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Letters to the Editor

551.515

SOME ASPECTS OF THE GOPALPUR CYCLONE OF OCTOBER 1999

1. A very severe cyclonic storm hit Orissa coast around early morning hours of 18 October 1999. Throughout its course over the Bay of Bengal, for nearly three days, the system moved mainly in a northwesterly direction and crossed Orissa coast very close to Gopalpur. The system was tracked in INSAT-1D cloud imagery from its development over Andaman Sea and neighbourhood on 15 till it crossed the coast. Coastal radars at Paradip and Visakhapatnam also tracked the system when it came within their radar range. The track of the system, its central pressure, associated gale force winds and the damage caused by the storm are discussed in RSMC report IMD (2000) and IMD (2000).

Gopalpur lies in Ganjam district of Orissa. Available records show that during the last 109 years (1891-1999) 11 cyclones have crossed this district and 4 of them in the month of October. It is interesting to note that all the four storms that crossed this district in October were severe cyclonic storms (SCS). Prior to 1999, severe cyclonic storms had crossed the district in 1968,1935 and 1909 (all in October). Sridharan *et al*. (1991) studied some salient features of the Bay of Bengal cyclone of November 1989. Sridharan and Rao (1992) studied the intensity of the Bay of Bengal cyclone of May 1990 based on satellite, radar and ship data . In this paper satellite and radar data of the Gopalpur cyclone of October 1999 have been studied and the results are presented. Salient synoptic aspects have also been discussed.

2. In addition to INSAT -1D, NOAA - 12 & 14 satellite data Paradip and Visakhapatnam radar data have been used. Synoptic data of Kalingapatnam, Gopalpur, Puri, Bhubaneswar and Balasore (all coastal stations) have been utilised for the study. Upper air observations of Karaikal, Chennai, Machilipatnam, Visakhapatnam and Calcutta have also been considered.

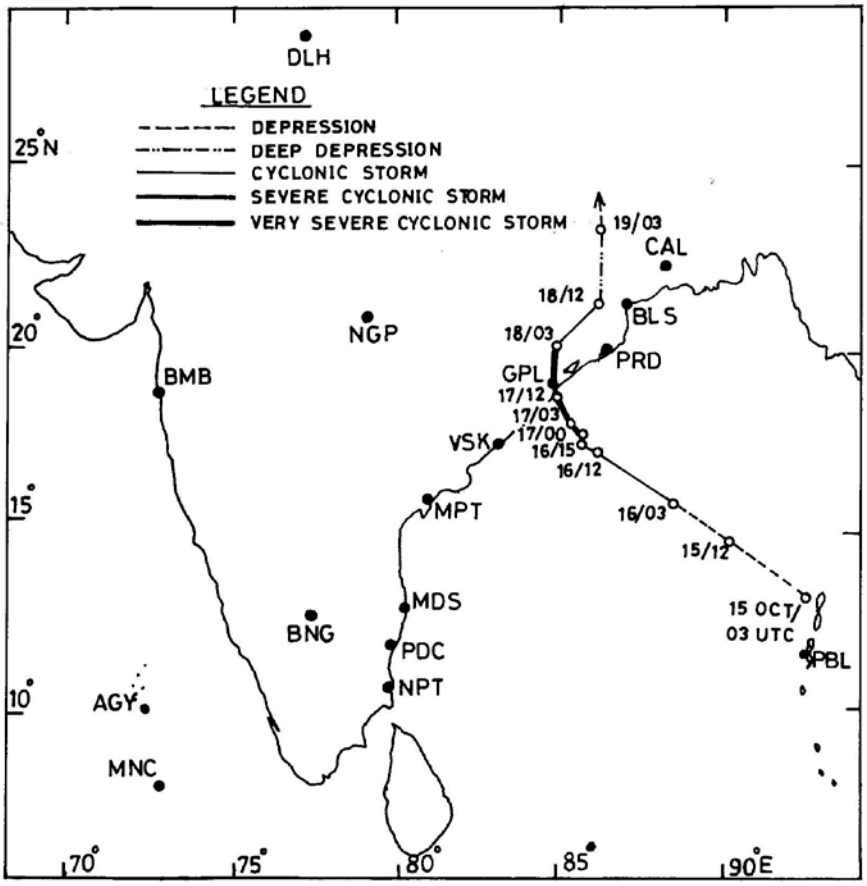

Fig. 1. Track of Bay of Bengal very severe cyclonic storm 15-19 October 1999

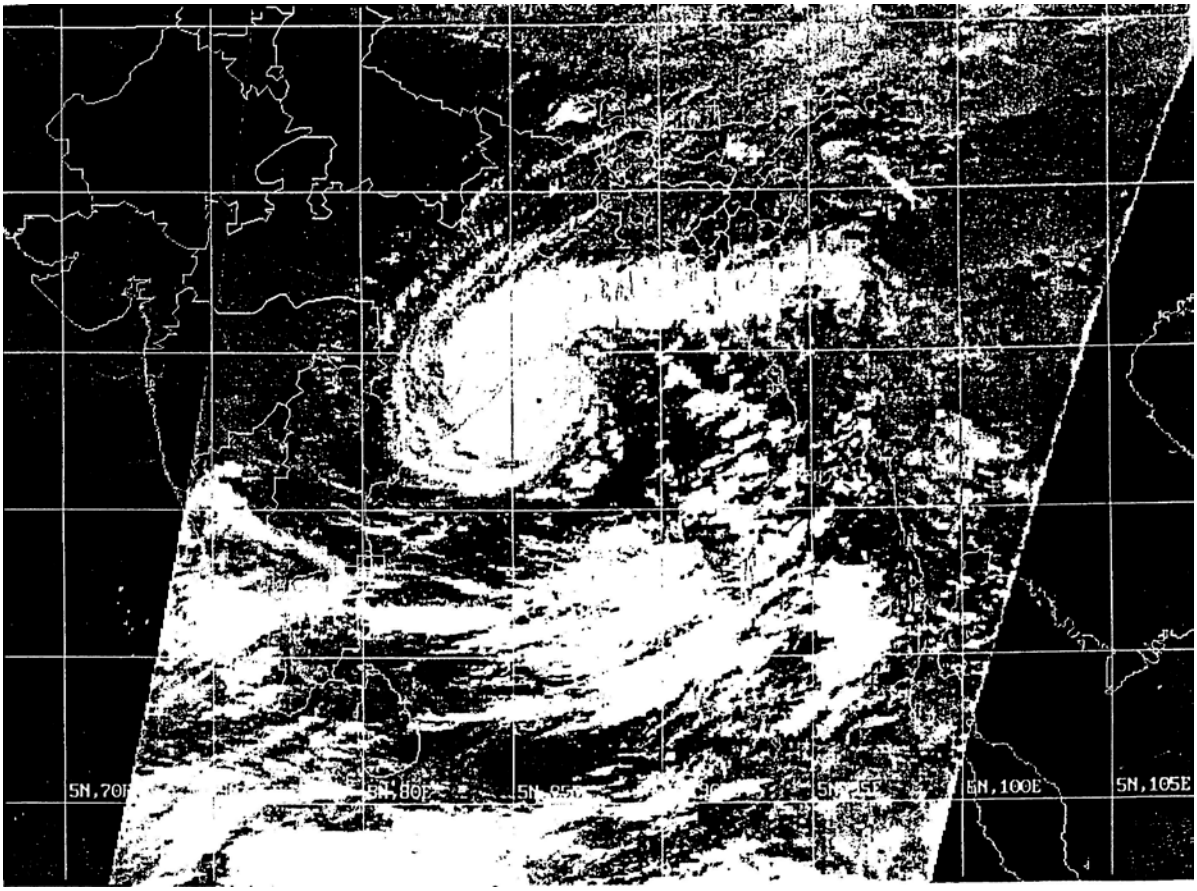

Fig. 2. Satellite NOVA-14 view of Gopalpur cyclone at 2144 UTC on 16 October 1999

3.1. *History of the cyclonic storm* - Under the influence of an upper air cyclonic circulation, a depression formed over north Andaman Sea and neighbourhood and was centred at 0300 UTC of 15 October near 13.5° N/92.5° E. It intensified into a cyclonic storm and lay centered at 0300 UTC of 16 near 16.0° N/ 88.5° E. It further intensified into a severe cyclonic storm at 1500 UTC of 16 and lay centered near 17.5° N/86.5° E. It further intensified into a very severe cyclonic storm and lay centred at 0300 UTC of 17 near 18.0° N/85.5° E. It moved in a northnorthwesterly direction and crossed Orissa coast between 1900 and 2000 UTC of 17 close to Gopalpur. The system weakened into a severe cyclonic storm at 0300 UTC of 18 and lay centered near 20.5° N/ 85.0° E about 50 km west of Bhubaneswar. It weakened rapidly into a deep depression at 1200 UTC of 18 and lay centered near 21.5° N/86.5° E. It further weakened into a depression near 23.5° N/86.5° E at 0300 UTC of 19 and then weakened into a low pressure area. The track of the storm is shown in Fig 1.

3.2. *Satellite observations* - From the satellite observations (INSAT & NOAA) it is observed that initially the system was intensifying gradually and attained the intensity of T 2.0 by 2100 UTC of 15. At 0900 UTC of 16 the system intensified to T 3.0 and the intensity at 1500 UTC of 16 was 3.5. After about 12 hours the system intensity was T 4.5 and the system crossed the coast with the same intensity. It is seen that the system intensified rapidly from T 2.5 to T 4.5 with in a period of 24 hours. It is further seen that the system maintained the highest T-Number 4.5 from 0300 UTC of 17 till it crossed the coast. NOAA -14 satellite view of the cyclone at 2144 UTC on 16 October is shown in Fig. 2. Well defined eye and spiraling cloud bands could be seen in the picture. At the time of storm crossing the coast Gopalpur recorded the lowest pressure of 955.9 hPa at 1900 UTC on 17 and the wind speed recorded was 180 kmph at 2000 and 2100 UTC. Based on Gopalpur observation and using the formula of Mishra and Gupta (1976) the storm had intensified to the stage of T 5.5 before crossing the coast.

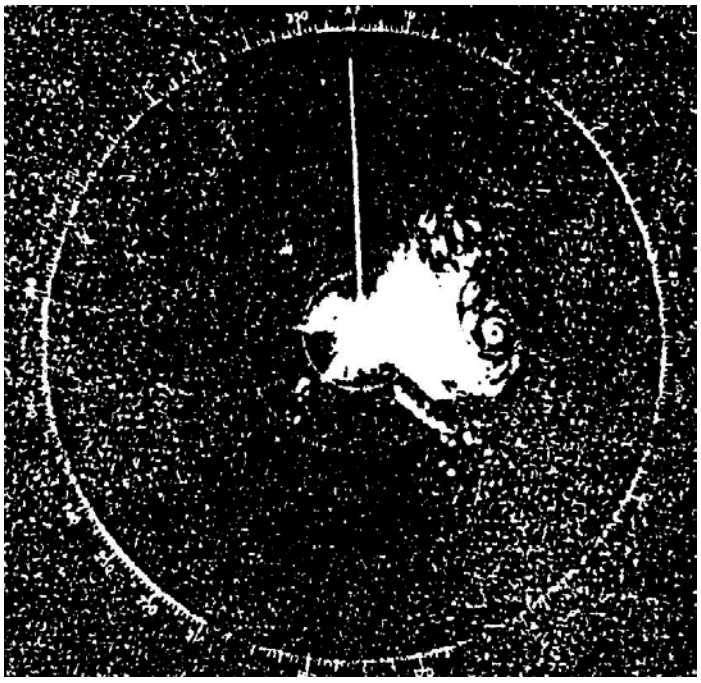

Fig. 3. Visakhapatnam Radar picture at 2300 UTC, 16 October 1999

3.3. *Radar observations* - Since the storm was away from both Visakhapatnam and Paradip radars the system was tracked through radar only for a short period with good confidence level. The system in its intense stage as seen by Visakhapatnam radar at 2300 UTC of 16 when the system centre was at a distance of 240 km to the east of Visakhapatnam is shown in Fig 3. The average diameter of the 'eye' as revealed by Visakhapatnam radar was 13 km with standard deviation (SD) of 3 km. The average 'eye' wall thickness was 10 km with SD of 2 km. Radar reports suggest narrow core feature of the system.

3.4. *Salient synoptic features* - Prior to the formation of the storm the equatorial trough was seen running cross Kerala, Tamil Nadu and Andaman & Nicobar islands. At 850 hPa the subtropical anticyclone was located over west Rajasthan and adjoining Pakistan. This anticyclone tilted southward with height and at 500 hPa level, it was located over Gujarat and adjoining Arabian Sea. As regards temperature profile, warm region was seen over Telangana at 700 hPa level and over north Kerala at 500 hPa level. The vertical wind shear was very low, of the order of 1.5 mps/km, between 850 hPa and 200 hPa level over east coast. The wind distribution in the Bay of Bengal suggested low level inflow and substantial higher level out flow which resulted in rapid intensification of the system. From the isobaric pattern of surface chart it can be seen that the latitudinal extent of the outermost closed isobar was 9° to the south and 4° to the north with respect to the system centre at the time of storm crossing the coast suggesting that the pressure gradient was steep to the north than to the south. From the system centre the trough extended upto south east Arabian Sea and low level strong westerlies were seen south of this trough over Arabian Sea islands. Similar to typical monsoon depression rainfall was recorded over west coast apart from some stations in other parts of south Peninsula. The system weakened rapidly after crossing the coast

3.5. *Pressure, wind and rainfall* - Pressure values of Kalingapatnam, Gopalpur, Puri, Bhubaneswar and Balasore during the period 1700/0000 UTC to 1800/0300 are shown in Fig 4. It can be seen that there was no significant fall of pressure in these stations except Gopalpur which recorded the lowest pressure of 955.9 hPa at 1900 UTC of 17. Another station where the storm came close is Puri which recorded the lowest pressure of 995.5 hPa at 2200 UTC. At Gopalpur the pressure gradient was very small (<0.1 hPa/km) when the storm centre (19.0/85.0 at 17/1200 UTC) was at 80 km and the wind speed observed was less than 65 kmph. When the system came closer to Gopalpur at 17/1700 UTC near 19.1° N/84.9° E pressure

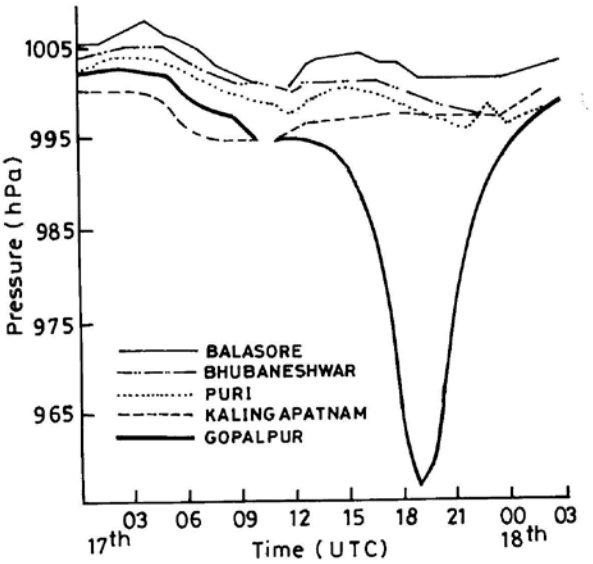

Fig. 4. Pressure values at the coastal stations in association with the storm

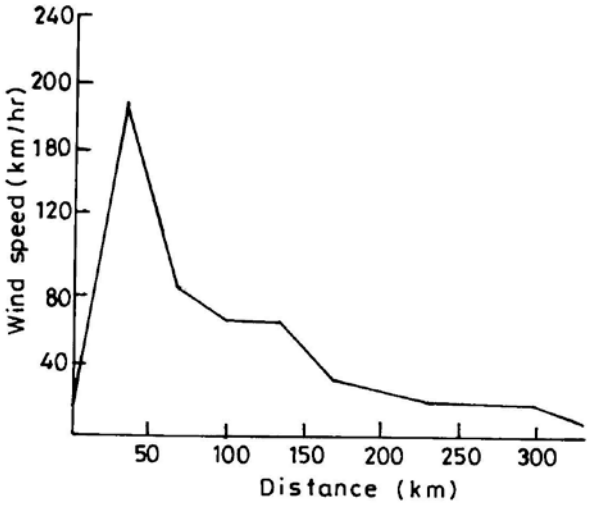

Fig. 6. Wind speed at different radial distance from system centre

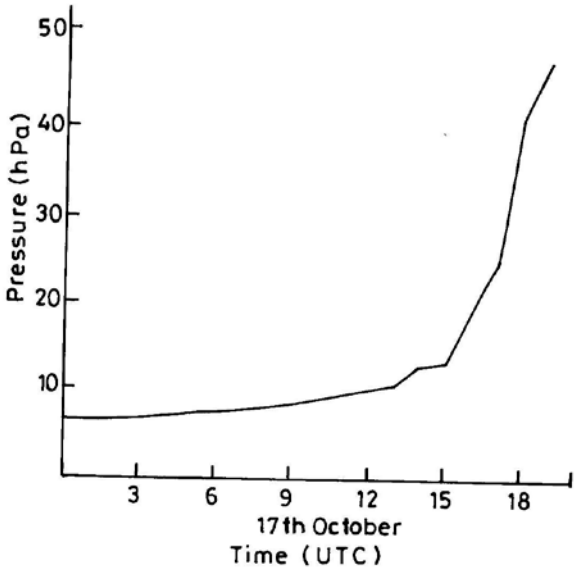

Fig. 5. 24 hours pressure fall at Gopalpur

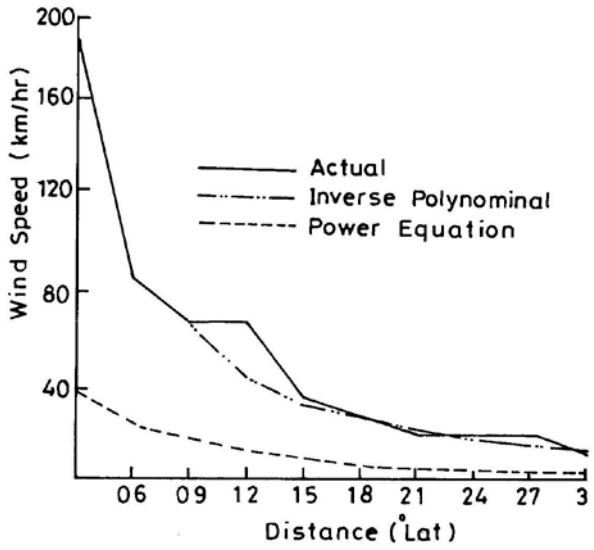

Fig. 7. Actual and estimated wind speed at different distances from the system centre

gradient increased to more than 0.5 hPa/km. The wind speed at Gopalpur was between 80 kt (148 kmph) and 98kt (182 kmph) during this period with almost calm wind around 17/1900 UTC. The pressure gradient was very high in the 'eye' wall close to the 'eye' and was of the order of 1.8 hPa/km at 17/ 1800 UTC. Pressure fall at Gopalpur as the storm approached the station is shown in Fig. 5. It is seen that maximum 24 hour pressure fall recorded was 47.9 hPa at 1900 UTC of 17. After 1900 UTC the pressure rose at Gopalpur very fast. Rate of rise of pressure after 1900 UTC was 4.9 hPa in the first hour, 16.9 hPa in the second hour, 6.8 hPa in the third hour. It

TABLE 1

Highest rainfall intensity, time of its occurrence at various stations in association with very severe cyclonic storm

Station	Period during which the system centre was from 135 to165 km distance (UTC)	Intensity of rainfall at 135-165 km (cm/hr)	Rainfall recorded in 24 hr ending at 18/0300 UTC (cm)
Balasore	–	–	9
Bhubaneswar	17/1500 to 18/0000 (9hr)	1.67	19
Puri	17/1200 to 17/1500 (3hr)	1.67	12
Gopalpur	17/0430 to 17/0700 (2.5 hr)	1.00	9
Kalingapatnam	17/0130 to 17/0300 (1.5 hr)	0	4

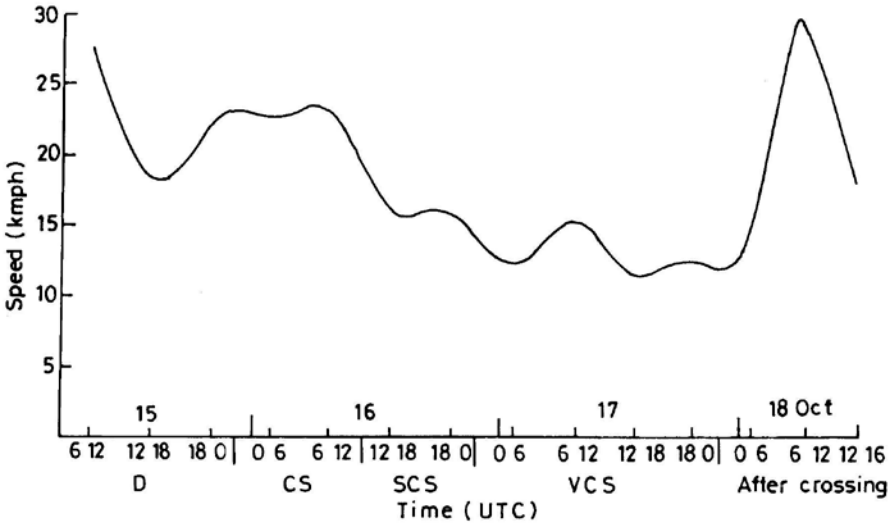

Fig. 8. Speed of movement of the storm at different stages of intensity and after crossing the coast

took 12 hours for the pressure to fall from 998 hPa to 955.9 hPa. After landfall it took only 8 hours for pressure to reach the same value.

Hourly synoptic observations from Kalingpatnam to Balasore recorded during the storm period was composited. For this purpose wind speed and pressure were estimated at different distances upto 300 km from the storm centre. The wind speed at different distances from the storm centre is shown in Fig.6. It is seen that the wind speed increase is noticed towards storm centre only from a distance of 150 km. Beyond this distance the wind speed was steady. While trying to estimate the wind speed based on power equation $V = a\ r^m$ where V is the wind speed in kmph, r-the radial distance(in latitude) from the system centre and 'a' and 'm' are constants (Riehl 1963) the correlation coefficient between radial distance and wind speed works out to 0.97. Chi-square test was applied for testing the goodness of fit between observed and estimated wind speed. A significant difference between

TABLE 2

Mean upper air temperatures on 14/0000 UTC and 20/0000 UTC

Station	14		20	
	850 hPa (°C)	500 hPa (°C)	850 hPa (°C)	500 hPa (°C)
All stations (KRL to CAL)	17.8	-5.2	18.9	-3.8
Excluding Calcutta	17.8	-5.2	19.0	-2.6

TABLE 3

Mean geopotential height in gpm on 1400/0000 UTC and 2000/0000 UTC

Date		700 hPa	500 hPa	300 hPa	200 hPa
14 Oct	All stations	3120	5840	9670	12420
	Excluding Calcutta	3110	5830	9650	12400
20 Oct	All stations (KRL to CAL)	3120	5830	9690	12440
	Excluding Calcutta	3120	5840	9720	12490

the two was noted. On the other hand the inverse polynomial of the form $V=a/(r^2+br+c)$ is found to give a better estimate of the wind speed. The values of the constant a(166), b(2.7), c(-0.02) were arrived at by applying three values of wind speed and distance close to the storm centre and solving the three simultaneous equations. The Chi-square test confirms the superiority of inverse polynomial to power equation for estimating the wind speed. The results are shown in Fig. 7.

It is interesting to note that the pressure difference between Gopalpur and Puri is having a good relation with wind speed at Gopalpur. The linear correlation between the difference in pressure and the wind speed at Gopalpur is 0.87. However the relation $V=ad^m$ where 'a' and 'm' are constants and '*d*' is the difference in pressure between Gopalpur and Puri is found to be more appropriate for estimating wind speed at Gopalpur.

Table 1 gives the intensity and 24 hr rainfall at different stations. It can be seen that when the storm center was at a distance of 135-165 km intensity of rainfall at Puri and Bhubaneswar was 1.67 cm/hr. It is further seen that Bhubaneswar though an interior station, recorded higher rainfall than other coastal stations.

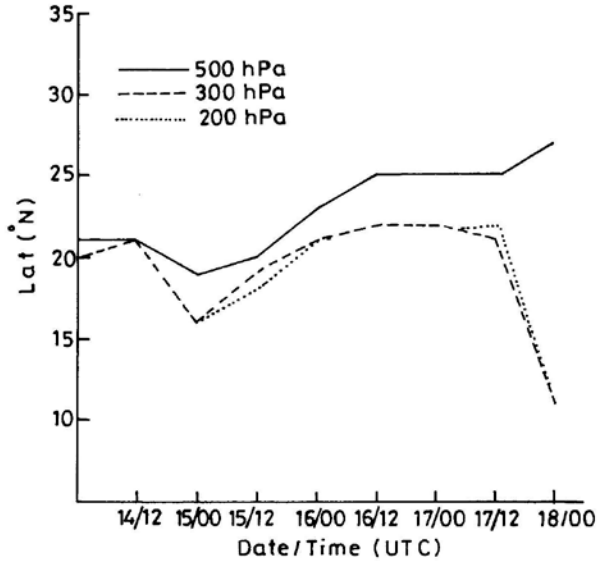

Fig. 9. Ridge position around 80° E at different pressure level

3.6. *Speed of the storm* - The six hourly average speed of movement of the system at various stages of intensities is shown in Fig.8. It is seen that when the storm was at lower intensity it moved faster and *vice versa*. The average speed of the storm was 23 km/hr when it was of depression / cyclonic storm intensity, decreased to 14.5 km/hr when it became severe cyclonic storm and further decreased to 12.2 km/hr when it reached very severe cyclonic storm intensity. After crossing the coast it moved with the speed of 22 km/hr towards north east. No peculiar behaviour in its movement was noticed.

3.7. *Impact on the environment* - An attempt is made to study the changes that took place in the atmosphere after the cyclonic storm crossed the coast. For this purpose the mean upper air temperatures and contour heights on 14/0000 UTC and 20/0000 UTC at different levels of Karaikal, Chennai, Machilipatnam, Viskhapatnam, Bhubaneswar and Calcutta were examined. The temperature values are shown in Table 2. It is seen that there was a significant rise in temperature of about 1.2° C at 850 hPa (all stations other than Calcutta) after the storm crossed the coast. At 500 hPa level also similar change is noticed and the increase in temperature was 2.6° C. The study is restricted to 850 hPa and 500 hPa level due to non availability of data at higher levels. The geopotential height at 700, 500, 300 and 200 hPa on 14 and 20 are shown in Table 3. It is seen that height increased after the storm crossed the coast at 300 hPa and 200 hPa level when all stations other than Calcutta are considered. In the lower level no significant change is noticed. Fig. 9 gives the ridge position around 80°E at different (500, 300 and

200 hPa) levels from 14/0000 UTC to 18/0000 UTC. It can be seen that the ridge position at all levels shifted southward at the initial stage of development of the system and the position moved northward with the intensification of the storm and its movement towards northwest. After the system crossed the coast ridge position at 300 and 200 hPa once again shifted southward.

4. The Gopalpur cyclone of October 1999 was a narrow core system. Inverse polynomial relation was found to be a good fit for estimating the wind speed.

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