551.515.2 (267.37)

SOME SALIENT FEATURES OF THE ARABIAN SEA SEVERE CYCLONIC STORM OF 5-10 MAY 2004

1. During pre-monsoon season (March - May) cyclonic storm activity in the Indian seas is more in May than in the other two months. Muthuchami and Dhanavanthan (2000a) found that the predominant direction of motion of cyclonic storms over Bay of Bengal in May is northward and storms forming west of 85° E move predominantly in westerly direction. Muthuchami and Dhanavanthan (2000b) concluded that in the month of May storms with wind speed more than 150 kmph strike the coast with the periodicity of 9-11 years. Sridharan *et al*. (2000) studied the climatology of cyclonic storms over Arabian Sea and found that in the month of May most of the storms cross the Oman coast. It is also noticed that there is bi-modal character of storm formation in Arabian Sea with maximum in October and November and the secondary maximum in June. Akhilesh Gupta and Muthuchami (1992) studied the wind structure of the May 1990 storm and found that the maximum value of cyclonic tangential wind lie between 700 and 600 hPa level within 200 km radius of storm centre and negative tangential

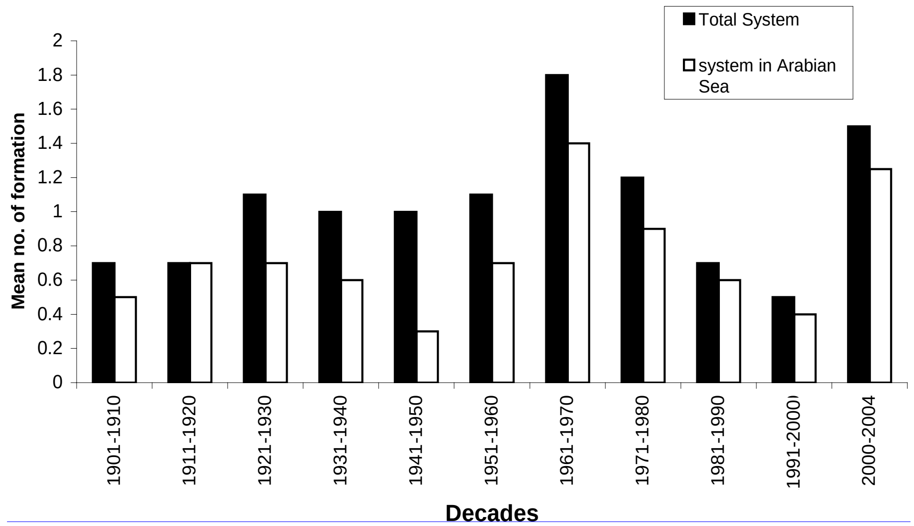
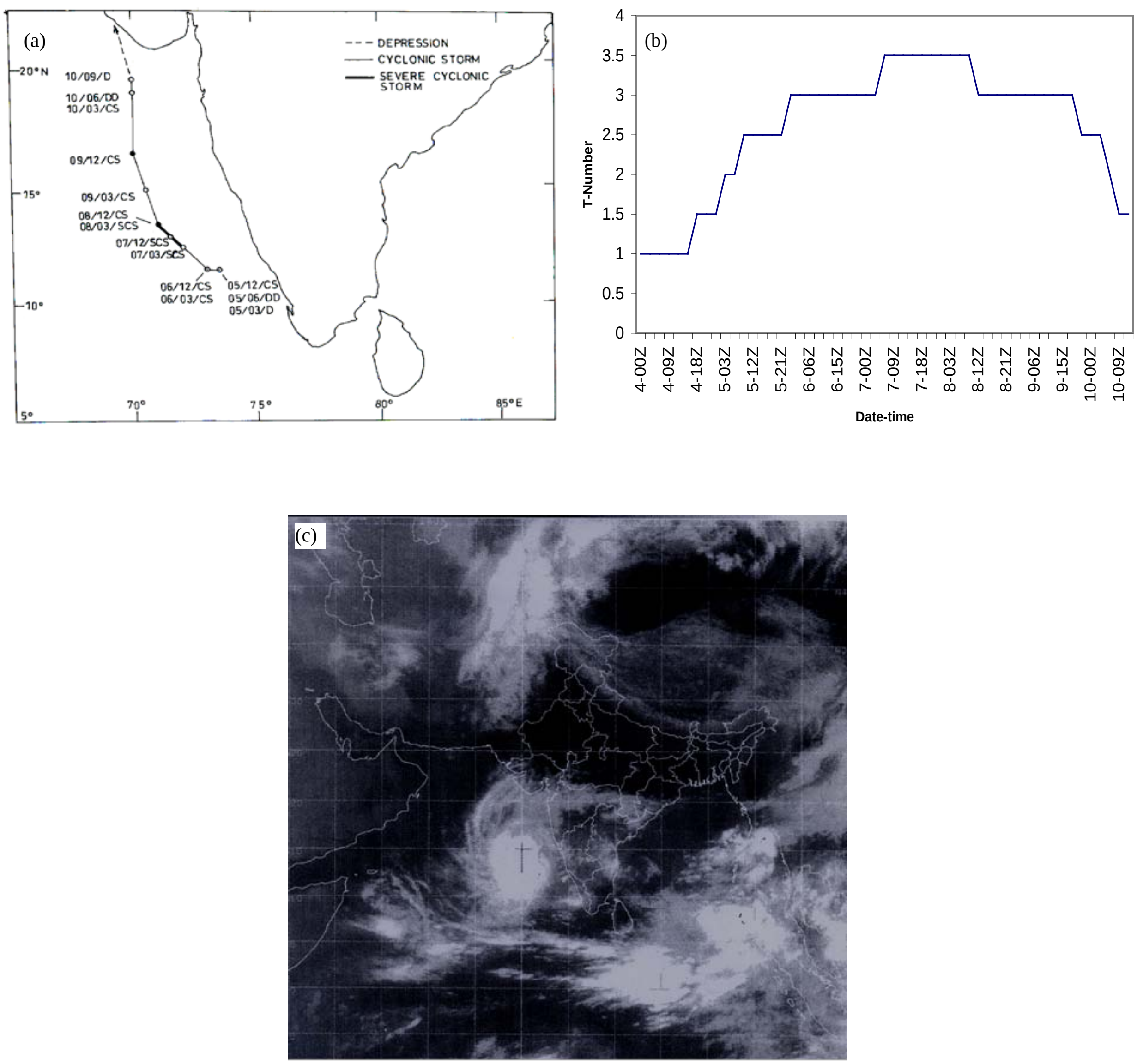


Fig. 1. Average number of cyclonic systems formed in a year in different decades in North Indian Ocean and Arabian Sea in the month of May

wind have maximum above 200 hPa level beyond 400 km radius. While studying upper air temperature of Gopalpur cyclone of 1999 Sridharan and Muthuchami (2002) found that there is a significant rise in temperature of the order of about 1.2° C at 850 hPa level and 2.6° C at 500 hPa level even after the storm crossed the coast. They further noticed that the ridgeline also moved northward along with the storm. Simon *et al*. (2003) studied the evolution of atmospheric moisture content at different levels during onset and the monsoon season and found that the initial water vapour maximum seen in the first week of May may be due to bogus onset condition(temporary onset). The wavelet analysis of model and upper level water vapour suggest the presence of 15-30 days oscillation before and during onset time. Madan and Julian (1994) found that intra seasonal oscillations involve significant modulation of SST and turbulent fluxes at the air sea interfaces. Moteki *et al*. (2004) found that when two rain bands one in the north and another in the south merged with weak northern rain band, the quasi stationary rain band intensified rapidly. Sikka and Gadgil (1980) have also discussed the tropical 30-60 day oscillation. In this paper different aspects of 5-10 May 2004 Arabian Sea severe cyclonic storm have been studied.

2. The data on the development and movement of cyclonic storms in May for the period 1971 to 1990 was collected from the Tracks of storms and depressions published by IMD (1996). For the remaining years the details were collected from ACR Reports and from the Annual Reports on Tropical Cyclones of RSMC New Delhi. Rainfall data and onset dates were collected from the weekly weather reports published by Deputy Director General of Meteorology (Weather Forecasting), Pune. Rainfall and position of the storm for May 2004 storm were collected from Area Cyclone Warning Centre Chennai. Parameters like wind shear, divergence and vorticity in the storm area were downloaded from the website of Co-operative Institute of Meteorological Satellite Service (CIMSS). The real time wind charts used in this study are taken from the analysed charts of RSMC New Delhi. The vertical velocity, convective precipitation etc. were derived from the NCEP/NCAR reanalysis of Climate Diagnostic Centre NOAA.

3.1. *Climatology of cyclonic storms in May* - Fig. 1 gives the mean number of cyclonic systems formed in a year averaged over a decade in the North Indian Ocean (NIO) and Arabian Sea during the month of May taken from Tracks of storms and depressions for the period 1901 to 1990 and for the period 1991-2004 from ACR reports and annual reports on Tropical cyclones of RSMC New Delhi. It is noticed that more number of systems formed during the period 1951 to 1980 and the least in 1990-2000 in NIO. It is further noticed that cyclonic activity is more pronounced after 1999 in Arabian Sea compared to the Bay of Bengal where it was subdued. On an average about one cyclonic system forms in NIO every year and for Arabian Sea the frequency is 0.26 About 68 % of the systems in the NIO intensify into cyclonic storm or severe cyclonic storm. However in Arabian Sea majority of systems weaken in the sea itself. The probability of a storm to weaken over Bay of Bengal is far less (7%) than that over the Arabian Sea (46%).



Figs. 2(a-c). (a) Synoptic track of 5-10 May 2004 storm and (b) T - Number of the storm from 4-10 May 2004 and (c) INSAT cloud imagery of the system at 0300 UTC on 7 May 2004

3.2. *Development of 5-10 May 2004 severe cyclonic storm* - A low-pressure area formed over southeast and adjoining areas of Bay of Bengal on 30 April and it became well marked on 1 May. It moved westward across parts of Sri Lanka, south Tamil Nadu and Comorin area, emerged into southeast Arabian Sea and Lakshadweep area and concentrated into a depression at 050300 UTC near 11.5° N / 73.5° E. Fig. 2 (a) gives the track of the storm. The storm remained practically stationary and intensified rapidly into a cyclonic storm by 5th evening. It slightly moved westward and lay centered at 060300UTC near 11.5° N / 73.0° E about 50 km northeast of Amini. It was stationary till evening. Then it moved northwestward and intensified into a severe cyclonic storm at 070300 UTC. On 8th evening it started showing sign of weakening and became cyclonic storm at 081200 UTC near 13.5° N / 71.5° E and moved north northwestward. Thereafter it moved in a northerly direction and was centered near 19.0° N / 70.0° E at 100600 UTC as Deep Depression. It further weakened into a Depression by 100900 UTC and became well marked low pressure area off Saurashtra coast on the same evening. Fig. 2 (b) gives

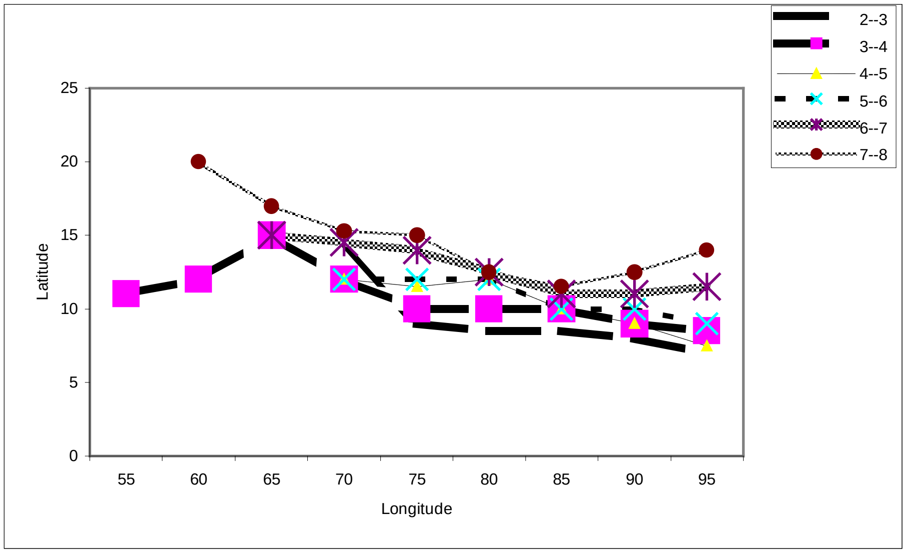


Fig. 3. Position of equatorial trough at different longitudes during storm period at 850 hPa. (*Source* : NCEP/NCAR Climate Diagnostic Centre NOAA)

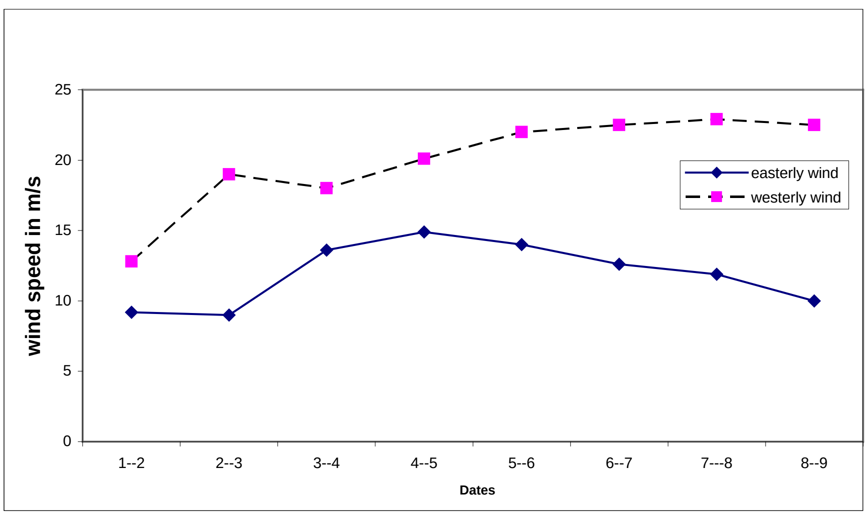


Fig. 4. Wind speed maxima of easterly and westerly flow to the north and south of the storm at 850 hPa. (*Source* : NCEP/NCAR Climate Diagnostic Centre NOAA)

the T - numbers of the storm from 4 to 10 May. The highest T - number attained by the system was T 3.5 during the period 070400 to 080900 UTC.

3.3. *Features as seen in Satellite Images* - On examining INSAT cloud imageries during the period it is observed that two bands of clouds seen on 4th merged as a single cloud mass after it emerged into Arabian Sea. The cloud band seen on the northern side of the system centre disappeared. Fig. 2 (c) gives the INSAT cloud imagery of the storm on 7 May at 0300 UTC. A circular cloud mass is seen over southeast Arabian Sea in association with this system. The cloudiness is seen not only over sea area but also over Indian land mass . The intense cloudiness is seen

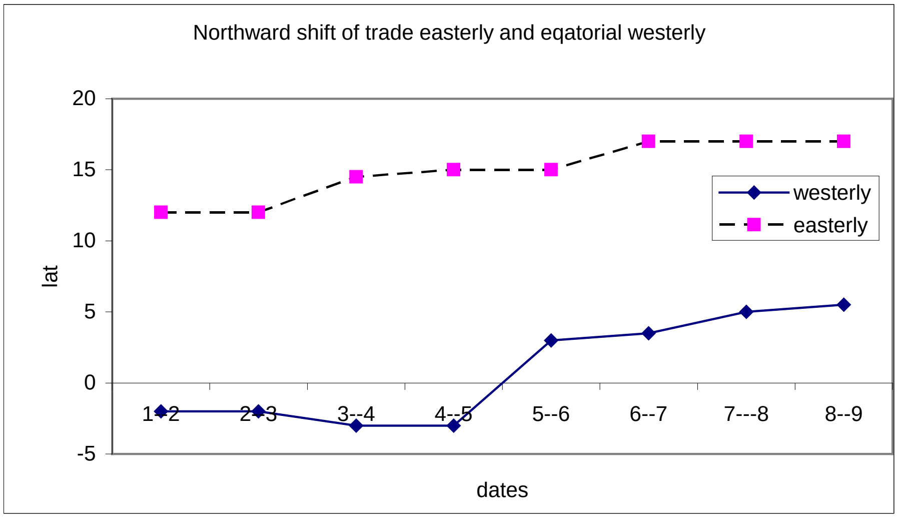


Fig. 5. Latitudinal position of wind core Maxima in westerly and easterly regime during storm period at 850 hPa (*Source* : NCEP/NCAR Climate Diagnostic Centre NOAA)

mainly over southwest quadrant of the storm as in the case of a monsoon depression. As the system moved north and weakened the cloudiness became north south oriented. By 10 May the cloud organization had weakened considerably.

3.4. *Rainfall* - The highest rainfall recorded due to this system is in Amini that received cumulative rainfall of about 181 cm in three days *viz*., 5th, 6th and 7th, which is more than annual rainfall of the station (157 cm). The highest amount of 117 cm occurred between 0300 UTC of 5 May and 0300 UTC of 6 May when the system was intensifying rapidly from depression to cyclonic storm. This is the highest rainfall recorded in any country around the NIO. The world 's highest recorded rainfall in 24 hours is 182.5 cm in 24 hours at a station named Foc-Foc in the island of La Re- Union in the south Indian Ocean when a storm passed across this island during 7-8 January 1966. In India, earlier highest recorded 24 hours rainfall is 97.4 cm at Cherrapunji in Assam on 5 June 1956 in association with a severe cyclonic storm that crossed West Bengal coast on 30 May 1956 and recurved northeastward as a depression and dissipated on 5 June. Over Lakshadweep islands Amini had the highest record of 254.2 mm on 21 November 1977 when a cyclonic storm affected the island. The island's highest recorded rainfall (213 mm) in May is in Minicoy on 23 May 1949.

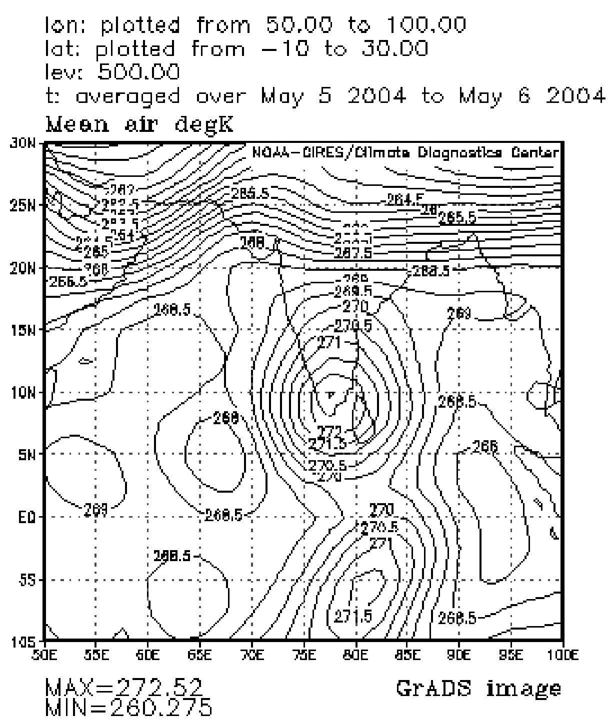
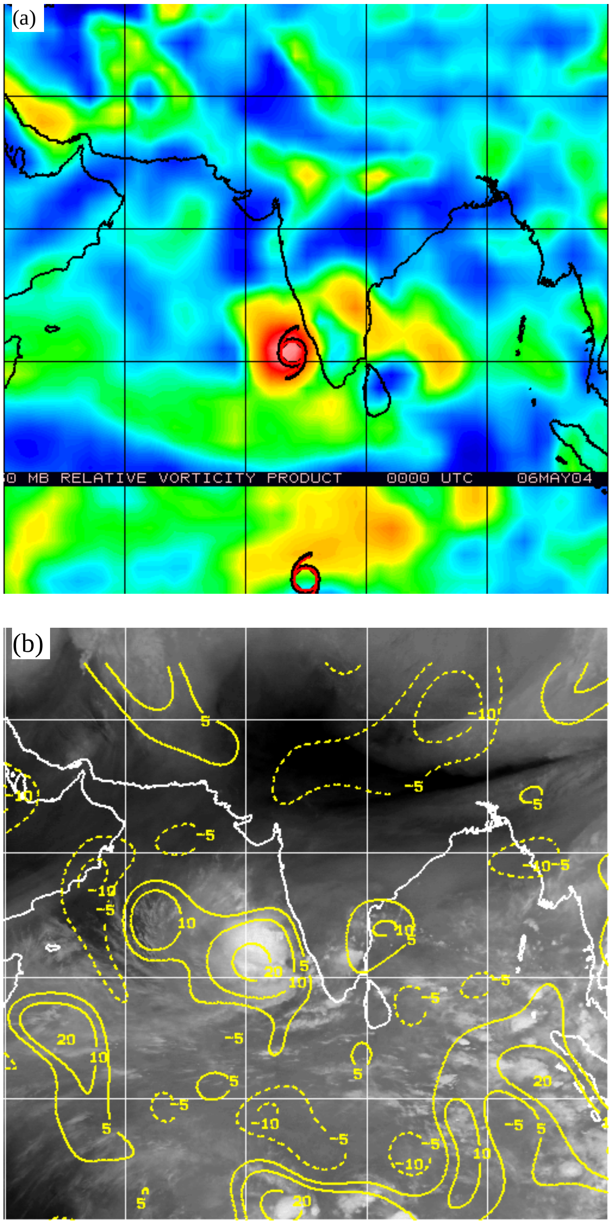


Fig. 6. Temperature distribution at 500 hPa during 5-6 May 2004



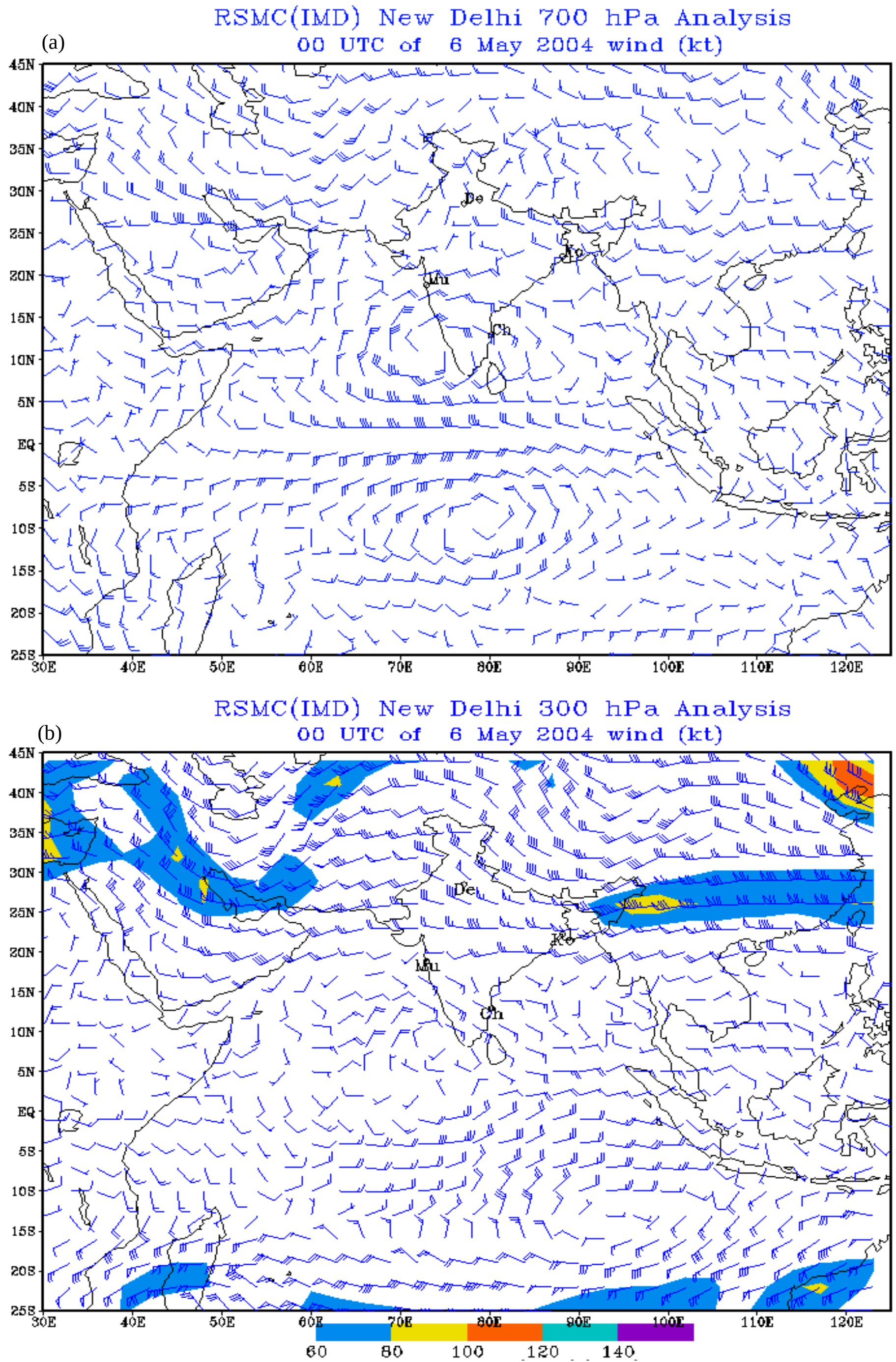
Figs. 7(a&b). (a) Upper air vorticity at 850 hPa in the storm field on 5 May and (b) Upper air divergence in the storm field on 5 May (150-300 hPa Layer Mean) (*Source* : Website of CIMSS)

3.5. *Structural aspects and movement of the storm* – Fig. 3 gives the position of equatorial trough at 850 hPa level over Indian Ocean from 2 May to 9 May. It can be seen that this trough gradually moved northward and at the northern edge of this trough, system formed as depression on 4 May. As the system moved northward the trough remained more or less at the lower level at places east of 75º E and west of this longitude trough also moved with the storm.

Fig. 4 gives the maximum wind speeds of easterly wind in the northern hemisphere and westerlies from the southern hemisphere during the cyclone period at 850 hPa level from 1 to 9 May. It can be seen that as the storm intensified, both easterlies and westerlies increased in speed. Fig. 5 shows the latitude of core of wind maxima at 850 hPa level. It is noticed that the core maxima of both winds moved northwestward as the storm moved north. The equatorial westerlies emerging from the winter hemisphere created a monsoon like situation not only over core region of cyclone but also elsewhere to the south of the system centre. After the decay of the system this flow continued to persist over south Arabian Sea and Bay of Bengal and provided sufficient moisture flux for the formation of another system in the Bay of Bengal on 16 May near 17.0° N / 91.5° E.

The temperature distribution in the storm was also studied. For this purpose the temperature averaged over two days during the storm period is computed and the location of maximum temperature is noted. It is seen that at 500 hPa level on 1-2 May the warm region (269.5°K) is located over south Arabian Sea and a cold pool (268°K) is seen over southwest Bay of Bengal. Fig. 6 gives temperature distribution in the storm field at 500 hPa level averaged on 5-6 May. When the storm is at its highest intensity the warm region is seen over land (south peninsula) with centre around 10.0° N / 77.5° E with the temperature of 272.5°K. The gradient of temperature is large and the outer most closed isotherm is 268.5°K. The next warm pool is in the southern hemisphere which is also associated with the cyclonic storm over south Indian Ocean. At the time of weakening stage warm region shifted to southwest Bay, one of the active parts of ITCZ with the temperature of 272°K. At 300 hPa level on 1-2 May the warm region is located at Tenaserim coast with temperature of 245.5°K and over the southwest Bay it is 244.5°K. At 300 hPa level when the storm is at its peak intensity the storm area has the highest temperature of 246.8°K As the storm started weakening the temperature in the storm area at 500 hPa decreased by 0.5°K and the difference in temperature between storm area and undisturbed area decreased to 3°K.

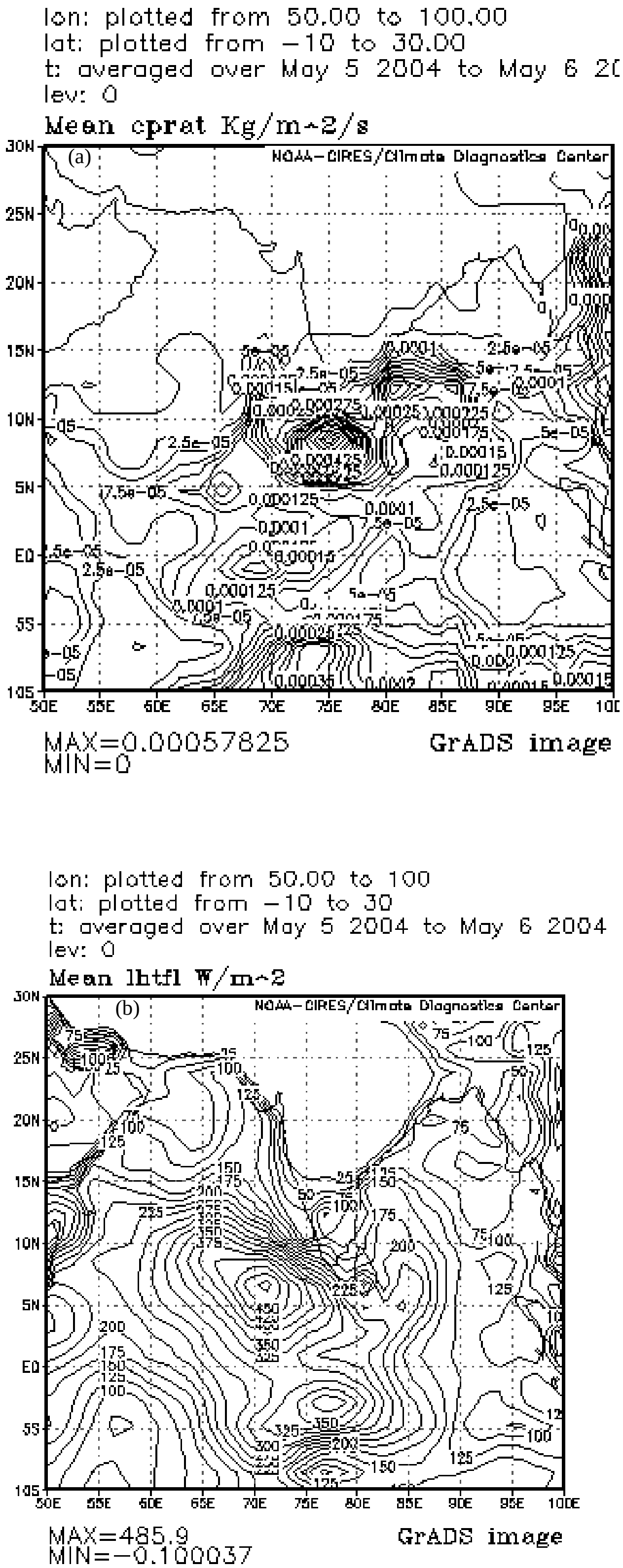
Figs. 7 (a&b) give the vorticity and divergence on 5 May. It can be seen from the figure that a core of maximum vorticity is at centre of the storm and a ridge of vorticity extends towards northwest direction. In the case of divergence the maximum divergence is seen near the centre of the storm and a ridge of divergence extends towards northwest direction on 5th when it was stationary for some time. On 4th the divergence field was seen elongated east west, which may be associated with ITCZ, with maximum over north Tamil Nadu and south Andhra Pradesh. This type of divergence created a large vertical



Figs. 8 (a&b). Approach of westerly trough in the storm area 0000 UTC of 6 May 2004

velocity over the land area of the south Peninsula and might have been responsible for good rainfall activity over Tamil Nadu, Rayalaseema and coastal Andhra Pradesh.

3.6. *Weakening of storm* - On 4th though there is a large gradient in shear at the periphery of system but very small shear is noticed in the system area which allowed the system to intensify rapidly on 4th and 5th. The zero line of the shear value also runs towards Persian Gulf, which took the system towards that direction. It is noticed that east west trough disappeared west of 70° E and the circulation became more prominent after 4th.



Figs. 9 (a&b). Convective precipitation over north Indian Ocean during 5-6 May 2004 and (b) The averaged latent heat flux in Arabian Sea during 5-6 May 2004

Figs. 8 (a&b) give the position of westerly upper air trough at 700 and 300 hPa level on 6th. It is seen that at 700 and 300 hPa level a westerly trough is seen on 6th over Iran and Iraq area. By 8th 0000 UTC the same trough after moving eastward is located just north of the system and southern end of the trough entered into the system area. The next day the westerly trough extended further south and part of the flow entered into the system area as seen from the wind pattern on 8th (not shown). This created a strong vertical wind shear over the storm area. Hence due to strong shear and incursion of dry air from the north made the system to weaken from 8th evening onwards.

Fig. 9 (a) gives the convective precipitation in the storm field during 5-6 May. It is seen that the maximum convective precipitation is seen over the southern portion of the system centre in almost all the days and the maximum is seen on 5th and 6th. The highest vertical velocity is seen during the period 050000UTC to 060000 UTC and the value of maximum convective precipitation averaged during 5-6 is 0.0005783 kg/m^2/sec and the centre of maximum convective precipitation is located at 8° N / 75° E. Amini recorded 117 cm of rainfall which is a record rainfall in a storm over NIO. The Lakshadweep island experienced abnormal weather condition during the period.

Fig. 9 (b) gives the latent heat flux in the storm field on 5- 6 May. The maximum latent heat flux is noticed on 5 and 6 May. Flux gradually decreased as the storm moved north and weakened. The large quantity of latent heat generated out of condensation produced high activity of rainfall and accelerated the system to intensify quickly by creating large vertical velocity due to buoyancy on account of strong temperature gradient. The maximum flux of latent heat in an unit area was released during 5-6 May and it is about 485.9 W/m^2 and its centre is at about 7.3° N / 72.5° E. The next day the latent heat flux reduced to 475.5 W/m^2 and the centre slightly shifted northward.

4. *Conclusions* – (*i*) The storm formed at the northwestern periphery of the ITCZ and as it moved north the ITCZ in the area other than system area did move north.

(*ii*) The system produced large quantities of rainfall in the sub-divisions of south peninsula except Telangana. At Amini the system created a record 24 hours rainfall in the country by contributing 117 cm during the period 0300 UTC of 5th to 0300 UTC of 6th.

(*iii*) As the storm intensified and moved north the wind in the maximum wind core (not the core of the storm) in respect of westerly from southern hemisphere and easterlies in north of the storm increased its speed and core also moved north. This created a monsoon like situation over NIO.

(*iv*) At 500 hPa level storm area is 5° K warmer than undisturbed area and after weakening, it is warmer by 3° K

(*v*) The vorticity, divergence and vertical motion indicated the possible direction of motion on 5th. The strong vertical wind shear created by eastward moving westerly trough induced system to weaken in the sea itself.

Acknowledgements

Authors are thankful to S/Shri M. Bharathiar and N. Selvam Draughtsmen for their assistance.

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(*17 March 2005, Modified 1 August 2006*)