droughts) over the state of AP. During the southwest monsoon season from June to September, the depressions move in west-north-westerly direction and cause considerable rainfall over many meteorological sub-divisions of India. Philip *et al*., (1973) have shown that during the southwest monsoon season, the meteorological sub-divisions of CAP and TEL get rainfall in association with depressions and lows in the Bay and the east-west oriented trough across the north Peninsula. They have also shown that the synoptic situations causing active rainfall over the sub-division of RAY are upper-air cyclonic circulation and north-south trough, which are more likely during a weak or 'break' monsoon over the country. Thus, in this respect RAY is very much different from CAP and TEL.

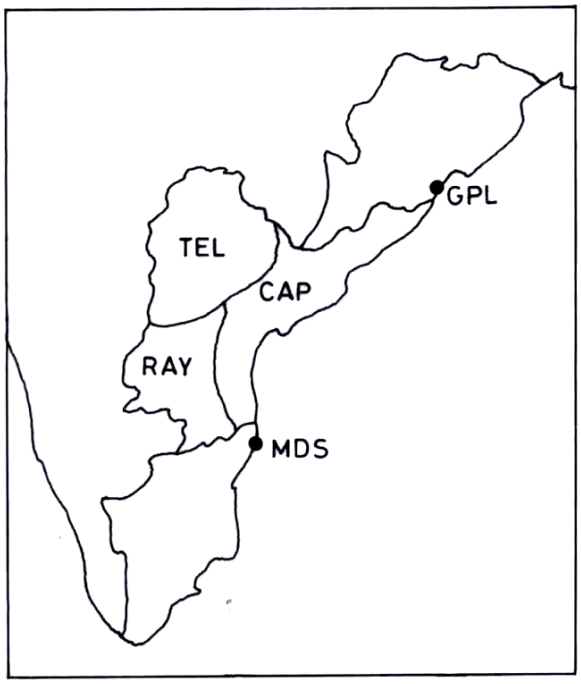


Fig. 1. Coastal map of eastern coast showing three meteorological sub-divisions of Andhra Pradesh *viz*., Coastal Andhra Pradesh (CAP), Telangana (TEL) and Rayalaseema (RAY)

The influence of CDs on southwest monsoon rainfall over India have been studied by many authors. Mooley and Parthasarathy (1983) have found that during the monsoon season from June to September the CDs have greater westward penetration during years of good monsoon than that during years of deficient monsoon. Pattanaik and Thapliyal (2004) have also shown that the southwest monsoon rainfall over Orissa is highly influenced by CDs crossing the coast. In the present study we have analysed the variability of CDs over AP coast during the 100-year period from 1901 to 2000. The impact of CDs on rainfall variability of three meteorological sub-divisions of AP *viz*., CAP, TEL and RAY for southwest monsoon season from June to September and post monsoon season from October to December is also analysed during the same 100 years period.

2. The detailed data of CDs along with their tracks during the period 1901 to 1990 were collected from the storm atlas and its addendum published by India Meteorological Department (IMD 1979, 1996). The data for recent period (1991 to 2000) have been obtained from the office of Deputy Director General of Meteorology (Weather Forecasting), India Meteorological Department,

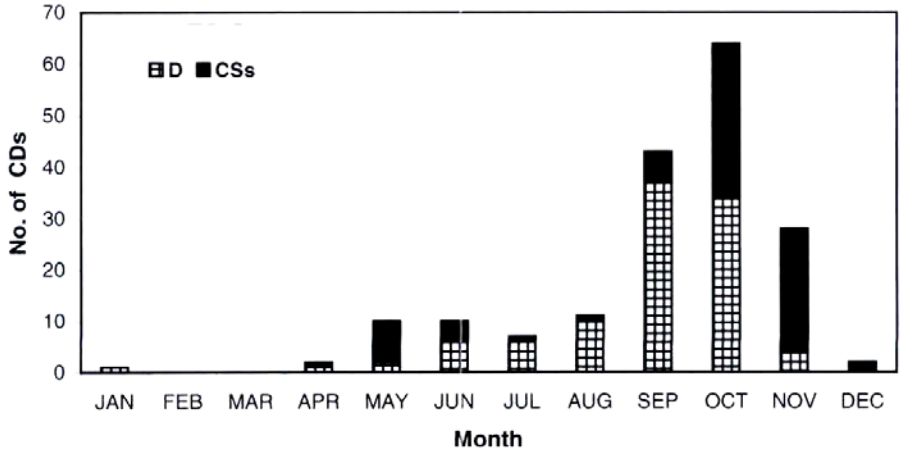
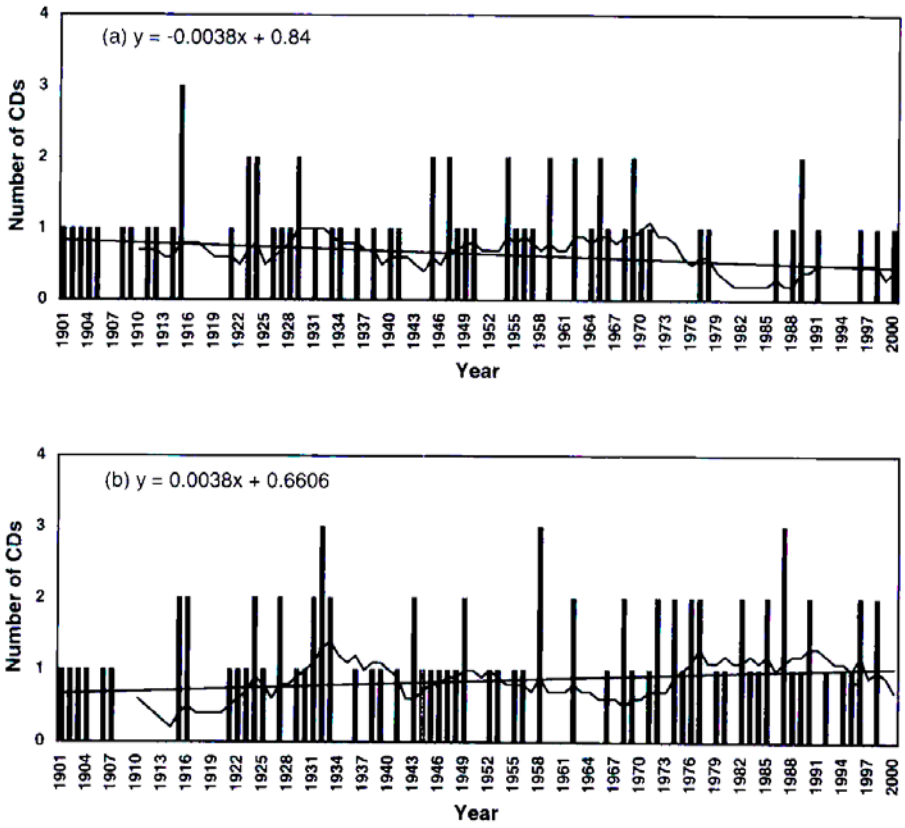


Fig. 2. Monthly total cyclonic disturbances crossed Andhra Pradesh region between Gopalpur and Chennai during 1901 to 2000. Shaded portion indicated cyclonic storms and small square portion indicates depressions

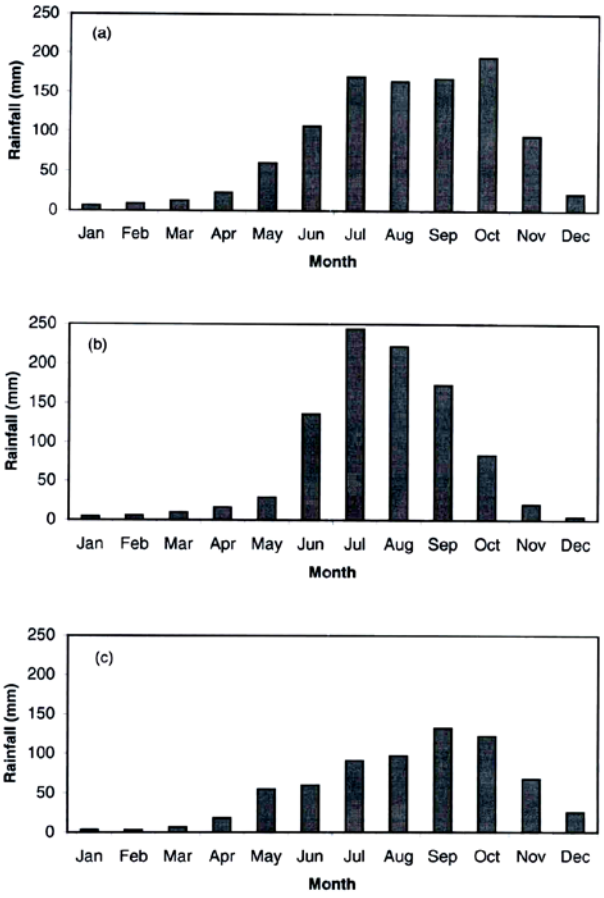


Figs. 3(a&b). Seasonal number of cyclonic disturbances that crossed Andhra Pradesh region during 1901 to 2000, (a) June to September and (b) October to November

Pune. The monthly and seasonal (actual and normal) rainfall over three meteorological sub-divisions of AP *viz*., CAP, TEL and RAY has been collected from India Meteorological Department.

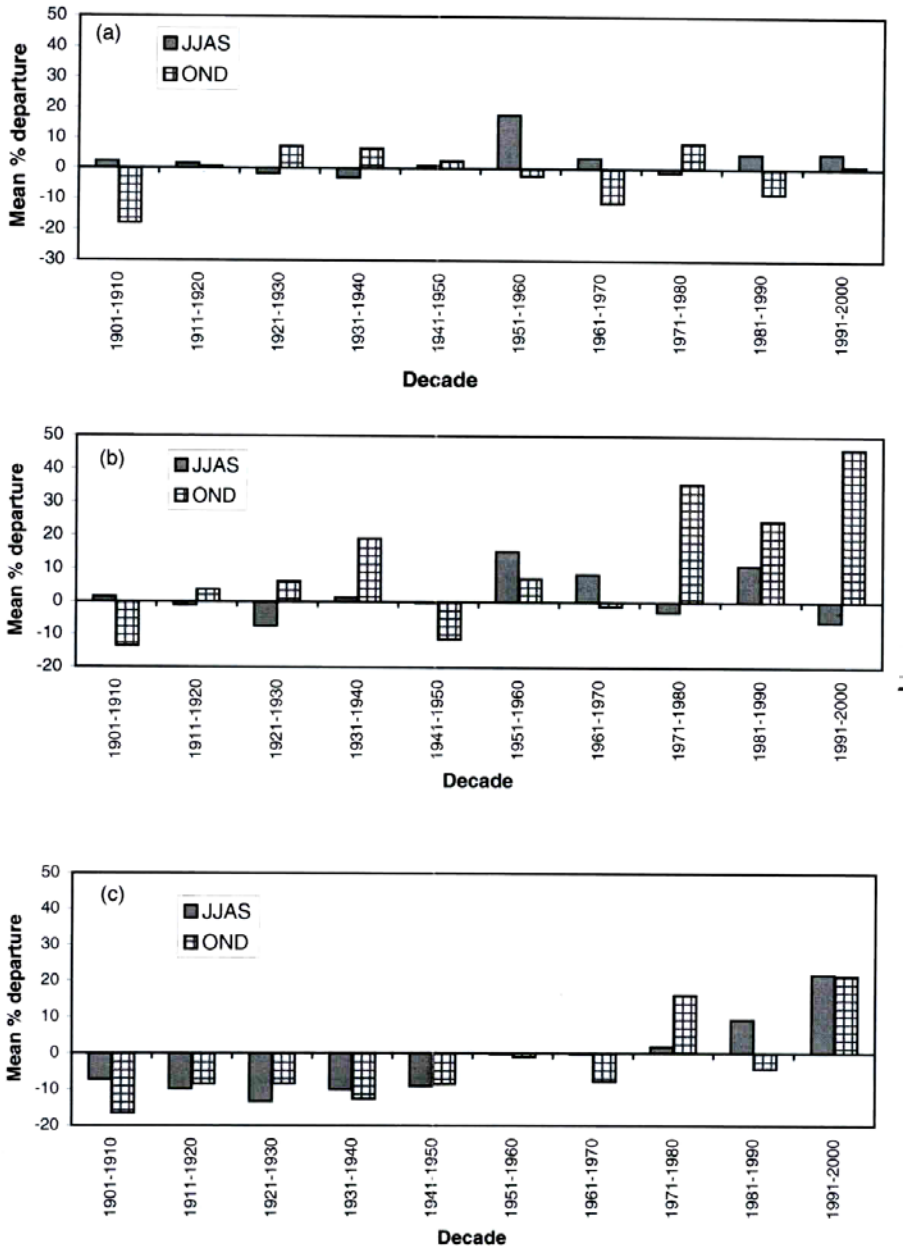
3.1. *Analysis of CDs that influenced Andhra Pradesh coast* - The origin and formation of CDs varies from season to season and from month to month (Ganeshan *et al*., 1994). Muthuchami (2000) has shown that during the month of April, only the coasts of Tamilnadu and AP are affected, whereas during the month of December CDs mainly pass through southern latitudes close to equator. Rao and Rao (1993) have found that the CDs crossing not only the coastal parts of AP but also those of south Orissa and north Tamilnadu can cause heavy rain over the ghats in AP. Thus, here we considered the CDs which pass through south of Gopalpur in Orissa and north of Chennai (formerly Madras) in Tamilnadu for its influence on rainfall distribution over three meteorological sub-divisions of AP (Fig. 1). The monthly total CDs which crossed eastern coast between Gopalpur and Chennai during the period from 1901 to 2000 is shown in Fig. 2. It is seen from Fig. 2 that the highest number of CDs crossed the AP region during the month of October (36% of annual) followed by September (24% of annual) and November (16% of annual). It is also seen that about 40% of CDs crossed AP region during entire southwest monsoon period from June to September while 52% during two month period from October to November. The peak southwest monsoon months of July and August as a whole constitute only 10% of the total CDs over this region. Thus, the CDs which pass through AP region during peak monsoon months of July and August is considerably less compared to that during latter part of the southwest monsoon season (September) and post monsoon months (October to November). Pattanaik and Thapliyal (2004) have found that most of the CDs form over Bay during July and August cross Orissa coast between 20°N-22°N. It is also found that in case of only CSs, 70% of the total form during October to November with peak during October with 39%. Fig. 2 also indicates that though the month of October has got highest number of CSs, the probability of a CD to intensify into CS is maximum in November (86%) followed by October (47%).

The variability of number of CDs on different time scales (annual, decadal and epochal) form over north Indian Ocean has been reported by many earlier studies. There exist large decadal variations in the frequency of CD in north Indian Ocean (Jayanthi 1997 and Pattanaik 2004). Pattanaik *et al*., (2004) have also reported variability in westward movement of CDs during southwest monsoon season from June to September. It is also observed that the number of CDs formed over Indian region during southwest monsoon season from June to September is decreasing in recent time (Pattanaik *et al*., 2004; Rajeevan *et al*., 2000; Singh and Khan 1999 etc.). The annual number of CDs crossed AP region between Gopalpur and Madras during June to September and October to November is shown in Fig. 3. Fig. 3 shows that the number of CDs crossed AP region during June to September (October to December) show decreasing (increasing) trend although it is not statistically significant.



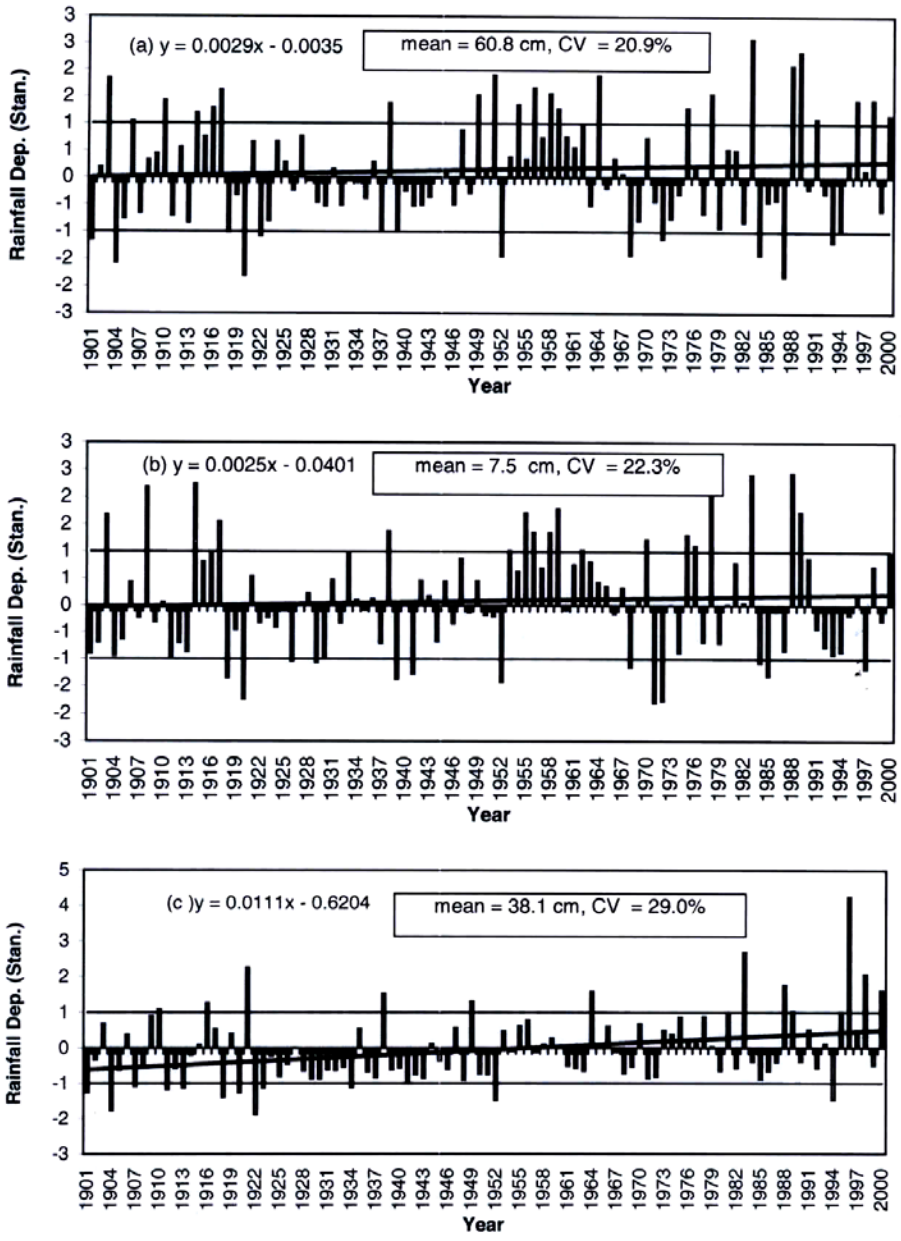
Figs. 4(a-c). Monthly climatological mean rainfall in mm based on 1941 to 1990, (a) Coastal Andhra Pradesh, (b) Telangana and (c) Rayalaseema

3.2. *Interdecadal and interannual rainfall variability over Andhra Pradesh* - The climatological monthly normal rainfall distribution over three meteorological subdivisions *viz*., coastal Andhra Pradesh (CAP), Telangana (TEL) and Rayalaseema (RAY) of AP during the period from 1941 to 1990 is shown in Fig. 4. With the decreasing frequency in the formation of CDs, in recent times, it is interesting to note that significant rainfall over the three meteorological sub-divisions of Andhra Pradesh occurs in association with Low Pressure areas (LOPARS) and Upper Air Cyclonic circulations forming over West Central Bay and East-West Upper Air troughs passing through the state. It is seen that the monthly rainfall distribution is not identical in all three sub-divisions. Just like the monthly climatological normal



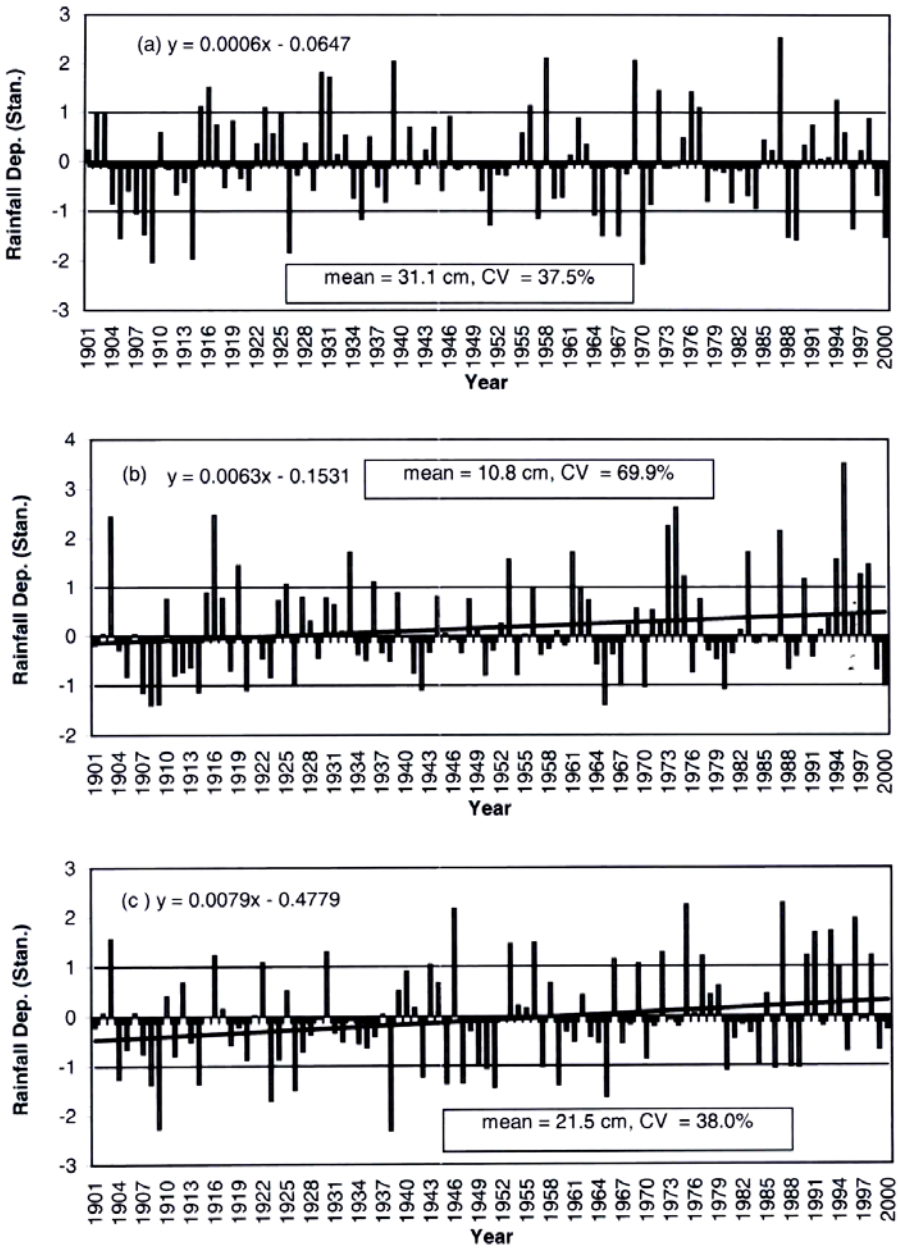
Figs. 5(a-c). Decadal mean percentage departure of rainfall during June to September and October to December during 1901 to 2000, (a) Coastal Andhra Pradesh, (b) Telangana and (c) Rayalaseema

rainfall distribution for the country as a whole, TEL sub-division [Fig. 4(b)] has got peak rainfall during July followed by August, September and June with about 82% of annual total rainfall received during June to September and only about 11% during October to December. But for CAP [Fig. 4(a)] the peak rainfall is reported during October and the southwest monsoon season from June to September constitutes about 59% of annual total. The post monsoon season from October to December contributes about 30% of annual total rainfall for CAP. In case of RAY [Fig. 4(c)], the peak rainfall is in September followed by October with June to September contribute about 56% of annual total and about 32% during October to December. Thus, the sub-divisions CAP and RAY receive considerable amount of rainfall (about 30% or more) during northeast monsoon season from October to December in addition to southwest monsoon season from June to September.



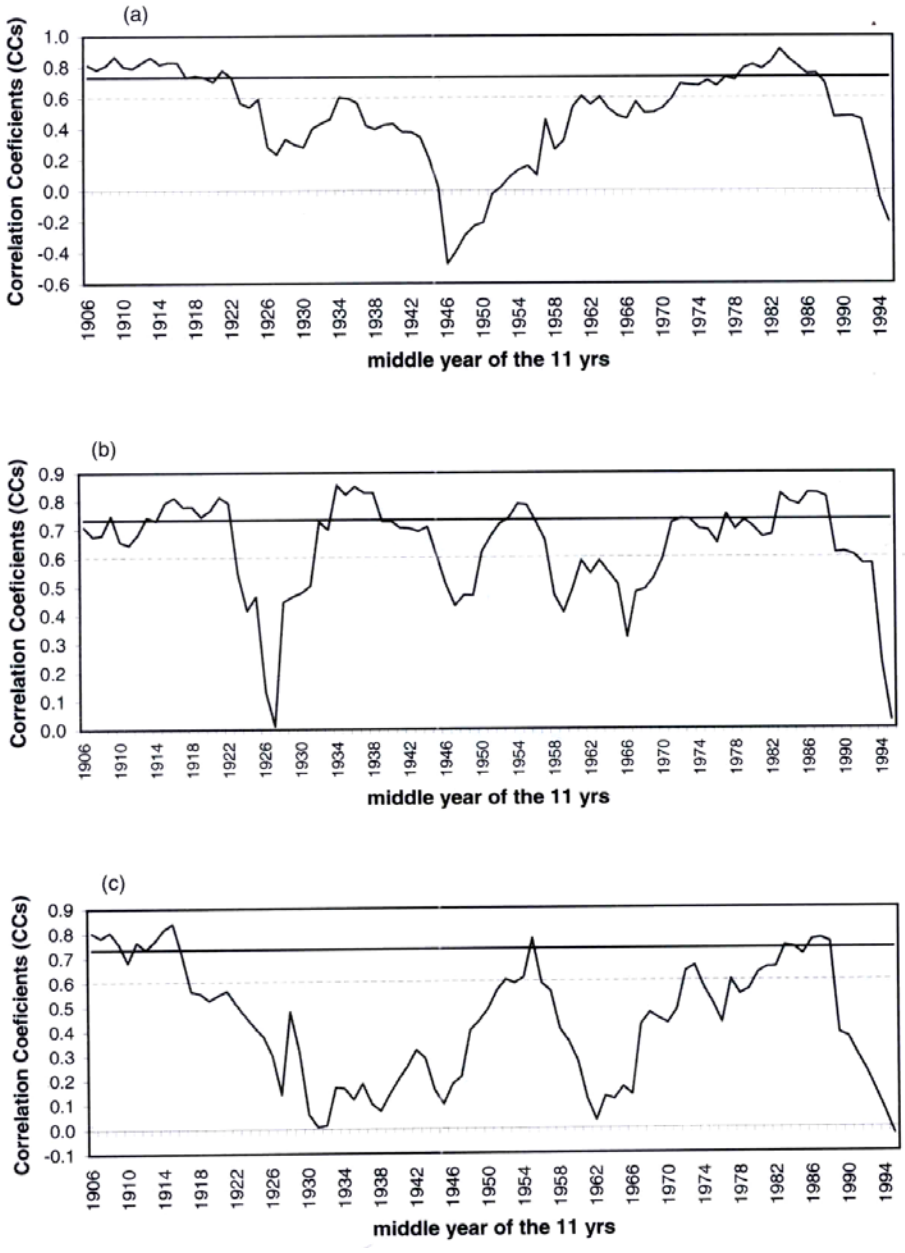
Figs. 6(a-c). Standarised rainfall anomalies during June to September from 1901 to 2000, (a) Coastal Andhra Pradesh, (b) Telangana and (c) Rayalaseema

The decadal mean percentage rainfall departure during June to September and October to December for the three sub-divisions of AP is shown in Fig. 5. It is seen from Fig. 5(a) that for CAP sub-division, seven out of ten decades from 1901 to 2000, the mean rainfall departure during June to September and October to December are with opposite signs. It is also seen that the peak rainfall for CAP during June to September is observed during the decade from 1951 to 1960 and lowest during the decade from 1931 to 1940. For October to December, the highest rainfall amount is reported during the decade from 1971 to 1980 and lowest rainfall amount during the decade from 1901 to 1910. It is also seen from Fig. 5(a) that during the last decade from 1990 to 2000 the rainfall departure is on the positive side during both seasons over CAP. For TEL [Fig. 5(b)] too, the highest rainfall amount is received during June to September during the decade from 1951 to 1960 followed by decades of 1981 to 1990 and 1961 to



Figs. 7(a-c). Standarised rainfall anomalies during October to December from 1901 to 2000, (a) Coastal Andhra Pradesh, (b) Telangana and (c) Rayalaseema

1970 and the highest negative departure is reported during 1921 to 1930. Though TEL received only about 11% of annual rainfall during October to December, it is very interesting to see that there is very large positive departure of rainfall during last three decades from 1971 to 2000 over TEL during October to December [Fig. 5(b)]. It is also seen from Fig. 5(a) and Fig. 5(b) that on decadal scale the rainfall received during June to September and October to December were of opposite sign on 7, out of 10 occasions over CAP and TEL. In case of RAY [Fig. 5(c)], the first seven decades from 1901 to 1970 have reported mean negative departure of rainfall during both seasons with large negative departure during first five decades. It is also seen that in case of RAY except on one occasion for the decade from 1981 to 1990 the mean rainfall departure during June to September and October to December are of same sign for all remaining nine decades. Thus, the sub-division of RAY is different from CAP and TEL in the sense that on most of occasions rainfall during June to September and October to



Figs. 8(a-c). 11 year running correlation coefficients between June to September rainfall over the country as a whole with corresponding rainfall over three sub-divisions of Andhra Pradesh, (a) Coastal Andhra Pradesh, (b) Telangana and (c) Rayalaseema. The significant CC at 95% and 99% are drawn as dotted and solid lines respectively

December are in same phase on decadal scale and it is just the opposite for CAP and TEL.

In order to see the linear trend of rainfall over three sub-divisions, the seasonal rainfall departure during June to September and October to December are shown in Fig. 6 and Fig. 7 respectively for all the three meteorological sub-divisions of AP. As we have seen from Fig. 5(a), the sub-division of CAP shows highest rainfall during the decade from 1951 to 1960 in June to September and the decade is associated with 5 excess years (1951, 1954, 1956, 1958 and 1959) and 4 years with positive rainfall departure (1953, 1955, 1957 and 1960) as shown in Fig. 6(a). Similarly for TEL also, 5 excess years reported during the decade of 1951 to 1960 (1953, 1955, 1956, 1958 and 1959) in June to September [Fig. 6(b)]. As it is

seen from Fig. 5(a) and Fig. 5(b) the rainfall during June to September and October to December on decadal scale shows opposite sign on 70% occasions for CAP and TEL and same sign on 90% occasions for RAY; on interannual scale the Correlation Coefficients (CCs) between June to September rainfall and October to December rainfall for CAP, TEL and RAY sub-divisions (Fig. 6 and Fig. 7) is found to be -0.18, 0.04 and 0.12 respectively. Though the CCs are not highly significant but RAY shows clear in-phase relation between southwest monsoon and post monsoon rainfalls and CAP shows out of phase relation with CC significant at 90% level. It is also observed that the seasonal rainfall is showing an increasing trend for both seasons for all three sub-divisions (Fig. 6 and Fig. 7). However, the significant increasing trend of rainfall is reported for the sub-division of RAY which is significant at 99% level during June to September and at 98% during October to December. The increasing trend of rainfall during June to September is also in agreement with decadal rainfall of RAY with negative mean departure during first seven decades and positive mean departure during recent three decades [Fig. 5(c)].

On comparing the all India monsoon rainfall from June to September (Fig. not shown) with corresponding seasonal rainfall departure over CAP, TEL and RAY, it is found that the relation between rainfall of three sub-divisions of AP with that of all India rainfall is very strong with CCs of 0.39, 0.54 and 0.64 respectively during 100 year period from 1901 to 2000. These CCs are significant at 99.9% level. Again in order to see the epochal variation of the relationship, 11 years running CCs have been plotted between sub-divisional rainfall of three meteorological sub-divisions of AP during June to September with corresponding all India rainfall departure during 100 years period (Fig. 8). It is seen from Fig. 8(a) that the sub-division of CAP shows higher CCs during initial two decades and during eighties with CCs exceeding the value of 95% significance level. Thus, it was in phase with all India rainfall during these periods. However, during 1940s, early 1950s and recent decade of 1990s the CCs have become negative. Thus, during the recent period the CC between sub-division rainfall of CAP and that of all India rainfall during June to September has decreased and became negative. Similarly the sub-divisions of TEL and RAY also show secular variation of relationship with all India rainfall with almost no correlation or negative correlation with all India rainfall during recent decade.

3.3. *Association of CDs on rainfall over Andhra Pradesh* - Monsoon depression which form over Indian region or develop from the remnants of depressions/storms which strike the Viet Nam coast and move into the Bay region can give wide spread rainfall over India after crossing the coast. During the monsoon season from June to September the CDs have greater westward penetration during years of good monsoon than that during years of deficient monsoon as shown by Mooley and Parthasarathy (1983). Pattanaik and Thapliyal (2004) have shown that the CDs crossed Orissa coast between 18° N – 22° N during July and August show significant positive correlation with the rainfall of the state. Philip *et al*., (1973) have shown that during the southwest monsoon season from June to September the sub-divisions CAP and TEL gets rainfall in association with depressions and lows in the Bay and the east-west oriented trough across the north Peninsula. As most of the CDs crossed AP coast during June to November (Fig. 2), the impact of CDs on rainfall over the three sub-divisions of AP can be found by correlating the number of CDs crossed AP region as shown in Fig. 3 with corresponding rainfall over the three sub-divisions of AP. The rainfall departure during June to September and October to November over three sub-divisions of AP were correlated with corresponding number of CDs crossing AP coast as shown in Fig. 3 and the CCs with corresponding significance levels are given in Table 1. It is seen from Table 1 that the CCs are higher during October to November compared to June to September over all three sub-divisions and the CCs during October to November are highly significant for CAP, TEL and RAY. As it is seen from Table 1, during June to September the CCs are statistically significant for CAP and TEL and not significant at even 90% level for RAY. Thus, in addition to the CDs other synoptic scale systems also contribute for rainfall over RAY during June to September. Philip *et al*., (1973) have also shown that the synoptic situations causing active rainfall over RAY are upper-air cyclonic circulation and north-south trough, which are more common during a weak or 'break' monsoon period over the country. Thus, in this respect RAY is very much different from CAP and TEL.

TABLE 1

Correlation between rainfall departure over CAP, TEL and RAY with CDs crossing AP coast for 100 years periods from 1901 to 2000 during June to September and October to November. The significance level is written in the bracket

Months	CAP	TEL	RAY
June to September (JJAS)	0.25 (98%)	0.21 (95%)	0.10 (Not sig.)
October to November (ON)	0.51 (99.9%)	0.39 (99.9%)	0.31 (99%)

4. *Conclusions* - The results of this study show that the peak months of CDs to cross AP region is from

September to November (76% of total) with highest during October (36%). It is also seen that in case of only storms (CS and SCS), October to November constitute 70% of annual total with highest during October with 39% and the probability of a CD to intensify into a CS is maximum during November (86%) followed by October with 47%.

The analysis of decadal rainfall variability over three sub-divisions of AP indicate highest rainfall during June to September over CAP during 1951 to 1960 and lowest rainfall during 1931 to 1940. Similarly over Telengana, the highest rainfall reported during June to September from 1951 to 1960 and lowest during 1921 to 1930. It is also seen that 7 out of 10 decades from 1901 to 2000, the mean rainfall departure during June to September and October to December are of opposite signs for CAP and TEL. However, in case of RAY, the decadal mean rainfall departure during June to September and October to December are of same sign on 9 out of 10 decades. The linear trend analysis of yearly seasonal rainfall indicates significant increasing trend for RAY during June to September and October to December. The CC between all India rainfall and sub-divisional rainfall over CAP, TEL and RAY during June to September is decreasing during recent time.

The correlation between number of CDs crossed AP coast during June to September and October to November with corresponding rainfall over CAP, TEL and RAY shows higher and significant positive CCs during October to November compared to June to September for all three sub-divisions. The positive CC being not significant for RAY during June to September indicate that the CDs are not the main synoptic systems for southwest monsoon rainfall from June to September over RAY.

5. The author is thankful to the Director General of Meteorology, India Meteorological Department, New Delhi and to Dr. (Mrs.) N. Jayanthi, Deputy Director General of Meteorology (Weather Forecasting), Pune for the encouragement and for providing all facilities to carry out this research work. Thanks are also due to Mr. M. Krishnamurthy, IMD, Pune for his valuable suggestions.

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(*13 April 2004, Modified 23 November 2004*)