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The Porbandar cyclone of October 1975

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ABSTRACT. A severe cyclonic storm formed over the east central Arabian Sea, from the remnants of an earlier depression over the Bay of Bengal, and crossed north Gujarat coast near Porbandar at 1530 IST on 22 October 1975. This cyclone showed rapid intensification during its formative stages and was singular for its track and severity. A detailed study of the information, movement and intensity of the storm has been made in this paper on the basis of the synoptic as well as weather satellite data. It is concluded that the thermal structure of the cyclone and the marked upper tropospheric divergence were responsible for its rapid intensification.

1. Introduction

Cyclonic storms originating in the Indian Seas are the principal weather systems which cause heavy damage to life and property in the maritime States of our country. The losses are mainly due to gale winds, tidal waves and consequent inundation of coastal areas, and torrential rains. The destructive wind force, at times reaching 250 kmph, causes widespread disaster along the path of the cyclone from the time of its landfall.

The authors present here a study of a severe cyclonic storm which crossed Gujarat coast near Porbandar on 22 October 1975. This cyclone was unique in several ways. This is the first time since the year 1877 that a severe cyclonic storm crossed Gujarat coast in the month of October. Secondly, it developed very rapidly. It intensified from a low pressure area into a severe cyclonic storm with core of hurricane winds and reached its peak intensity within a period of less than three days. Usually a cyclonic storm weakens rapidly after crossing the coast, but this cyclone lay over land close to Porbandar after landfall throughout the evening of 22 October 1975 without showing signs of any significant weakening. In absence of ships' data from the storm field, this cyclone was tracked over the sea mainly with the help of satellite pictures. The present paper presents a sequence of satellite pictures, taken by Scanning Radiometer (SR) Sensor of the U.S. Weather Satellite NOAA-4 in the visible and infra-red (IR) channles in day time passes, depicting significant stages of the cyclone development (Fig. 1). The track of the cyclone and principal amounts of rainfall caused by it during the 72 hour period from 0300 GMT of 21st to 0300 GMT of 24 October 1975 are shown in Fig. 2.

2. History of the Cyclone

2.1. *Formation*

The cyclone formed from a pre-existing disturbance which was the remnant of an earlier depression in the west central Bay of Bengal, centred near 15°N, 82°E on the morning of 17 October 1975. On 18th morning the depression crossed Andhra coast near latitude 16°N and weakened into a low pressure area with associated cyclonic circulation extending upto 500 mb. The low continued to move westwards across the Peninsula. By this time another low pressure area formed in the east central Arabian Sea. The NOAA-4 satellite picture of 18th at 0416 GMT (Fig. 1) showed a dense convective overcast area at 'A' corresponding to the low over the land. Another convective overcast area associated with the low level circulation over east central Arabian Sea was seen at 'B'. The visible channel picture clearly showed loosely organised curved cloud lines to the north and northeast of 'B', which consisted of cumulus as well as cumulonimbus clouds and appeared to hook at a small area around 14·5°N, 72.5°E. The curved cloud lines to the north, starting from Maharashtra coast, were more conspicuous in the infra-red pictures (bottom row of Fig. 1) due to cirrus plumes. The cloud system centred at 14·5° N, 72·5° E was close to the edge of the dense overcast cloud mass 'B' associated with deep layer convection. The cirrus organisation also indicated the absence of any strong unidirectional flow at the cloud level. These features indicated the initiation of storm development on 18th morning and fixed the system intensity at T1 in the classification of Dvorak (1975).

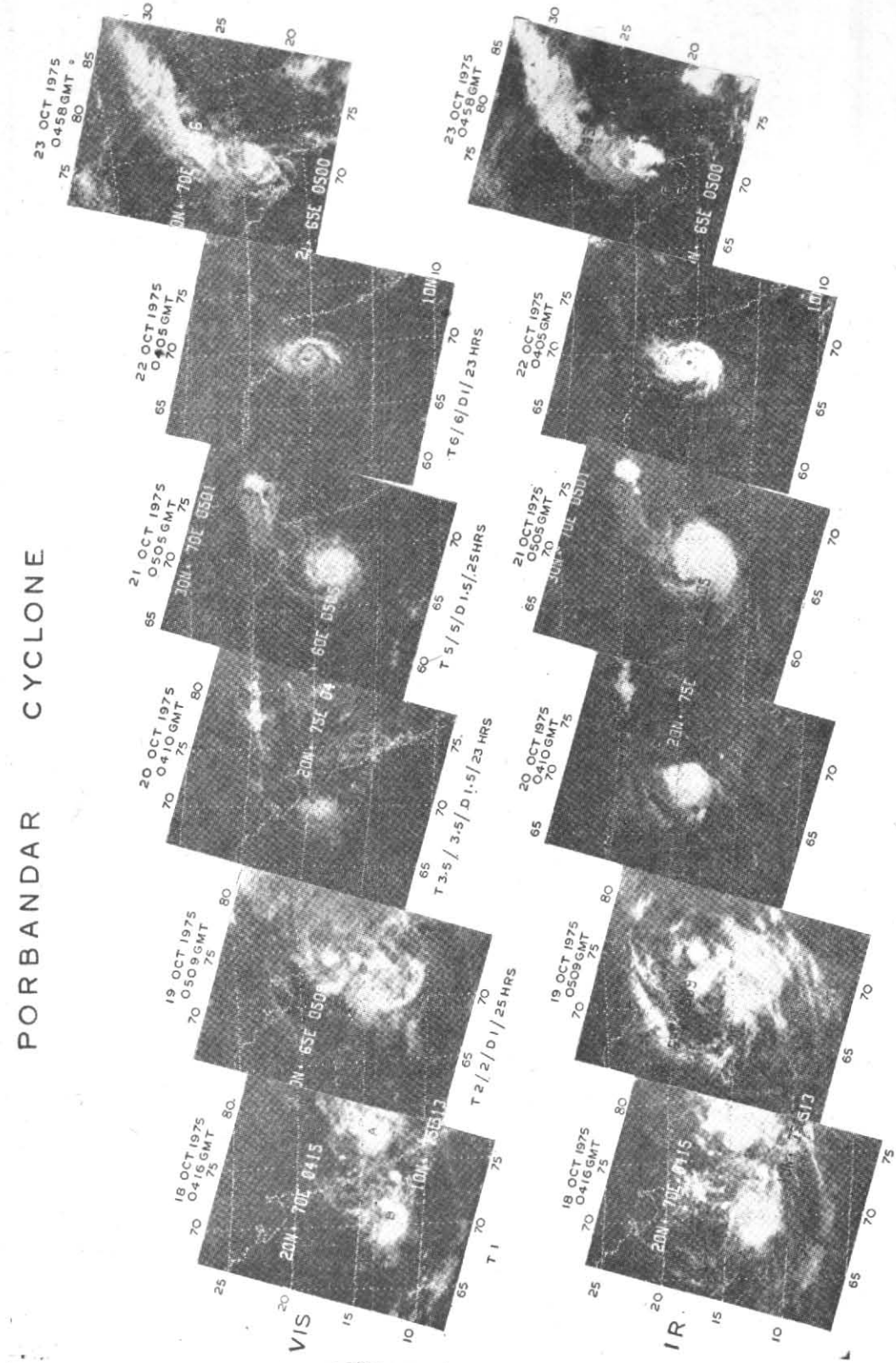

Fig. 1. NOAA-4 scanning radiometer visible and infra-red channel day time pictures of Porbandar Cyclone from 18 to 23 October 1975

2.2. *Depression stage*

By 19th morning, the two low level circulations, corresponding to the low pressure areas on land and sea, merged together and concentrated into a depression centred near latitude 17°N, longitude 73·5°E at 0300 GMT. The associated cyclonic circulation extended upto 500 mb level and was sloping southeastward with height. The satellite picture of 0509 GMTof 19th showed that the cloud structure was getting more organised. Cumulus and *Cb* cloud elements had formed into a broken curved convective band over Maharashtra coast which was organising into a spiral shape and curving around a small irregular Central Dense Overcast (CDO) area over land near 17°N, 73·5°E. The cirrus band to the northwest of the overcast had increased considerably in size and organisation during the previous 24 hours as seen in IR picture. The system intensity from the picture was T2. The depression moved westnorthwestwards to east central Arabian Sea and was centred near 17·5°N, 72°E at 1200 GMT. The associated cyclonic circulation extending upto 500 mb had now become almost vertical with height. The depression continued to intensify and moved westnorthwestwards.

2.3. *Cyclonic storm stage*

On 20th morning it intensified into a deep depression and was centred near 18·5°N, 70°E at 03 GMT. In the satellite picture of 0410 GMT the CDO had developed into a round shape of about 1·7 degrees in diameter and the Central Feature (CF) could be described as 3·5. Small curved cumulus lines appeared to the southeast of CDO. The outer Banding Feature (BF) was O. The system intensity, therefore, was T 3·5 and the cloud system centre at 18·7°N, 69·8°E. Cirrus bands which appeared to the northwest and north of CDO, showed an outflow towards northeast. The large size of cirrus canopy over the CDO as seen in IR picture, and its increase from the previous day, characterise the strong vertical motion that was taken place inside the CDO as also the rapid on-going intensification. By 12 GMT of 20th the deep depression intensified into a cyclonic storm centred near 19°N, 69·5°E. It continued to move northwestwards.

2.4. *Severe cyclonic storm stage*

On 21st morning the cyclonic storm was centred near 19·5°N, 68·5°E at 03 GMT. In the satellite picture of 0505 GMT, the CDO increased to about 2·5° in diameter. It also developed a ragged, rather indistinct eye covered by cirrus clouds aloft. The embedded distance of the eye was slightly less than 1° (CF 4·5). The band in the

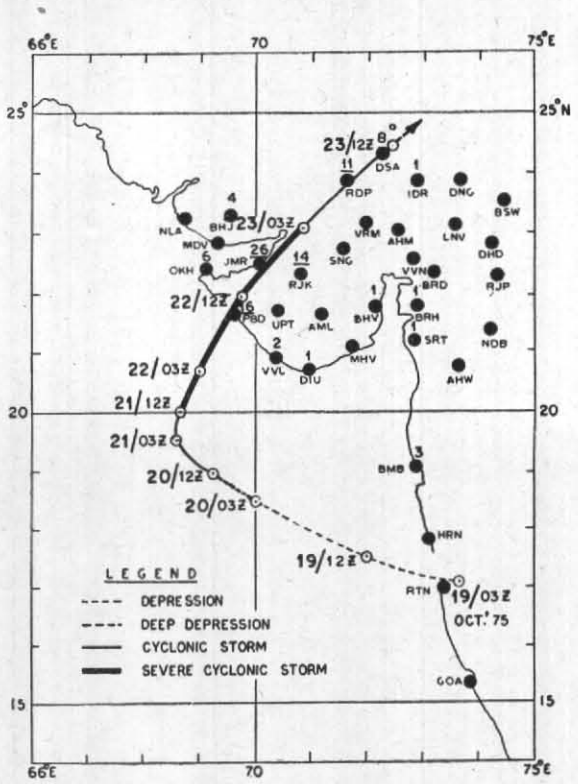

Fig. 2. Track of Porbandar cyclone and the 72-hour cumulative rainfall distribution for the period ending at 03 GMT of 24 October 1975

western and northern sectors showed signs of increased convection and was more dense (BF 0·5). The storm intensity had thus reached T5. The circular cirrus canopy, spreading out from the central feature, had increased considerably in size, indicating that the rapid intensification was continuing. The movement of the storm was slow and it had started recurving on 21st morning. Moving northwards it intensified into a severe cyclonic storm centred near 20°N, 68·5°E at 12 GMT of the same day. The associated upper air cyclonic circulation now extended at least upto 300 mb. Figs. 3 to 7 show the related sea level, 500, 300, 200 and 100 mb charts respectively. A well developed anticyclone over the storm field at 100 mb level indicated an intense outflow from the storm. The fact that the system had intensified into a severe cyclonic storm on 21st evening was also supported by the NOAA-4 infra-red picture of 1551 GMT (not presented here) which showed a sharp distinct eye inside a round CDO. The storm was now moving northnortheastwards.

2.5. *Peak intensity and landfall*

By 22nd morning the severe cyclonic storm had a core of hurricane winds and was centred near 20·5°N, 69°E. It had upper air cyclonic

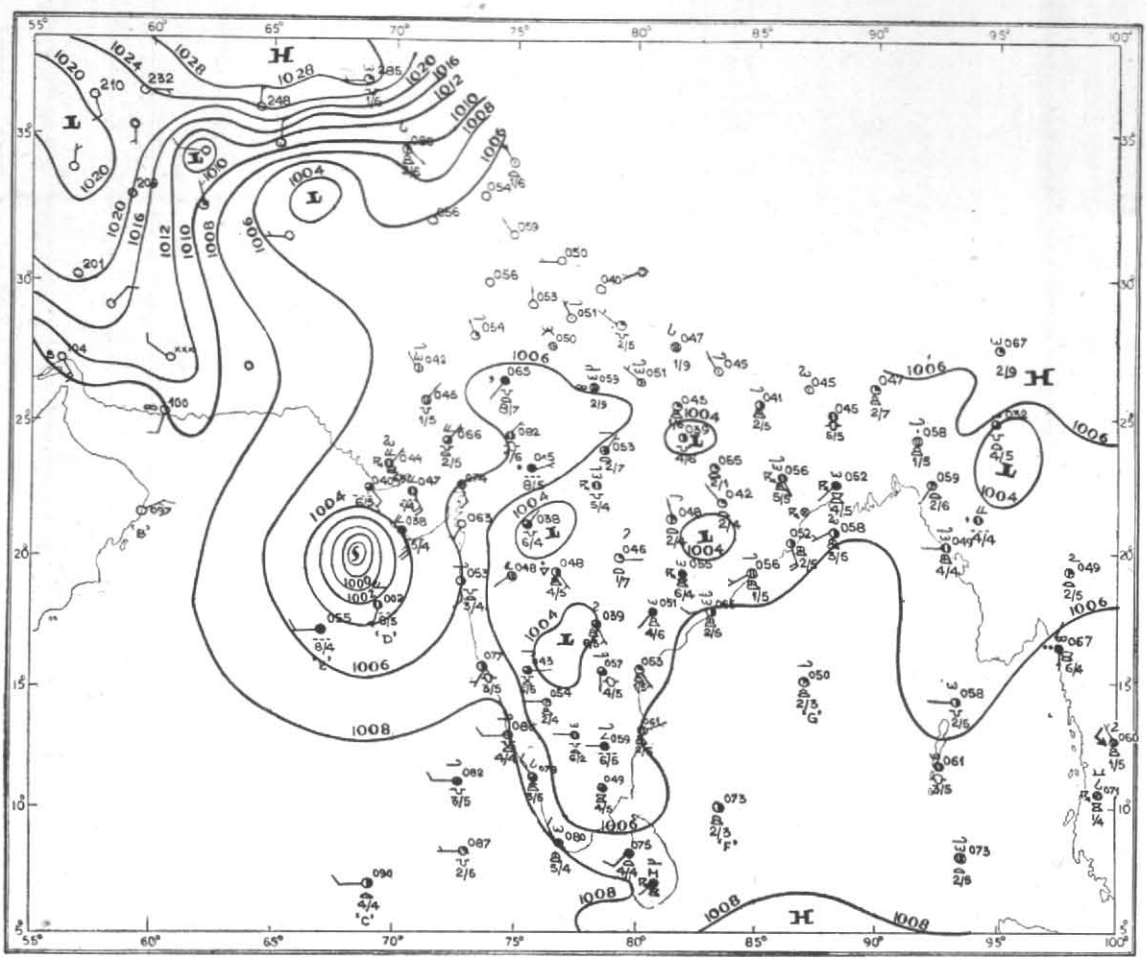

Fig. 3. Mean sea level chart of 12 GMT on 21 October 1975

circulation extending upto 250 mb. The 0405 GMT satellite picture showed a typical comma pattern with tight circular banding. There were indications of inner banding inside the CDO. The sharp round eye of the cyclone was approximately 60 km in diameter. It was centred near 20·5°N, 69° E, and had an embedded distance of about 3/4 degree (CF5). The CDO was surrounded by a well organised convective band about 1/2 degree in width, which coiled once round the CDO (BF1). The storm intensity was T6. By this time the severe cyclonic storm was close to north Gujarat coast. The satellite picture clearly showed that the cyclone's environment had been modified due to its proximity to land. The cirrus outflow had reduced, resulting in a smaller cirrus canopy and sharper edges of banding feature surrounding the CDO. This indicated the ongoing weakening. The vertical motion was less vigorous and the storm showed signs of slight weakening after having reached its maximum intensity, perhaps a few hours before the picture time. However, the system was still a severe cyclonic storm with a core of hurricane winds. The storm continued its northnortheastward movement and crossed north Gujarat coast about 10-15 km north of Porbandar around 1000 GMT.

2.6. *After landfall*

At 12 GMT of 22nd the severe cyclonic storm was centred near 22° N, 69·7° E over land, about 50 km northeast of Porbandar. The associated cyclonic circulation extended upto 300 mb. That the system had retained its intensity as a severe cyclone over land was evident from the fact that NOAA-4 scanning radiometer IR picture at 1452 GMT still showed a sharp round eye. Besides, gale winds with speed exceeding 90 kt as recorded at Jamnagar between 1400 and 1430 GMT (Table 1) prevailed in the storm field.

2.7. *Further movement and weakening*

Moving further inland in northeasterly direction, the system weakened into a cyclonic storm and

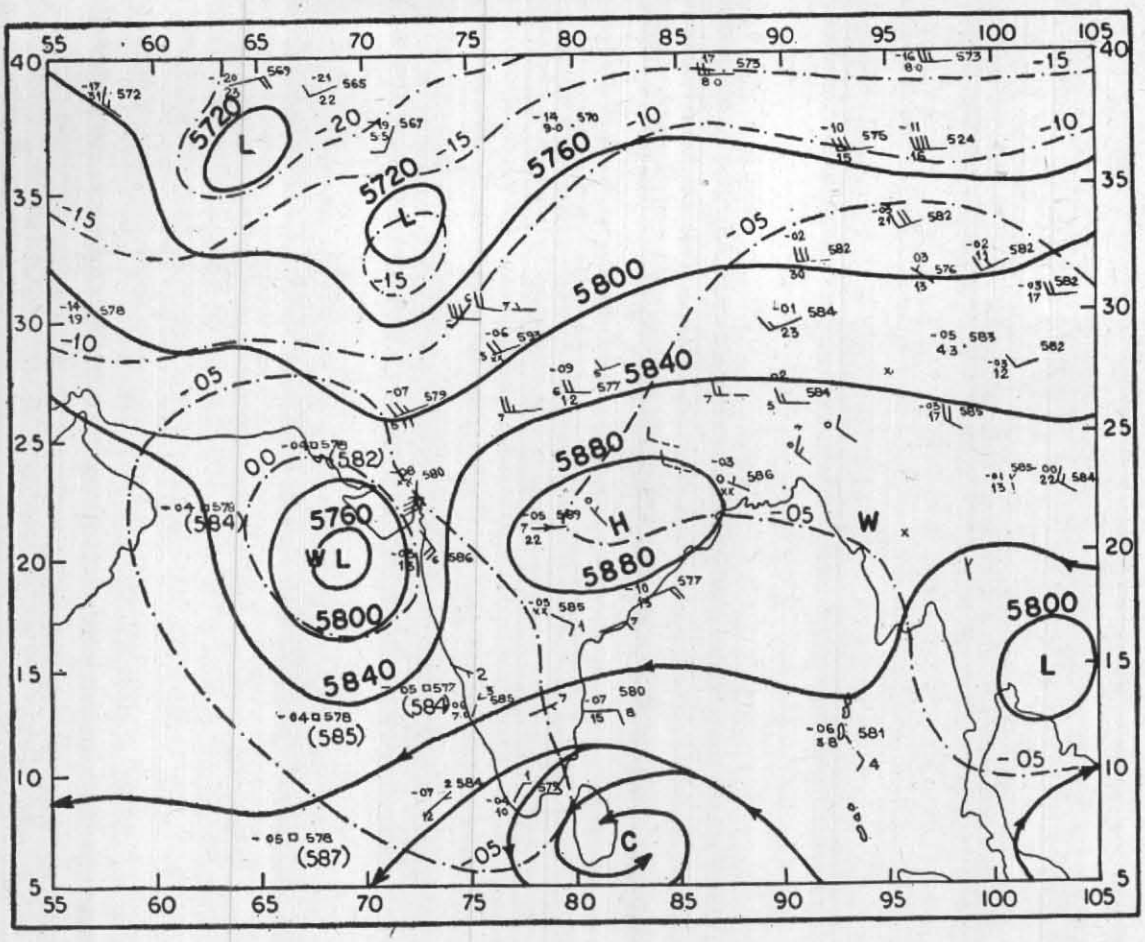

Fig. 4. 500 mb chart of 12 GMT on 21 October 1975

was centred near 23°N, 71°E at 03 GMT of 23rd, with the associated cyclonic circulation extending upto 500 mb only. The satellite picture at 0458 GMT showed that the system had considerably weakened. The eye had disappeared. The CDO was less organised and showed small curved convective cloud lines within the overcast. A large convective band with cirrus aloft appeared towards its north in association with an upper tropospheric westerly trough moving eastwards across extreme NW India and neighbourhood. It is seen from vertical time section of Ahmedabad (Fig. 8) that the upper winds upto 300 mb level had progressively strengthened between 00 GMT of 22nd and 00 GMT of 23rd, as they came in the grip of the storm. At 00 GMT of 23rd the wind speed was 80 kt at 850 mb and 70 kt at 600 mb. The upper winds decreased sharply thereafter. Such strong upper winds suggest that the system was still a cyclonic storm at 00 GMT of 23rd, even after 14 hours of landfall.

At 12 GMT of 23rd the storm weakened into a depression centred near 24.5°N, 72.5°E. Thereafter it rapidly weakened into a low pressure area and moved northeastwards.

3. Other significant features

3.1. *Surface wind and pressure*

3.1.1. Table 1 shows some of the important hourly surface wind and mean sea level pressure observations of 22nd from the affected area. The lowest pressure reported was 972.2 mb at Porbandar at 1000 GMT of 22 October 1975. The highest wind speed reported from the storm field was from Jamnagar Airport on the 22nd between 1430 and 1500 GMT, when the wind speed recorder pen of Dines' PT anemograph shot beyond the maximum range of the scale, *viz.*, 90 kt. The severe cyclonic storm was then located close to the station towards its south. The maximum wind speeds reported from some of the other stations were 54 kt at 1200 GMT from Okha, and 53 kt at 1000 and 1100 GMT from Porbandar. Since these values of wind speed were recorded at fixed times of observation, it may be expected that the absolute maximum wind speeds experienced at these stations would have been substantially larger. The plot of hourly surface wind and pressure observations recorded at Porbandar observatory (Fig. 9) shows that the wind veered from SE/44kt at 0800 GMT to W/49kt at 12 GMT and that the lowest pressure was reach-

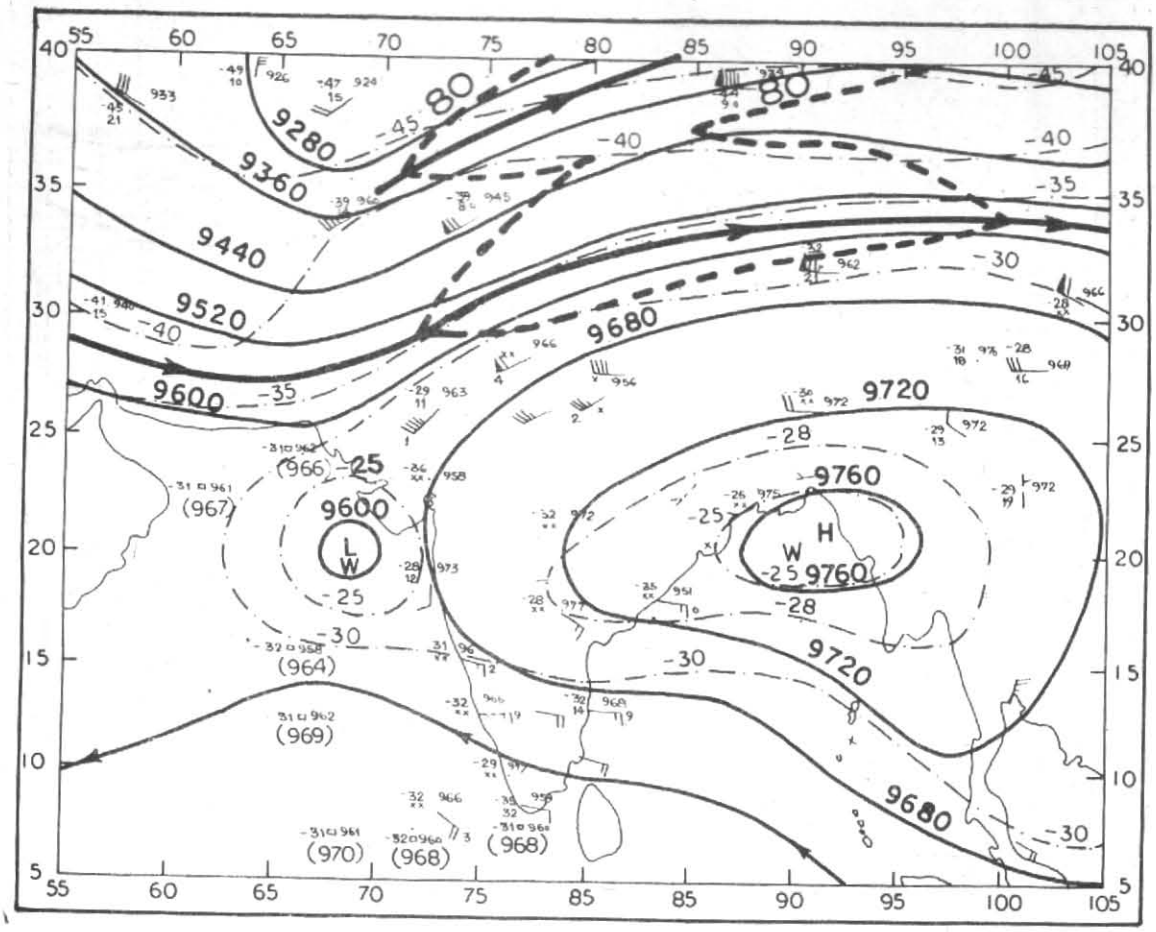

Fig. 5. 300 mb chart of 12 GMT on 21 October 1975

TABLE 1

Hourly surface wind and pressure observations of 22 October 1975

Time (GMT)	Station	Wind Direction (°)	Wind Speed (kt)	Pressure (mb)	Time (GMT)	Station	Wind Direction (°)	Wind Speed (kt)	Pressure (mb)
					1200	Porbandar	270	49	991·5
0200	Veraval	140	40	1001·6		Dwarka	360	28	999·4
						Okha	050	54	999·9
0600	Veraval	160	42	1003·0		Jamnagar (IAF)	090	30	997·3
	Porbandar	110	36	996·4	1300	Porbandar	270	28	995·3
						Okha	050	50	1000·6
0800	Veraval	180	44	1002·5	1330	Jamnagar Airport	090	40	991·4
	Porbandar	140	44	981·7					
	Okha	090	35	1002·7	1400	Jamnagar Airport	090	85 (max 90)	—
0900	Veraval	180	36	1002·3					
	Porbandar	230	49	972·7	1430	Jamnagar Airport	090	>90	982·0
	Okha	070	39	1001·5					
1000	Veraval	180	43	1002·4	1500	Jamnagar Airport	090	>90	979·3
	Porbandar	200	53	972·5		Rajkot	140	26	981·8
	Okha	070	49	999·8	1530	Jamnagar Airport	090	90	982·4
	Dwarka	360	26	998·7					
					1700	Rajkot	140	48	978·2
1100	Veraval	230	32	1002·6	1800	Rajkot	140	43	980·5
	Porbandar	230	53	981·8					
	Okha	050	44	999·6	1800	Jamnagar Airport	090	60	997·6
	Dwarka	360	36	998·8	1900	Rajkot	140	48	981·5

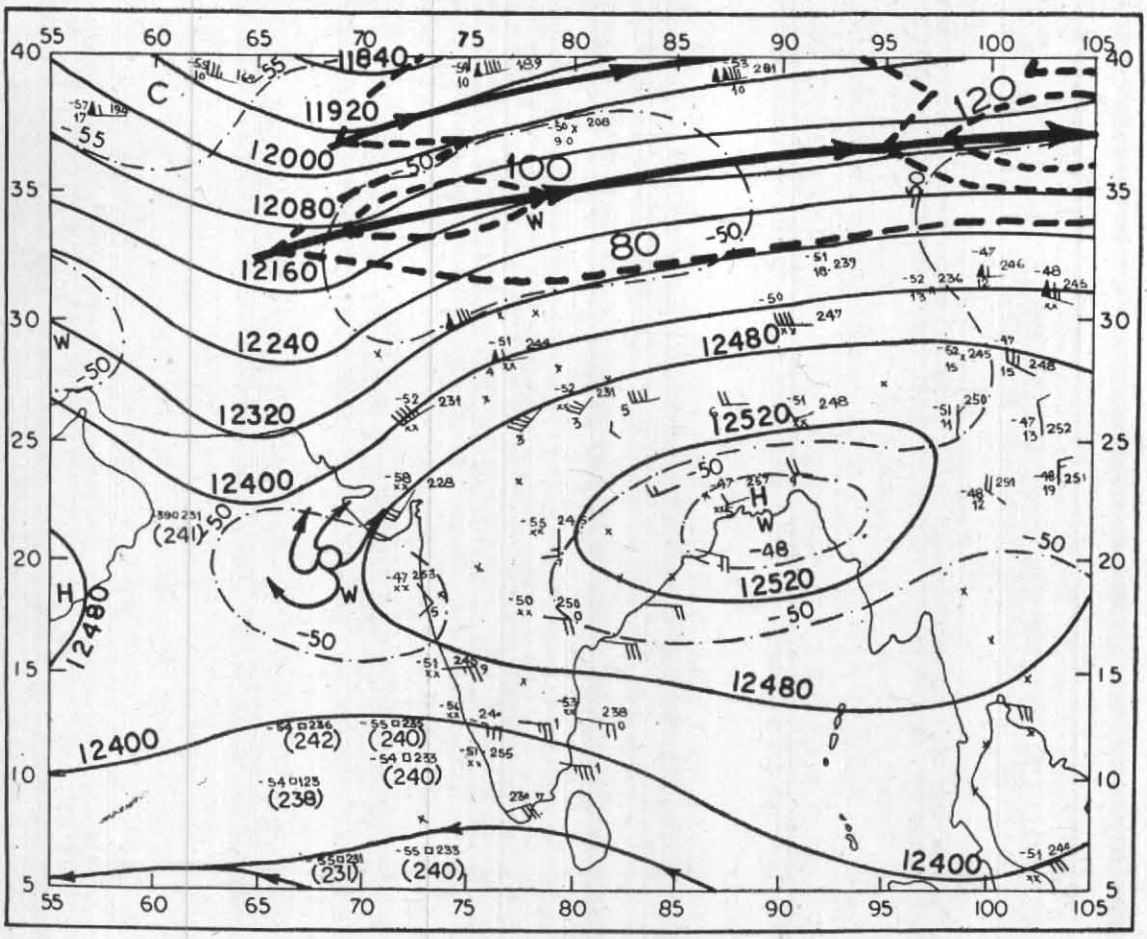

Fig. 6. 200 mb chart of 12 GMT on 21 October 1975

ed between 0900 and 1000 GMT. Subsequent reports of visits to affected areas have indicated that the cyclone crossed coast nearly 10-15 km north of Porbandar. It is estimated that the eye of the storm crossed Porbandar a little before 1000 GMT when wind speed dropped sharply and cloudiness decreased for a short duration of about 10 to 15 minutes. Surface winds again rose sharply after this lull period.

3.1.2. As mentioned earlier, the peak storm intensity derived from satellite pictures was T6 on 22nd at 0405 GMT. This corresponds to a maximum wind speed of 115 kt. The corresponding pressure depth at the centre of the cyclone as estimated from the table given by Mishra & Gupta (1976) would be 66 mb, so that the central pressure of the cyclone could be estimated at 944 mb while it was over the open sea. This estimation of maximum wind is supported by the observation of more than 90 kt wind speed at Jamnagar even 5 hours after the landfall. The lowest pressure of 972.2 mb observed at Porbandar at 10 GMT, was higher than the above estimate, perhaps because the storm centre passed 10-15 km north of Porbandar, and also due to time lapse of about 6 hours between the satellite and the pressure observations.

3.2. *Swells*

The maximum height of swells was estimated at about 4 m at Porbandar, 5 m at Dwarka and 6 m at Okha. It is of interest to observe that the swell height was only 4 m at Porbandar in the field of surface westerlies which were blowing from open sea towards the shore, while it was 5-6 m at Dwarka and Okha in the field of off-shore surface winds which were northerlies and easterlies respectively. This needs further investigation.

3.3. *Rainfall*

The cumulative rainfall chart for the 72 hour period ending at 03 GMT of 24 October 1975 (Fig. 2) shows that the rainfall distribution was almost symmetrical about the storm track, with the maximum amounts lying along the track.

Jamnagar reported 19.0 cm of rain between 12 and 18 GMT of 22nd; and the rainfall for 24 hours ending 03 GMT of 23rd was 24.6 cm.

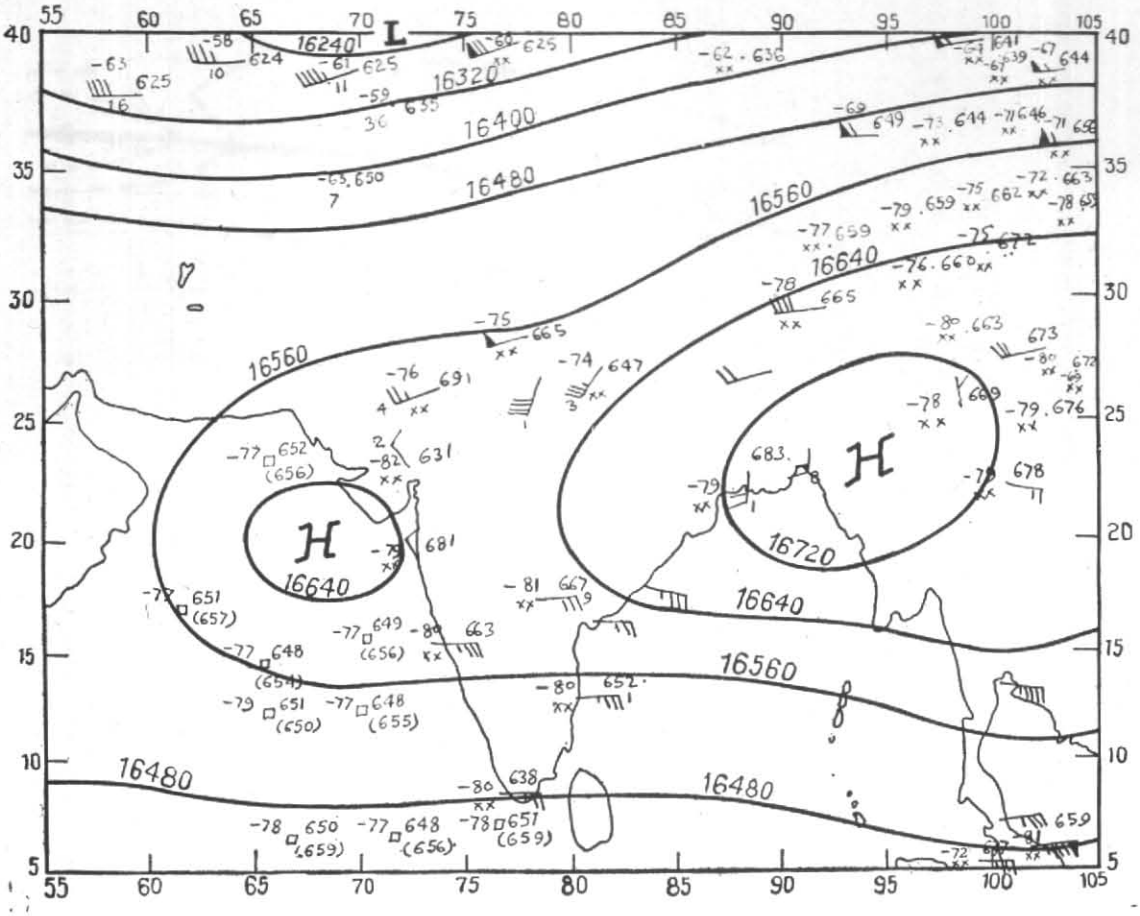

Fig. 7. 100 mb chart of 12 GMT on 21 October 1975

4. Development and intensification of the storm

4.1. As mentioned in para 2.1 and 3.4 above, the cyclone formed from a pre-existing low level disturbance off Maharashtra coast where sea surface temperatures of about 28°C prevailed. The region of formation near latitude 17°N was far away from equator for the coriolis parameter to be sufficiently large and surface circulation to develop and intensify.

4.2. *Sea surface temperatures*

Sea surface temperature distribution over the Arabian Sea during the period 18-23 October 1975 based on ships' observations (Fig. 10) indicates relatively cold waters with temperatures of about 28°C off south Maharashtra coast, and the warmest temperatures around 30°C prevailing off Gujarat coast. It is seen that the storm progressively intensified as it moved from relatively colder sea surface temperatures over east central Arabian Sea to warmer waters off north Gujarat coast. Since sea surface temperature normals for Arabian Sea are not available, these temperatures can only be compared with the mean of sea surface temperatures for the month of October available for two years (*i.e.*, 1963 and 1964), from the data collected during International Indian Ocean Expedition (Ramage *et al.* 1972). The mean temperatures were 27.9°C off Maharashtra coast, and 27.7°C off north Gujarat coast and in the rest of central Arabian Sea. It is seen that from 20th morning onwards, when the system had attained a deep depression stage, it travelled over the sea which was at least 1° to 2°C warmer than the mean. Such warm waters were perhaps responsible for the enormous conditional and convective instability of the warm moist tropical air in the storm field which resulted in the rapid growth of the severe cyclone.

4.3. *Upper air temperature*

The upper air temperatures showed interesting characteristics. Throughout the period of development, a warm pool of air existed above the

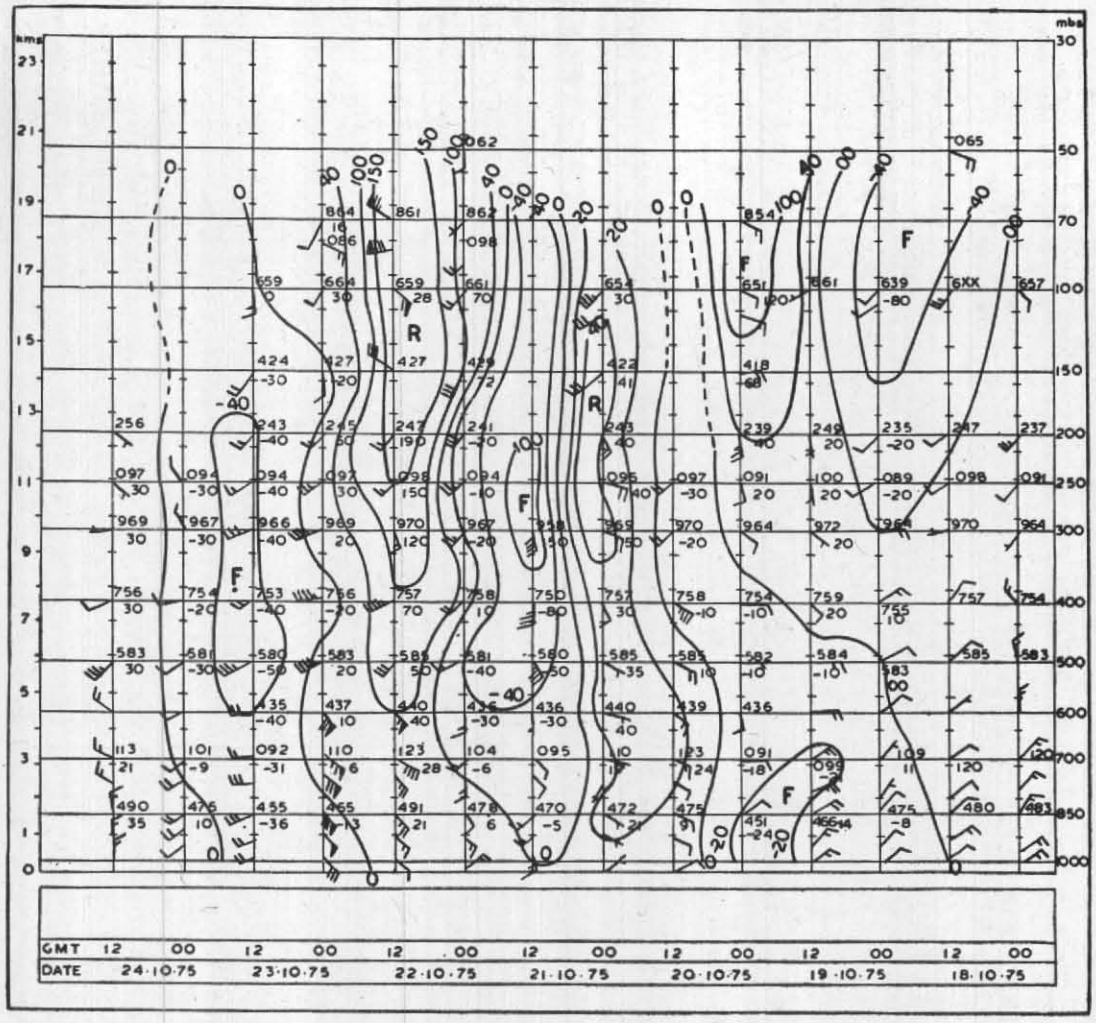

Fig. 8. Vertical time section of Ahmedabad, 18 - 24 October 1975

disturbance. Figs. 4 to 6 shows the well marked warm pool above the surface circulation centre of the cyclone between 500 mb and 200 mb at 12 GMT on 21st. Similar thermal field existed at all levels below 100 mb. The 850-500 mb thickness charts also showed a warm pool over the cyclone area between 12 GMT of 20th and 00 GMT of 23rd. The upper air temperatures at Bombay were above normal at all the levels from surface upto 200 mb level from 18th to 21st. The maximum departure was at 300 mb level where the temperatures were 3° to 4°C above normal on 19th and 20th. Also, on 22nd when the cyclone had reached its peak intensity, temperatures between 700 and 200 mb levels were uniformly 2° to 3°C above normal. This is in agreement with the conclusion of Zipser (1964) that in most cases the temperatures above a developing storm are 1° to 2° above normal in the layer between 5 and 12 km for atleast 24 hr prior to the time that the storm winds reach hurricane force.

The above data reveal some of the characteristics of the warm core thermal structure of this cyclone.

4.4. *Vertical wind shear*

Gray (1968) has considered the inhibition of tropospheric ventilation by initially existing small vertical wind shear as a condition for tropical cyclone formation, so that the vertical wind shear in the layer from near the surface to about 14 km should not be more than about 15 knots. Since no wind profiles from the region of storm development were available, the authors have examined upper wind data of Bombay and Goa for the period

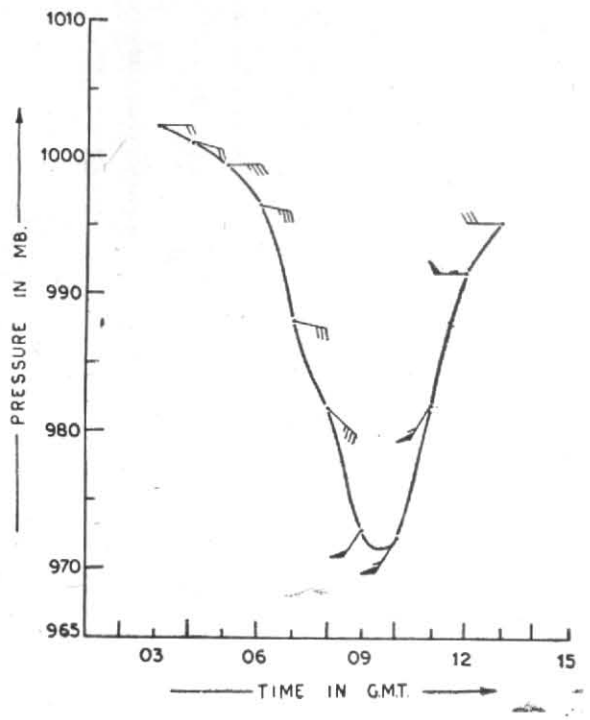

Fig. 9. Hourly surface wind and pressure observations recorded at Porbandar Observatory on 22 Oct 1975

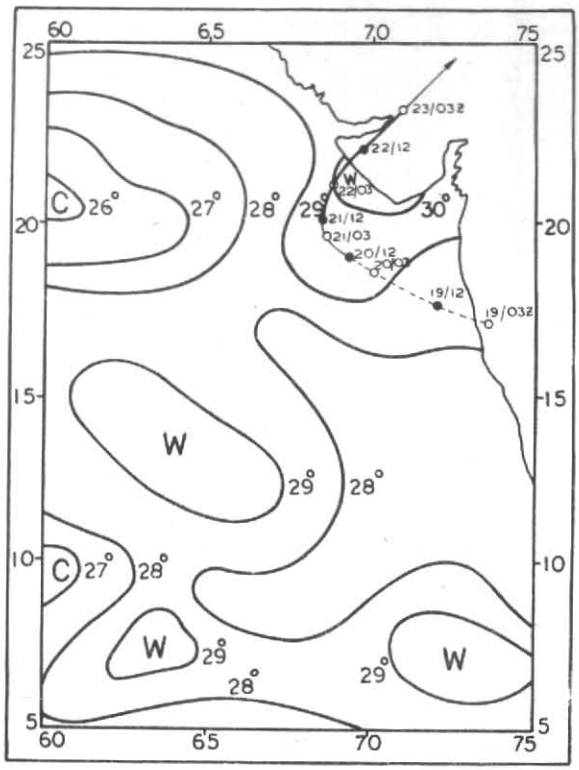

Fig. 10. Sea surface temperature distribution over Arabian Sea during 18-22 Oct 1975

just before the depression was formed. It is seen that on 17th and 18th the winds were light to moderate throughout the tropospheric layer and that the vertical wind shear between 850 and 200 mb levels was about 15 to 20 kt. It is important to note that during this period the axis of the subtropical ridge in the upper troposphere lay along latitude 20°N over the Arabian Sea and the Peninsula, and this was the region of the weakest winds at these levels.

4.5. *Outflow*

The western edge of the anticyclonic cell over India at 200 mb level lay over Gujarat, Maharashtra and adjoining Arabian Sea with its axis along 20°N for the entire period 17 to 23 October 1975. This position of the anticyclone was more or less steady, as the in Fig. 6 for 12 GMT of 21st. Throughout the period of development, the cyclone was under the influence of this strong anticyclone which provided the necessary upper tropospheric divergence for intensification. By 21st, a westerly trough approached this region and was lying along Long. 65°E at 200 mb at 12 GMT, sloping westward with height (Fig. 6). The combined influence of the westerly trough and the anticyclone in the upper troposphere provided increased divergence and strong outflow from the storm field towards northeast. The intense sustained outflow from the storm field in the upper troposphere is also confirmed by the following—

(*i*) Strong westerly to southwesterly winds increasing in strength downwind, at 300 and 200 mb levels (Figs. 5 and 6);

(*ii*) Appearance of a separate well marked anticyclone over the storm at 100 mb level (Fig. 7) and

(*iii*) Increased cirrus canopy of the cyclone in the satellite picture of 21st (Fig. 1).

By this time the storm was moving towards northeast, where 200 mb divergence pattern was stronger, and this also was favourable for intensification. Consequently, the cyclone continued to intensify until the morning of 22nd, as described in para 2.5 above.

On 23rd the system retained its intensity as cyclonic storm over land, as evident from the outflow at 200 mb level. The vertical time section of Ahmedabad (Fig. 8) shows that the upper winds

strengthened as the storm approached the station. At 00 GMT of 23rd when it was the closest to the station, wind speed of 80 kt was reached at 850 mb and 70 kt at 600 mb levels. It appears that the cyclone maintained its intensity on 23rd under the influence of the upper tropospheric westerly trough, and did not weaken as fast as it should have done otherwise.

4.6. *Discussion*

It is seen from the above discussions that the two criteria of tropical cyclone formation outlined by Riehl (1948), *viz.*, a pre-exiting low-level disturbance and a region of upper level divergence or outflow above the surface disturbance, are satisfied in this case. Also, the conditions outlined by Palmen (1956) and Gentry (1973) regarding (*i*) sea surface temperatures being at least 25.5°C, (*ii*) region of formation being more than 5° latitude away from equator and (*iii*) light wind shear have also been met.

The rapid intensification could be attributed to the following factors —

(*i*) Very warm sea surface; the temperatures were 28°-30°C as against the requirement of 25.5°C (Gentry 1973);

(*ii*) Existence of warm pool in the upper air, with temperatures 3°-4°C above normal;

(*iii*) Marked upper tropospheric divergence.

The satellite picture of 22nd morning (Fig. 11) is remarkable for its clarity, showing the cyclone near its peak intensity. It shows absolutely circular cloudless eye with wall clouds around. Surrounding the wall clouds is the region of rain bands which merge with the former. The outer convective band around the CDO also has a tight curvature. This is the first ever photograph of a cyclone in the Indian Seas depicting these central features with such great clarity and details.

5. Movement and recurvature

It has not been possible to arrive at any definite conclusion about the movement of the cyclone with the available data. Hence, a few points which appear to have a bearing on the movement are mentioned here. The characteristics of the basic current in which the cyclone moved were (*i*) weak lower level wind field upto 700 mb and (*ii*) anticyclonic flow in the upper troposphere with ridge axis roughly along Lat. 20°N. These characteristics remained more or less undisturbed throughout the storm period.

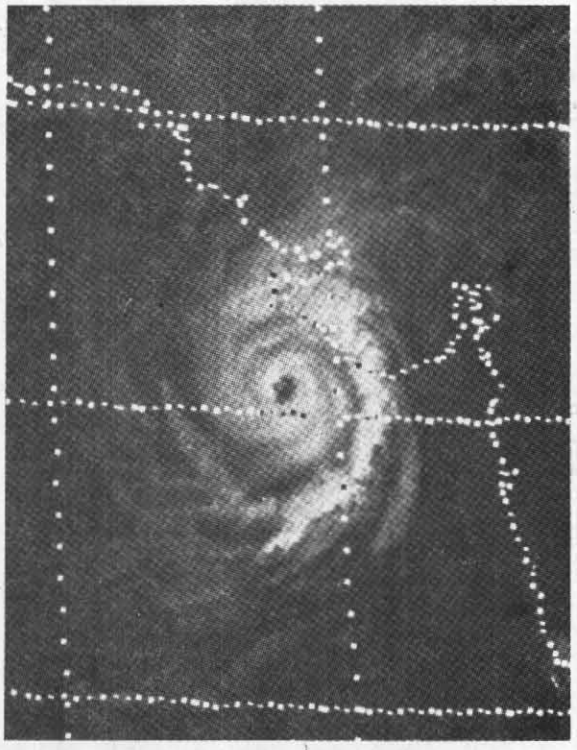

Fig. 11. NOAA-4 SR visible picture of Porbandar cyclone on 22 October 1975

Initially, the storm moved in a direction between westnorthwest and northwest, which was roughly along the gradient of sea surface temperatures. Also, for the most part the storm track was along the 200 mb flow.

The storm started recurving on 21st. By 12 GMT of 21st it was centred at 20°N, 68.5°E and had started moving towards northnortheast, along the periphery of the anticyclone at 200 mb level. An indication of the impending recurvature was given by Ahmedabad upper air data. Between 00 and 12 GMT of 21st, Ahmedabad upper winds strengthened considerably and contour heights at 500 mb level and above fell by more than 100 gpm (Fig. 8). Another factor responsible for recurvature was the approach of the upper tropospheric westerly trough on 21st, which caused the storm to recurve simultaneously with its intensification. Thereafter, the storm moved in a northeasterly direction, while it was lying ahead of the trough and in its divergence field.

6. Conclusions

Porbandar cyclone formed from a pre-existing low level disturbance over east central Arabian Sea where sea surface temperatures above 28°C and weak vertical wind shear prevailed. It rapidly intensified into a severe cyclonic storm apparently

under the influence of warm sea surface with temperatures 28° to 30°C, a warm pool above the surface circulation with temperatures upto 4°C above normal, and marked upper tropospheric divergence. Probably the highest temperature anomalies in the storm were present around 300 mb level. The cyclone generally moved along the periphery of the upper tropospheric anticyclone, and over the sea its movement was towards the warmer waters.

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