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Heavy rains in coastal Andhra Pradesh due to distant effect of storm/depression in southwest Bay

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सार – अक्तूबर और नवम्बर की अवधि में मद्रास के दक्षिण के अक्षांशों से दक्षिण-पश्चिम खाड़ी का तूफान/अवदाब जब तमिलनाडु तट को पार करता है तब तटीय आंध्रप्रदेश में भारी से भीषण वर्षा तक होती है और कभी-कभी बाढ़ें भी आ जाती हैं। इस रोचक तथ्य को सिनॉप्टिक अध्ययन से देखना कठिन होता है। यद्यपि यह पूर्वानुमान के प्रयोजन के लिए बहुत उपयोगी है। इस प्रभाव को तूफान/अवदाब का दूरगामी प्रभाव कहते हैं। इस दूरगामी प्रभाव को 6 मामलों के अध्ययनों में देखा गया है और ऐसे प्रभाव की क्रिया विधि को अपसरण क्षेत्र की गणना से समझाया गया है। यह भी ज्ञात हुआ है कि यह दूरगामी प्रभाव केवल अक्तूबर के और नवम्बर के प्रथम पक्ष में आने वाले तूफानों के लिए प्रयोज्य है। यहां दो तूफानों का अध्ययन किया गया है, वे हैं : नवम्बर के द्वितीय पक्ष एवं दिसम्बर के प्रथम सप्ताह के तूफान। ये तूफान इस दूरगामी प्रभाव का पूर्णतः अनुसरण नहीं करते ।

ABSTRACT. Coastal Andhra Pradesh (CAP) gets heavy to very heavy rainfall – sometimes leading to floods, when a storm/depression in southwest Bay crosses Tamil Nadu coast south of Madras latitude during October and November. This interesting fact is difficult to visualise from the synoptic study though it is very useful for forecasting purposes. This effect can be called as distant effect of the storm/depression. This distant effect is observed in six case studies and the mechanism for such an effect is explained by calculating field of divergence. It is also found that 'distant effect' is only applicable to the storms of October and those occurring in the first fortnight of November. Two storms studied here, one in the second fortnight of November, and other in the first week of December do not completely follow this 'distant effect'.

1. Introduction

In an earlier study, Mukherjee *et al.* (1966) investigated the role of October storm/depression over southwest Bay in causing heavy rains in coastal Andhra Pradesh (hereafter called CAP) leading to floods. They found that when a depression/storm over southwest Bay crosses Tamil Nadu coast south of Madras latitude, CAP gets heavy rains which is really an interesting fact of observation. Their finding was based on the study of all the cases from 1900 to 1963. In the present study, in all six cases are studied in detail. In view of more data coverage in the recent years, this interesting fact is re-examined, and the possible explanation for the mechanism of heavy rains over CAP is verified. The details of the cases studied are given in Table 1 and the tracks of the storms are given in Fig. 1.

This finding is very useful for forecasting purpose. Forecasters generally give heavy rainfall in the neighbourhood of storm/depression centre and are surprised to find heavy rains away from the storm field. Moreover, the synoptic charts do not indicate any clue of giving such a forecast over CAP. Further, in between these two maxima of rainfall, there is a minimum which also is an interesting fact useful for forecasting purposes. This distant effect was also observed over the Arabian Sea storm/depression as studied by Mukherjee *et al.* (1980) where a storm/depression crossed north Gujarat coast and caused heavy rains over north Bombay. Raghavan *et al.* (1981) confirmed this distant effect from radar studies.

Fields of divergence, vorticity and vertical velocity for 1963 and 1977 storms are prepared to examine the mechanism of heavy rains over CAP. The trajectory of air parcel associated with storms/depressions showed that they converge over CAP causing low level moisture incursion.

2. Data utilised

The tracks of storm/depression as published by the Meteorological Office, Pune are used in this study. The rainfall reports are collected from the *Indian Daily Weather Reports* and *Weekly Weather Reports* published by the India Meteorological Department.

TABLE 1

Details of storm/depression studied

Period	Type	Date and place of crossing coast
19-24 Oct 1963	S.C.S.	21st morning between Pondichery and Cuddalore. 'Distant effect' is very clearly seen in this case where CAP gets rainfall between 22nd and 26th, as shown in Table 2(a).
4-9 Nov 1964	S.C.S.	8th morning south of Madras. 'Distant effect, is clearly seen here where CAP gets rainfall on 6th and 7th, as shown in Table 2(b).
25-30 Nov 1966	S.C.S.	28th morning south of Madras. 'Distant effect' is *not* clearly seen here as rainfall on 30th over CAP due to some other system., because storm was emerging into Arabian Sea on 30th. *See* Table 2(c).
21-23 Oct 1969	C.S.	23rd forenoon south of Madras. 'Distant effect' is seen when CAP gets rain on 24th. *See* Table 2(d).
1-8 Dec 1972	S.C.S.	6th early morning, close to north of Cuddalore. 'Distant effect' is *not* clearly seen here. *See* Table 2(e).
9-13 Nov 1977 (23 Nov)	S.C.S.	12th early morning close to and south of Nagapattinam. 'Distant effect' is clearly seen as in Figs. 5(a) and 5(b).

S.C.S.—Severe Cyclonic Storm, C.S.—Cyclonic Storm

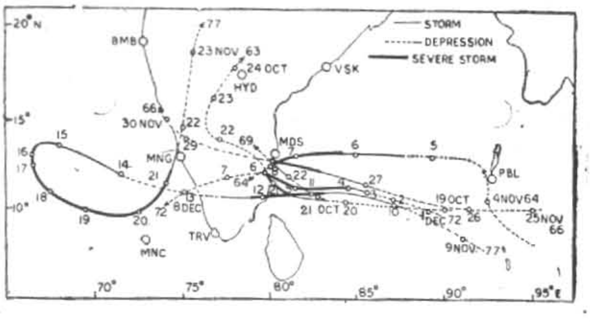


Fig. 1. Tracks of storms studied

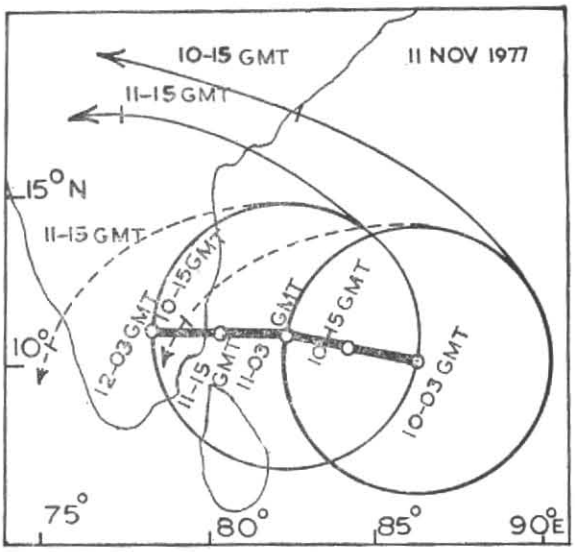


Fig. 2. Trajectories for 10-11 Nov 1977 storm

3. Discussion

3.1. Six cases of storms/depressions over south Bay which crossed Tamil Nadu coast south of Madras latitude are studied here. Two out of these six storms, one formed in the second half of November and the other in the first week of December do not show the distant effect. Whereas, other four storms occurring by first half of November satisfy the 'distant effect' in causing heavy rain in CAP. A table of datewise rainfall reports during the period of storm crossing coast along the east coast of India from Nagapattinam to Bhubaneshwar is prepared for all the storms. The graphs on Tables 2(a), (b) & (d) show clearly that there are two belts of rainfall maximum one near the centre of storm/depression and the other over CAP. The rainfall maximum occurs in the neighbourhood of storm/depression a day before crossing coast and continues for one or two days more. The second maximum of rainfall occurs over CAP, only one day after the storm/depression crosses coast and continues for another two or three days further. Between these two epochs of rainfall belts, there is a minimum of rainfall. Thus, there is a primary rainfall maximum near the centre of the storm/depression and secondary rainfall maximum over CAP and neighbourhood due to distant effect and both are separated by a belt of rainfall minimum in between. Whereas, in Tables 2(c) and 2(e) for the two storms, one during second half of November and other during first week of December, this distant effect is not clearly seen.

3.2. The mechanism of heavy rainfall over CAP must be due to three important factors, *viz.*, (a) supply of moisture in the lower levels, (b) low level convergence and (c) high level divergence over the region. To understand the exact mechanism two cases of cyclonic storms are studied in detail and presented here.

(a) *Supply of moisture in the lower levels*

Isobaric/streamline analysis of surface/low level charts does not give direct evidence of moisture incursion over CAP and neighbourhood where second rainfall maximum occurs. Therefore, the trajectories of the air particles associated with the depression/cyclonic storms were calculated by using the Blaton's equation. We can consider

TABLE 2 (a)

Rainfall (cm) from 20 to 26 October 1963

(Storm crossed coast north of Cuddalore on 21st morning)

Station	October 1963						
	20	21	22	23	24	25	26
Nagappattinam (10.8N, 79.9E)	—	28	—	1	1	—	—
Cuddalore (11.8, 79.8)	1	—	9	—	—	—	—
Madras (13.1, 80.3)	7	7	4	—	—	—	—
Nellore (14.5, 80.0)	1	10	4	—	—	—	—
Masulipatnam (16.2, 81.1)	—	4	7	5	—	—	1
Kakinada (16.9, 82.2)	—	1	8	13	2	—	1
Visakhapatnam (18.3, 84.1)	—	1	13	11	11	7	5
Kalingapatam (18.3, 84.1)	—	2	8	6	3	3	5
Jagadaplur (19.1, 82)	—	—	—	1	3	3	6
Gopalpur (19.3, 84.9)	—	8	11	16	13	1	4
Cuttack (20.5, 85.9)	—	—	3	—	—	1	2

TABLE 2 (b)

Rainfall (cm) from 7 to 9 November 1964

(Storm crossed coast south of Madras on 8th morning)

Station	November 1964		
	7	8	9
Nagappattinam (10.8N, 79.9E)	2	2	—
Cuddalore (11.8, 79.8)	5	1	1
Vellore (12.9, 79.2)	5	5	1
Madras (13.1, 80.3)	10	3	—
Nellore (14.5, 80)	3	3	1
Ongole (15.6, 80.1)	1	1	5
Masulipatnam (16.2, 81.1)	—	4	1
Nidadavulu (16.9, 81.7)	1	3	—
Kakinada (16.9, 82.2)	1	4	1
Visakhapatnam (17.6, 83.3)	—	3	6

circular concentric streamlines associated with depression/cyclonic storm and use the Blaton's equation to calculate the trajectory of the air particles with the help of the streamlines as :

$$K_t = K_s\,[1 - (C/V)\cos\alpha]$$

where, K_t = Curvature of the trajectories

K_s = Curvature of the streamline

C = Velocity with which the system moves

V = Wind velocity

α = Angle between the winds V and C

The details are given by Holton (1977).

Applying Blaton's equation, the trajectories of the air particles are found in the case of 1977 cyclonic storm which crossed Tamil Nadu coast south of Madras latitude. The trajectory of air particle at 850 mb are shown in Fig. 2. This clearly shows that the trajectories of air particles converge over CAP and are mainly responsible for incursion of moisture there. This incursion of moisture takes place as the storm/depression crosses the coast and is evident from the dew point temperatures over CAP (not shown here). This principle holds good in the case of the five storms discussed

TABLE 2 (c)

Rainfall (cm) from 28 to 30 November 1966

(Storm crossed coast south of Madras on 28th morning)

Station	November 1966		
	28	29	30
Cuddalore (11.8N, 79.8E)	1	4	—
Vellore (12.9, 79.2)	4	2	2
Madras (13.1, 80.3)	11	—	—
Nellore (14.5, 80.0)	6	5	—
Ongole (15.6, 80.1)	—	7	—
Masulipatnam (16.2, 81.1)	2	8	8
Kakinada (16.9, 82.2)	2	5	8
Visakhapatnam (17.6, 83.3)	—	1	8
Kalingapatnam (18.3. 84.1)	—	3	—
Gopalpur (19.3, 84.9)	—	1	—

TABLE 2 (d)

Rainfall (cm) from 21 to 24 October 1969

(Storm crossed coast south of Madras on 23rd forenoon)

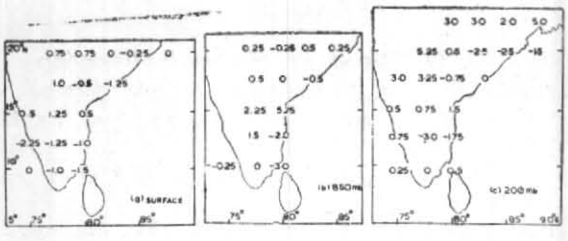
Station	October 1969			
	21	22	23	24
Nagappattinam (10.8N, 79.9E)	2	—	1	—
Kallakuruchi (11.7, 78.9)	8	6	7	—
Cuddalore (11.8, 79.8)	3	11	13	—
Vellore (12.9, 79.2)	1	3	9	3
Madras (13.1, 80.3)	4	23	5	—
Nellore (14.5, 80)	1	1	15	2
Ongole (15.6, 80.1)	3	—	—	9
Masulipatnam (16.2, 81.1)	—	—	—	2
Kakinada (16.9, 82.2)	—	—	1	8
Visakhapatnam (17.6, 83.3)	—	—	—	3
Kalingapatnam (18.3, 84.1)	—	—	—	8

in this paper and explains clearly the mechanism of low level moisture incursion over CAP.

(*b*) & (*c*) — To study the low level convergence, upper level divergence and vertical velocities associated with the rainfall over CAP, fields of divergence, vorticity and vertical velocities at surface, 850, 700, 500 and 200 mb are examined for 1963 and 1977 storms. The rainfall reports for 1963 storm were taken from the paper of Mukherjee *et al.* (1966) and were compared with the divergence, vorticity and vertical motion fields for the period 20 to 25 October 1963. The November 1977 storm was also studied in detail where the fields of divergence, vorticity and vertical velocity are compared with the rainfall reports. This shows that the 'distant effect' is applicable to October and first half of November storm/depression over Bay of Bengal which cross south Tamil Nadu coast south of Madras latitude. Divergence and vorticity fields are calculated by picking out wind values at 2.5° grid points and using finite difference method. The vertical velocity is calculated by using the equation of continuity in pressure co-ordinate systems. These fields reveal clearly that there are two fields of low level convergence and high level divergence, one near the centre of storm/depression and other over CAP. There is also a downward motion over adjoining Bay and upward motion over coastal belt from Madras to Puri. Figs. 3 and 4 indicate a few cases of the fields of divergence for November 1977 storm.

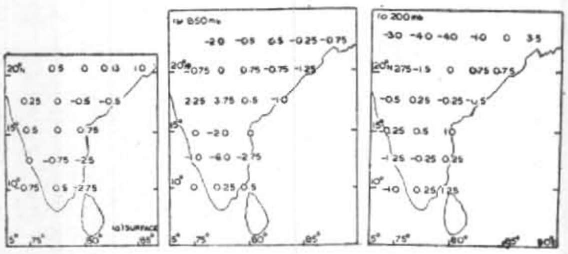
4. Conclusion

CAP receives heavy railnfall when a storm/depression over south Bay crosses Tamil Nadu coast south of Madras latitude. This effect can be called as 'distant effect' and is important from



(a) (b) (c)

Fig. 3. Field of divergence (10^{-5}sec^{-1}) 11 November 1977
(a) Surface, (b) 850 mb and (c) 200 mb



(a) (b) (c)

Fig. 4. Field of divergence (10^{-5}sec^{-1}) 12 November 1977
(a) surface, (b) 850 mb and (c) 200 mb

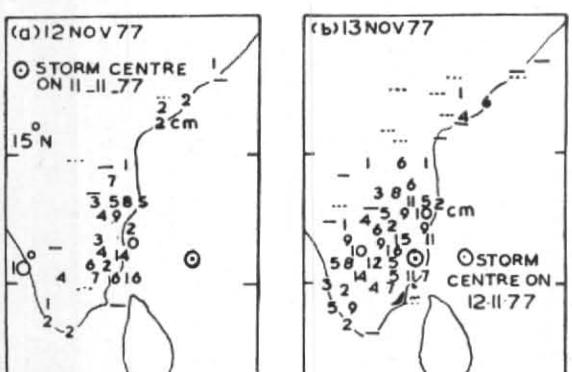


Fig. 5. Rainfall (cm)
(a) 12 November 1977 (b) 13 November 1977
.... 0.1 to 2.4 mm, — 2.5 to 7.5 mm

TABLE 2 (e)

Rainfall (cm) from 4 to 7 December 1972

(Storm crossed coast north of Cuddalore on 6th morning)

Station	October 1972			
	4	5	6	7
Vedaranyam (12.4N, 79.9E)	3	2	12	—
Nagapattinam (10.8, 79.9)	2	6	14	12
Tiruchirapalli (10.8, 78.7)	—	—	5	3
Cuddalore (11.8, 79.9)	—	8	18	8
Kallakuruchi (11.7, 78.9)	—	—	9	6
Vellore (12.9, 79.1)	—	—	7	6
Madras (13.1, 80.3)	2	9	14	5
Arogyavaram (13.5, 78.5)	—	—	4	—
Nellore (14.5, 80.0)	.—	—	6	9

he forecasting point of view. The heavy rain fall due to this 'distant effect' is mainly due to low level moisture incursion, low level convergence and upper level divergence over CAP. The low level moisture incursion, which is not explained by the stream line/isobaric analysis can be explained by the trajectory of air particles associated with storm/depression. Further, the fields of vorticity/divergence and vertical velocity over CAP explain the phenomenon of low level convergence and upper level divergence over CAP leading to very heavy rainfall.

Secondly, there are two epochs of heavy rains one near the centre of storm/depression and another over CAP, separated by a region of minimum rainfall in between.

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