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Radar-synoptic study of the Nagapattinam cyclone of 12 November 1977

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ABSTRACT. The severe cyclone which struck the Tamilnadu coast near Nagapattinam on 12 November 1977 was observed by the Cyclone Warning Radar at Madras from the 10th upto a few hours after landfall.

The storm followed a westerly course with a slight southerly component. The most important feature was a small eye shrinking gradually to an extremely small size suggesting intensification into a severe storm with a small core on the night of 11 November. The left sector of the eye wall was better developed. It may be mentioned that the radar sees the centre of the storm at a distance of about 270 km and hence the beam height is about 4.5 km above ground. Thus there can be some difference between the radar centre of the storm and the synoptic centre. However the touring officer's report corroborates that the severe damage was mainly to the south of Nagapattinam and confined to a narrow strip, thus agreeing with the radar positioning.

The rest of the radar echoes were concentrated in the right sector with a particularly prominent rainshield in the right rear sector (an unusual feature), giving heavy rainfall after the passage of the storm. This is confirmed from the rainfall distribution on 12th and 13th.

The 2-day cumulative rainfall map of 12th and 13th shows three areas of maximum precipitation, one coinciding with the point of landfall and the second showing the usual extension of the heavy rainfall belt northwards. The third maximum which was well inland, resulted in the bursting of the Kudaganaru earthern dam. The meteorological data as well as a knowledge of the structural damage tend to suggest that the storm was a severe one with a small core of hurricane winds.

1. Introduction

The period October to December is the northeast monsoon season when Tamilnadu gets a major portion of its annual rainfall. The southwest monsoon which starts withdrawing from northwest India from the middle of September starts giving rainfall over Tamilnadu from the middle of October as the retreating southwest monsoon or the northeast monsoon. On an average about 1 cyclonic storm develops in the Bay in each of the months of October and November. In the year 1977 the northeast monsoon set in over Tamilnadu on 13 October. The rainfall during the preceding southwest monsoon season, June to September, was generally normal to excess in Tamilnadu. Further there were very good rains in the second week of October just before the onset of northeast monsoon. 3 depressions out of which one intensified into a cyclonic storm, developed in the month of October resulting in excess rainfall over whole of Tamilnadu during October. Thus it can be seen that the soil was more or less saturated by the end of October and not in a position to absorb any more water when a depression formed in the southeast Bay of Bengal on 9 November. Moving in a westnorthwesterly direction, it intensified into a cyclonic storm on the morning of 10th (650 km eastsoutheast of Madras). It then practically moved westwards, became severe on the night of 11-12 November and crossed Thanjavur district coast just south of Nagapattinam in the early hours of 12th. The winds of Karaikal and Nagapattinam were 020/40 kt and 320/13 kt respectively at 0230 IST of 12th. With these observations, the centre of the storm comes just to the northeast of Nagapattinam, whereas the storm crossed the coast just south of Nagapattinam as per the visiting officer's report who toured the area after the cyclone. This observation shows that the cyclone moved in a southwesterly direction just before crossing, agreeing with the radar observation (Fig. 1). The touring officer's report suggests that the damages due to the strong winds of the cyclone was confined to a narrow latitudinal belt of about 30-40 km starting from Nagapattinam and south of it. This also agrees with the radar observation

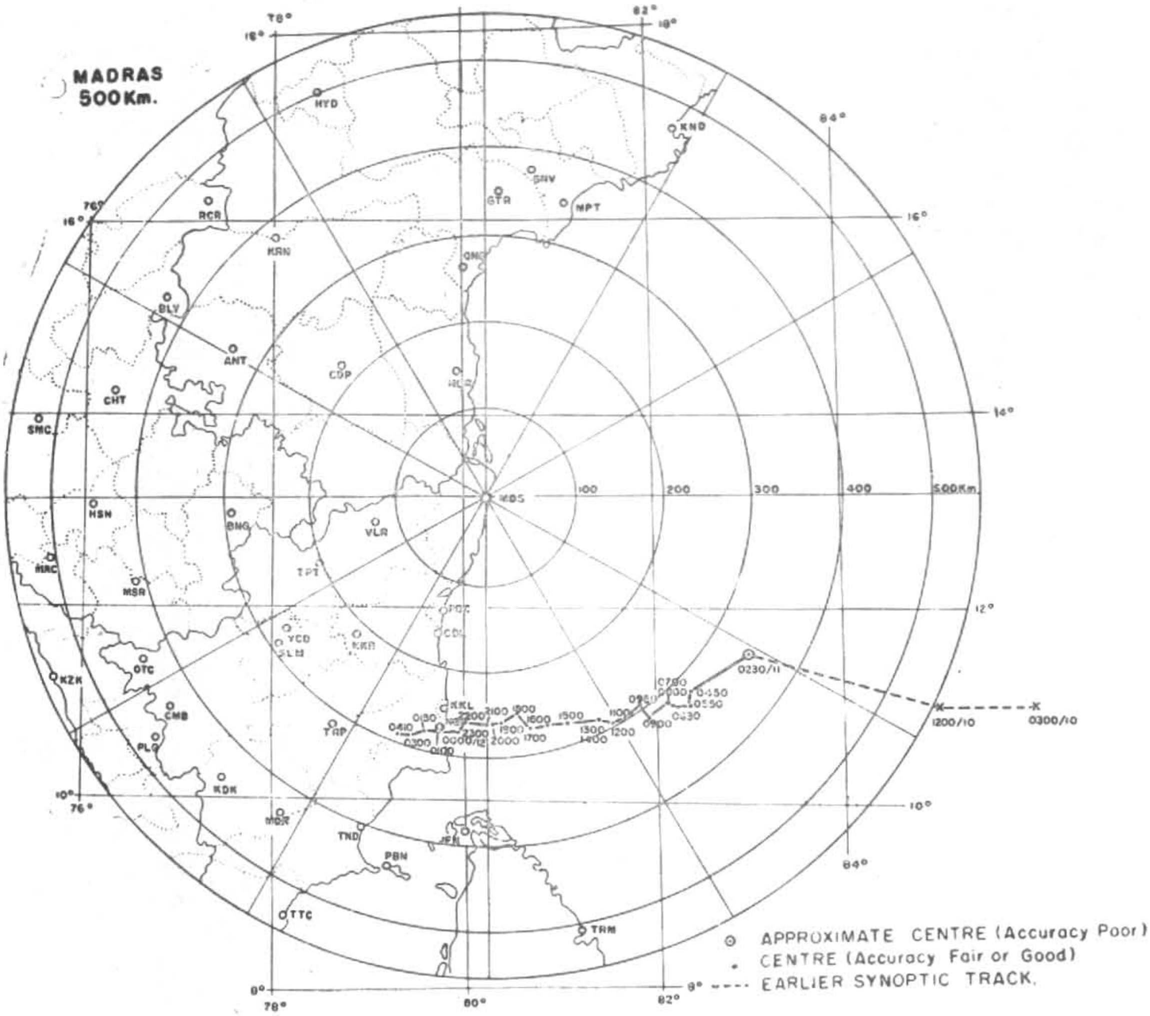

Fig. 1. Nagapattinam cyclone, 11-12 November 1977 (Radar track time in GMT)

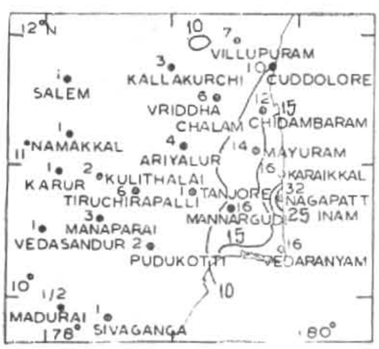

Fig. 2. Isohyetal map of 12 November 1977 (cm)

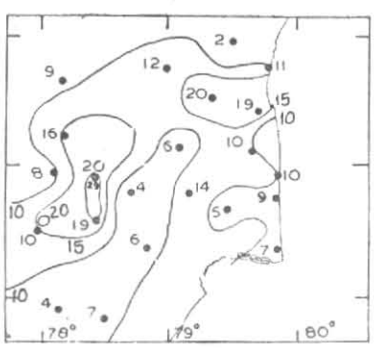

Fig. 3. Isohyetal map of 13 November 1977 (cm)

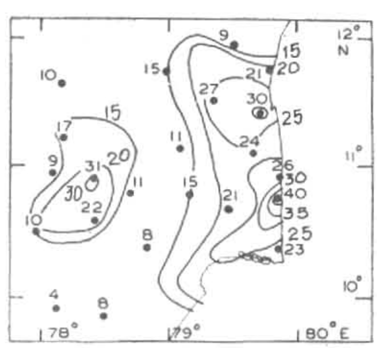

Fig. 4. Isohyetal map of 2-day rainfall (cm) of 12-13 Nov 1977

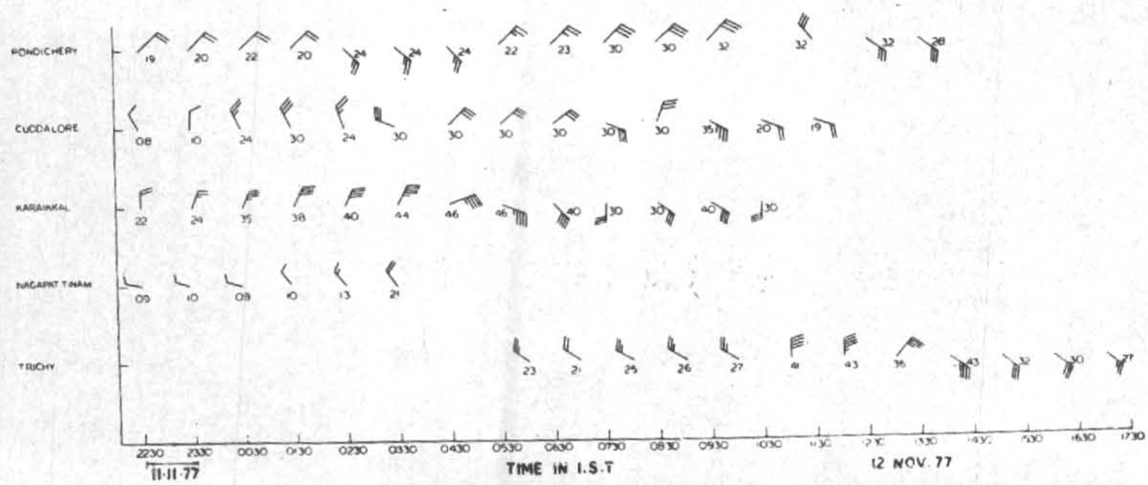

Fig. 5. Winds during the Nagapattinam cyclone on 11-12 November 1977

TABLE 1

Important amounts of rainfall in Tamil Nadu on 12 and 13 November 1977

Date	Stations (Rainfall in cm)
12 Nov 1977	*Thanjavur District* Nagapattinam 32, Karaikal, Vedaranyam Mannargudi and Adirampatnam 16 each, Sirkali and Nannilam 15 each, Tiruvarur and Mayuram 14 each, Tiruthuraipoondi 13
	South Arcot District Chidambaram 12
13 Nov 1977	*Thanjavur District* Thanjavur 14, Tiruthuraipoondi and Pattukkottai 12 each
	Tiruchi District Kulithalai 29, Manaparai 19, Musiri and Thathiengarpet 18 each
	Madurai District Vedasandur (Tobacco Research Station 24, Kodaikanal 14, Dindugal 12
	Pudukottai District Aranthangi 16, Alathur and Alangudi 11 each
	South Arcot District Chidambaram 19, Virudachalam 20, Kallakurichi 12

that the eye wall echoes were strong on the southern side, thereby implying that the damage also should be maximum on the southern side of the track. It is interesting to know that Karaikal and the area a few kilometres north of Nagapattinam suffered very little damage. The storm then moved in a westerly direction and remained as a cyclonic storm till the afternoon of that day and weakened *into* a deep depression the same evening with its centre about 40 km southwest of Tiruchy. The track of the storm is given in Fig. 1. The eye of the cyclonic storm could be clearly seen by the Cyclone Warning Radar at Madras from 1130 IST of 11th. From this time it was continuously tracked hour to hour by the radar till a few hours after it crossed the coast. We shall first consider the synoptic aspects and later the radar features.

2. Rainfall associated with the severe cyclone

In association with the severe cyclone, Tamilnadu had widespread rains in the 24 hour periods ending at 0830 IST on 12th and 13th with heavy to very heavy falls at a number of places. Some important amounts are given in Table 1.

While Thanjavur and coastal parts of South Arcot district received heavy to very heavy rains due to the cyclone on 12th and 13th, the interior districts of Tiruchy and Madurai and Pudukottai district got heavy to very heavy rains on 13th. The isohyetal maps for the period 12-13 November 1977 are given in Figs. 2, 3 and 4.

The 2-day isohyetal map indicates 3 areas of maximum rainfall. The first is the Nagapattinam area through which the storm passed. The second maximum is over South Arcot district where the extensive clouds seen on the radar in the right rear sector of the storm came over subsequently. The third maximum is over the Kulithalai Vedasandur area which was responsible for the bursting of the Kudaganaru earthern dam.

3. Winds due to the severe cyclone

The direction and speed of wind at a few observatories that recorded strong winds are given in Fig. 5 hour by hour during the period 2230 IST of 11th to 1730 IST of 12th.

It may be seen that Pondicherry had near gale winds of 55 kmph (30 kt) or more for 6 hours from 0730 to 1230 IST of 12th and Cuddalore

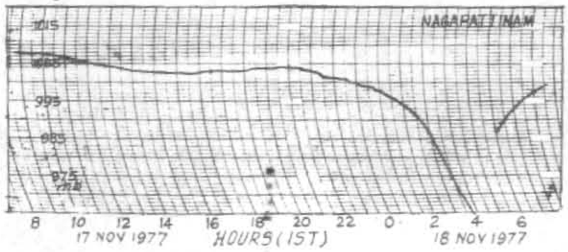

Fig. 6. Barogram of Nagappattinam of 11-12 November 1977

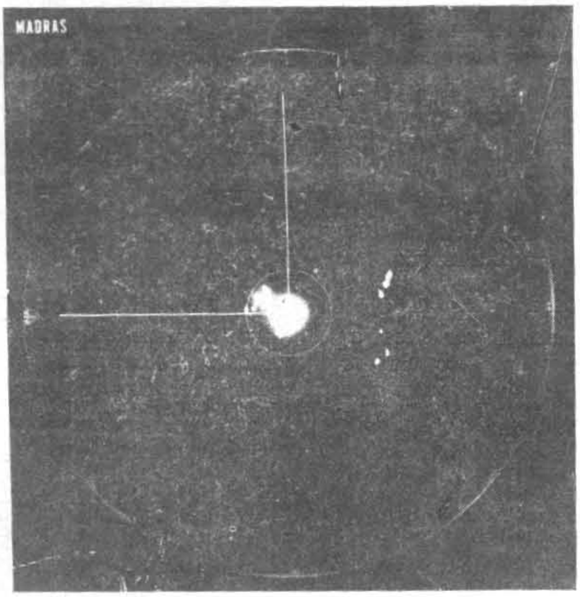

Fig. 7. Radar picture of 10 November 1977 at 1131 IST
(Range 500 km, Ring interval 100 km)

for 7 hours from 0330 to 0930 IST. Karaikal which was nearer to the storm centre than Cuddalore and Pondicherry had near gale winds of 55 kmph (30 kt) or more for more than 11 hours from 0030 IST of 12th.

It is interesting to note that Nagapattinam near which the storm crossed the coast did not report strong winds more than 38 kmph till 0330 IST of 12th (wind observations after 0330 IST are not available due to falling of the signal mast on the ladder leading to the wind instruments immediately after 0330 IST). Tiruchy to the south of which the storm passed about midday had near gale winds from 1110 to 1610 IST, that is, for 6 hours.

4. Estimation of wind speed over Nagapattinam

The need for estimation of maximum winds over Nagapattinam arose as the town was the worst affected by the cyclone and unfortunately we do not have wind observations beyond 0330 IST of 12th. Luckily an examination of the barogram of 11-12 November (Fig. 6) showed that the barograph of Nagapattinam was functioning normally on that day till 0345 IST when the pen got stuck up at the bottom rim of the clock drum. The trend of the fall and the recovery phase indicate that the pressure should have fallen to a value lower than 964 mb. Therefore it appears reasonable to assume a lowest pressure of only 965 mb as this will give a less than maximum wind speed and the actual maximum wind experienced at Nagapattinam will be atleast as strong as the computed value taking the central pressure of 965 mb. For the computation of maximum surface winds in hurricanes Fletcher (1955) proposed the equation $V_m = 16\sqrt{p_n - p_0}$, where V_m is the maximum surface wind in knots, p_o and p_n are the central and peripheral pressures in mb of the hurricane. Natarajan and Ramamurthi (1975) modified the above equation to suit the cyclonic storms in the Indian Seas and gave the equation $V_m = 13.6\sqrt{p_n - p_0}$. Taking p_0 as 965 mb on the foregoing considerations and p_n as 1010 mb (the last closed isobar being 1008 mb) we get $V_m = 13.6\sqrt{1010 - 965} = 91.2$ knots.

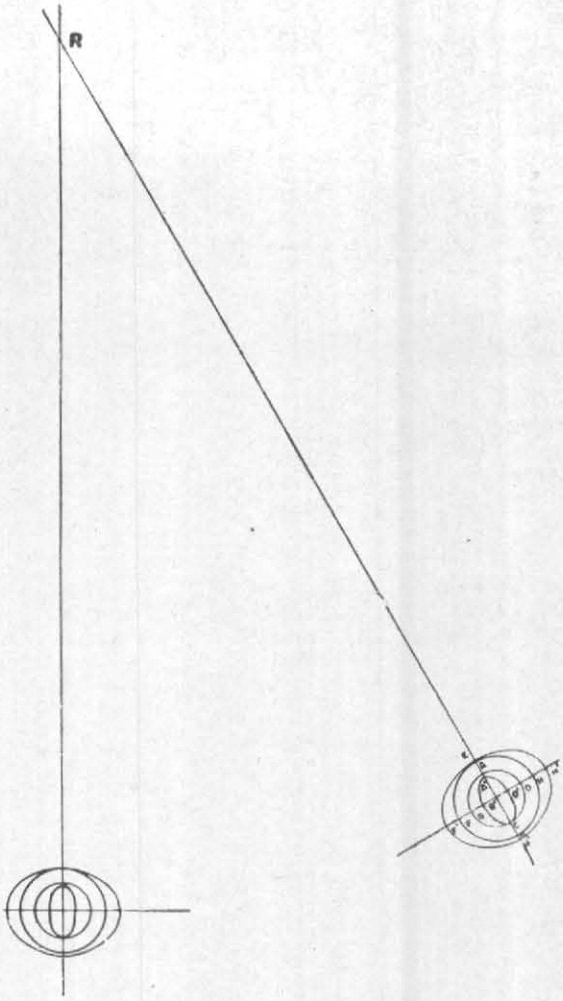

Fig. 8. Distortion of eye due to finite beam width

Thus the maximum wind that would have been experienced at Nagapattinam due to the severe cyclone would have been at least as strong as the computed value of 91 knots which is equal to 168 kmph. This estimate seems to be nearer to the estimate of educated local people. One such report is from Shri S. Arunajatesan, Chief Instructor, State Bank Staff Training Centre, Nagapattinam whose article in their 'Officers Forum' (Vol. IX, Feb. 1978, No. 2) reads as follows :

> 'It was a day after Deepavali, that is actually on the early hours of Saturday, the 12 November 1977, the inhabitants of Nagapattinam incurred the wrath and fury of nature. The cyclonic storm with a speed of about 150 km struck this ancient town at the dead of night causing devastation and damage unheard of in the memory of even the octagenarians. The training section building had faced several cyclones in the past but its account of 1977 cyclone is horrid to hear. Huge and old trees fell flat on the ground. The palatial building started gasping and groaning. It was about 6 A.M., the cyclonic storm subsided although rain went on unabated. The total loss in the town is estimated at Rs. 5 crores.'

One of the authors of this paper had discussions with Dr. A. G. Madhava Rao of the Structural Engineering Research Centre, Madras about the estimate of maximum winds at Nagapattinam on an examination of the structural damage that has taken place. Dr. Madhava Rao who sent a team of officers to Nagapattinam to photograph and survey the devastated areas was of the opinion that the damages suggest that a wind speed of about 160 kmph would have been experienced. This also fits in with the estimate of wind of about 165 kmph obtained by Fletcher's formula.

Shea and Gray (1973) have studied a large number of hurricanes and given a relationship between maximum wind and central pressure. According to their study, a central pressure of 965 mb will give a maximum wind between 55 and 98 kt and their best fit curve gives a maximum wind of 74 kt . This also to some extent fits in with the estimate of about 90 kt derived above.

Saffir and Simpson (Frank 1977) gave a scale relating the maximum winds in a hurricane and resultant damages. As per their hurricane scale ranges, the damage observed at Nagapattinam seems to suggest a scale number of 2 indicating a wind speed of 96-110 mph. This also fits in with the estimate of about 90 kt.

5. Estimate of maximum wind at Tiruchy

The severe cyclone after crossing the coast just south of Nagapattinam moved in a westerly direction and its centre was close to Tiruchy near about midday. Using the same Fletcher's formula as modified by Natarajan and Ramamurthi with the lowest pressure of 980.9 mb recorded in the barogram of 12-13 November, V_m becomes equal to $13.6\sqrt{29.1}=73.4$ kt.

Fletcher (1955) also proposed that a reduction factor of 60 per cent can be used to reduce the maximum wind obtained from the formula for an inland station to account for surface friction. This gives the maximum wind estimate at Tiruchy to be 44 kt which fits in with the actual of 43 kt reported in Fig. 5. Thus it seems reasonable to assume that the Fletcher's formula, as modified, is applicable to this system to estimate the maximum wind at Nagapattinam as the same formula has given an estimate of max. winds at Tiruchy which is very nearly equal to the actual winds recorded.

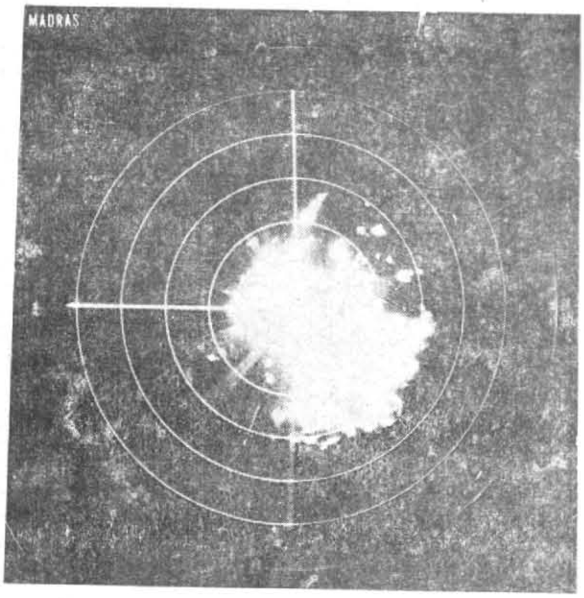

Fig. 9. Radar picture of 11 November 1977 at 1147 IST (Range 500 km, Ring interval 100 km)

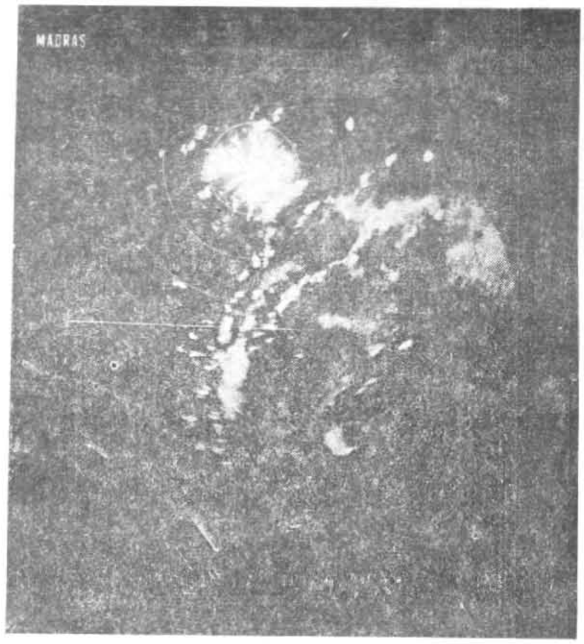

Fig. 10. Radar picture of 11 November 1977 at 2040 IST (Range 200 km, Ring interval 40 km)

6. Radar observation of the system

Several interesting and some unusual features were observed in the case of this storm on the Cyclone Warning Radar at Madras. North-south oriented squall lines started appearing since about 23 GMT of 9 November (Fig. 7) roughly corresponding to the time when the system became a cyclonic storm. These pre-cyclone squall lines formed about 300 to 400 km ahead of the storm and moved generally westwards. The orientation of these lines in this case as in many others, appears to be an indicator of the continued westward movement of the system. Since squall line orientation is not necessarily perpendicular to the storm track in the case of all storms, a study of more storms is required to establish the forecasting value of the squall line orientation. By the early morning of the 11th, irregular convective lines forming the typical outer convective activity were observable on radar. By 05 GMT of that day a part of the eye wall could be seen at about 320 km from Madras. There was no rainshield area between the convective bands and the eye. As will be discussed later the main rainshield of the storm was in the right *rear* sector of the storm and was therefore seen by radar only several hours later.

7. Eye shape and size and intensity of storm

The eye observed at this stage was quite small. A nearly closed and slightly elliptical eye with *apparent* major and minor axes of about 22 and 18 km respectively was seen at 06 GMT of the 11th, the longer axis being in the radial direction as seen from the radar. In the case of a small eye such as this, it is necessary to consider the errors of observation which are comparable to the size. Consider for example a circular eye ABCD (Fig. 8), 20 km in diameter at a range of 300 km southeast of the radar (R). Owing to the finite pulse width of the radar, the point A of the eye wall will appear shifted to point A′ where AA′ is about 600 m. There will be no effect on point C. Points B and D will be shifted inwards to B′ and D′ the distance BB′=DD′ being half the beamwidth, *i.e.*, about 5 km in this case. Hence the eye will appear elliptical (A′ B′ CD′) with major axis along the radial direction. In practice, the effective beamwidth at that range will depend on the reflectivity of the particles, and the error will consequently vary and be usually less than the 10 km postulated. Also if the real width of the eye wall cloud is say 5 km it will appear extended by half the beam width on either side in the tangential direction but there would be negligible extension in the radial direction. Hence the eye wall would appear stretched in the tangential direction periphery being EFGH′ instead of EFGH. Further if the storm moves to a different azimuth say 180 degrees there will be an apparent rotation of the major axis of the eye (Fig. 8). As storms often exhibit real rotations of the eye, the beam width effect will be superposed on any areal rotation. Hence the slight ellipticity of the

Fig. 11. Radar picture of 12 November 1977 at 0133 IST (Range 200 km, Ring interval 40 km)

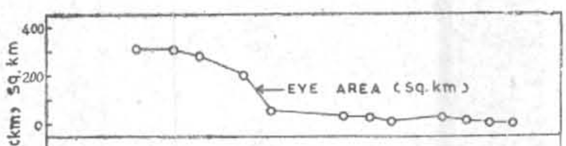

Fig. 12. Nagapattinam cyclone, November 1977, Changes in eye size

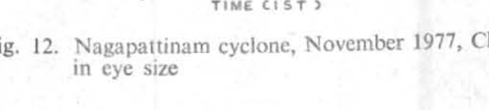

Fig. 13. Nagapattinam cyclone, November 1977. Intensity of eye wall in terms of maximum estimated rainfall rate (mm/hour)

eye observed at 06 GMT of 11th (Fig. 9) is probably due to this beamwidth effect. The rotation of the eye and the elongation of the eye wall may be noted in Figs. 10 and 11.

The eye size gradually decreased over the next several hours while the intensity and width of the eye wall increased. The appearance of the eye at 0133 IST of 12 November is shown in Fig. 11. The longer axis is 8 km in the north-south direction (*i.e.*, radial direction) and the shorter axis about 3 km in the east-west direction. An hour later the eye looked still smaller (about 3 km across). When the eye was close to land but still out at sea, the wall cloud started breaking up, although it could be identified on land upto 04 GMT of 12th. Fig. 12 shows the variations with time of the apparent eye dimensions. Although the absolute area in Fig. 12 is probably an underestimate for the reasons discussed above, the variation represents a real shrinking of the eye size. Also on the early morning of 12th the apparent outer dimensions of the eye wall were about 20 and 30 km respectively in the north-south and east-west directions. Decrease in diameter must, by angular momentum considerations, result in an increase in wind speed around the eye wall. Decrease of eye size is generally accepted as a sign of intensification of a storm (WMO 1977). Shea and Gray (1973) have found that the radius of maximum wind is, in the mean, about five miles beyond the inner radius of the eye. Hence from the Figs. 9, 10, 11 and 12 presented above it may be estimated that:

(*i*) The storm intensified during the evening or night of 11 November.

(*ii*) The core of maximum winds when the storm was close to coast on the early morning of 12th was not more than 30 to 40 km across.

The maximum observed echo intensity in the eye wall converted into an approximate rainfall rate taking account of the range attenuation is plotted against time in Fig. 13. The rapid increase in the evening of 11th coincides roughly with the shrinking of the eye size. Figs. 14, 15, 16 give an idea of the intensity and height of the eye wall at 0130 IST of 12th. It will also be seen from a comparison of Figs. 9, 10, 11, 14, 15 and 16 that while the western portion of the eye wall appeared well developed during the day on 11th the southern portion was the best developed later in the night, in terms of echo intensity and height and width of eye wall. As the southern portion was the one farther away from the radar, this cannot be attributed to any limitation of radar detection. Hence one more inference may be drawn, *viz.*,

(*iii*) At the time of landfall the southern portion of the eye wall was the best developed and should have caused relatively more damage.

At the range of about 270 km at which the eye was observed, the mean height of the radar beam is about 4.5 km. There is a possibility, therefore, that the observed eye position may not coincide with the surface centre of the storm. Examination of radar pictures at 0 and 1 degree of elevation do not suggest any shift in centre position greater than probable errors of radar fix. However as

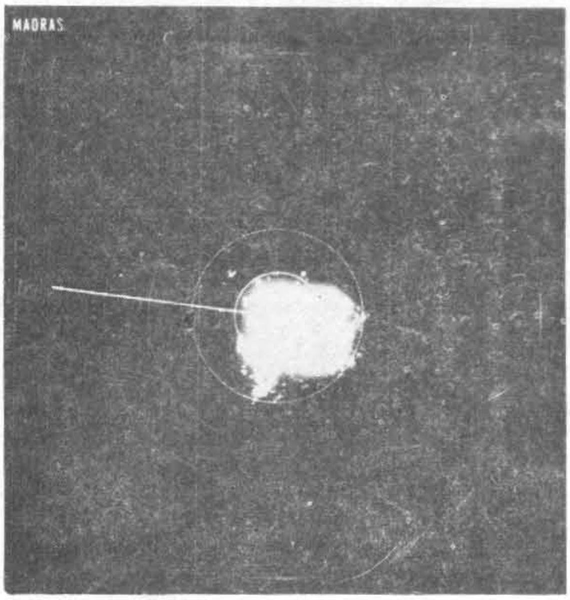

Fig. 14. PPI picture at 2 degrees elevation still showing a part of the eyewall (12 November 1977 at 0130 IST, Range 500 km, Ring interval 100 km)

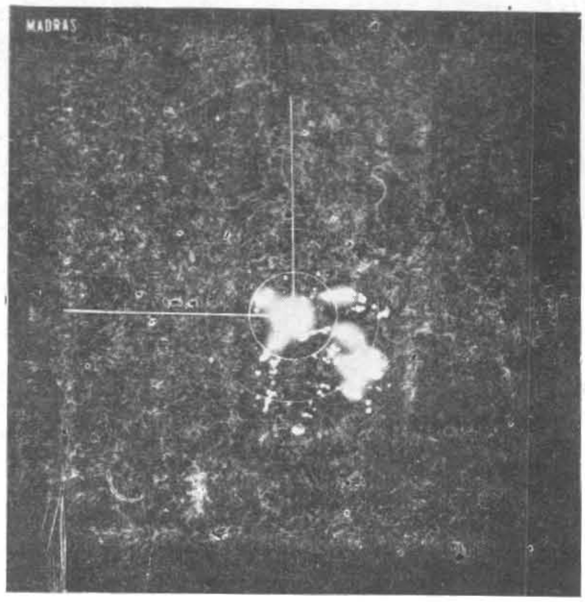

Fig. 16. Echoes at the 3rd 'isoecho level' threshold rainfall rate 15 mm/hr at 270 km (12 November 1977 at 0132 IST, Range 500 km, Ring interval 100 km)

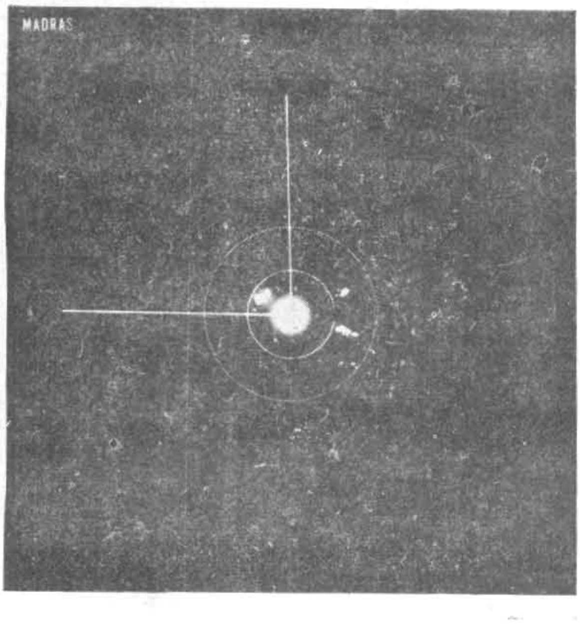

Fig. 15. PPI picture at the 5th 'isoecho' level showing the southern portion of the eyewall. The rainfall rate should exceed 65 mm/hr for this echo to appear (12 November 1977 at 0131 IST, Range 500 km, Ring interval 100 km)

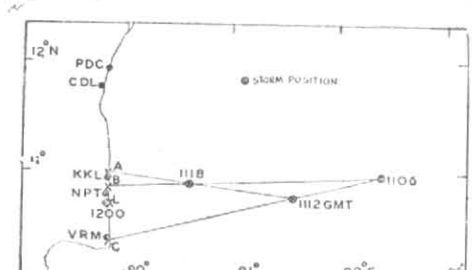

Fig. 17. Nagapattinam cyclone, November 1977, Extrapolation of radar track

L—Point of actual landfall (point of landfall predicted by extrapolations motion)

A—of six hour prior to 18 GMT of 11th

B—of 12 hour prior to 18 GMT of 11th

C—of six hour prior to 12 GMT of 11th

LA=31 km, LB= 17 km, LC=39 km.

discussed in sections 1 and 4 the largest pressure fall was at Nagapattinam and the heaviest damage is immediately to the south of Nagapattinam and confined to a strip of 30 to 40 km. This agrees with the radar fix giving the point of crossing as just south of Nagapattinam. This also indicates that there was no significant vertical tilt of the system. Hence it may be concluded that the system had indeed intensified into a severe storm with a small core on the night of 11th.

Studies of typhoons and hurricanes (Izawa 1964, Shea and Gray 1973) have shown that in the core region of most storms the maximum winds are found in the right forward quadrant and to some extent in the right rear quadrant. Mukherjee and Sivaramakrishnan (1977) found that in the Gujarat storm of June 1976 the maximum surface winds were in the right *rear* quadrant. In the present case, however, from the radar eye wall configuration and the evidence of damage, it appears likely that the maximum surface wind was in the *left* sector at the time of landfall.

8. Echo distribution outside the core

The storm as observed by the radar exhibited the usual features, *viz.*, pre-cyclone squall lines, outer convective activity and spiral bands ahead of the eye wall. All these features were mostly confined to the right forward sector with relatively few echoes south of the eye wall. The paucity of echoes in the left sector could be partly due to that sector being mostly beyond the effective range of the radar. However, the rainfall distribution of 12th and 13th (Figs. 2 and 3) as well as the survey of damage shows relatively less area of rainfall south of the eye wall.

The convective bands in the right forward sector thinned out and became rather poorly organised and widely spaced by the night of 11th (Fig. 10). An extensive rainshield formed in the right rear quadrant (Fig. 11, for example) which is an uncommon feature. This area persisted for several hours after the eye crossed coast with the result that places in South Arcot district of Tamilnadu which were well to the northeast of the storm centre got more rain after the passage of the storm on the 12th. This is confirmed from the isohyetal maps of 12th and 13th given in Figs. 2 and 3.

9. Storm motion

The average storm speed was about 15 kmph throughout the period when accurate radar fixes were available. This speed is not unusual at this latitude. However the westerly motion with a slightly southerly component throughout the 10th and 11th is not readily explained. As far as radar features are concerned the orientation of pre-cyclone squall lines, the direction with respect to the eye in which the echoes are concentrated and the sector in which the eye wall is best developed are three factors which are usually considered as possible indicators of storm motion (see, *e.g.*, Senn 1966 a and b). The north-south orientation of the pre-cyclone squall lines already mentioned supports in this case the westerly movement, but the squall lines refer to an earlier phase of the storm. The sector of crowding of the echoes would, however, suggest a northwesterly movement. 200 mb winds on 10th and 11th would suggest a westnorthwesterly movement. If the sector of best development of the wall cloud is considered, the movement should have been westerly or northwesterly during the day of 11th but southerly from the early morning of 12th. Hence it appears that no single indicator on the radar could be considered a reliable index of future motion. To see if extrapolation of the radar determined track would predict the point of landfall, the storm positions at H—18 hours H—12 hrs and H—6 hrs where H is the landfall time were considered. The mean motion over 6 hrs period preceding H—12 if extrapolated indicates a landfall 39 km south of the actual point of landfall (L Fig. 17). A similar extrapolation of the 6 hourly motion from H—12 to H—6 indicates landfall 31 km north of Nagapattinam. If twelve hourly motion from H—18 to H—6 is extrapolated the landfall would have been17 km north of Nagapattinam. Motion over a period less than 6 hours was not considered because the meandering of the track was sought to be smoothened out. This analysis indicates that the point of landfall could be predicted 6 to 12 hours ahead well within 50 km by extrapolation of radar track of the preceding 6 hours. Thus the motion is predicted better by extrapolation of the track in this case than by any of the other indicators discussed above. This kind of extrapolation could, of course, go seriously wrong if there is a change of course of the storm.

10. Conclusions

The radar features as well as the available meteorological data and the evidence of damage indicate that the cyclone of 12 November 1977 crossed coast just south of Nagapattinam as a severe cyclonic storm with a small core of hurricane winds. Nagapattinam town seems to have been lashed by hurricane winds of about 165 kmph as derived from Fletcher's formula as modified by Natarajan and Ramamurthi. The applicability of this formula to this storm seems very reasonable as the computed wind at Tiruchy, an interior station is agreeing with the actual recorded. The eye was very small and its southern portions, *i.e.*, the left sector was most well developed. The damage pattern also suggests maximum wind in the left sector. The storm structure outside the core had the usual features with a concentration of rainfall in the right sector. However, a rainshield area in the right rear sector giving high winds and heavy rain in the rear of the storm was an uncommon feature.

Acknowledgements

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