

Some aspects of Bay of Bengal cyclone of 29 January to 4 February 1987

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सार — समुद्र में असामान्य उष्णकटिबंधीय चक्रवात की उत्पत्ति, तीव्रीकरण गति और क्षय का अन्वेषण करने के लिए एक उपग्रह अध्ययन किया गया। इसकी तीव्रता विश्लेषण के लिए डवोरक तकनीक का प्रयोग किया गया। उपग्रह से प्रतिबिम्ब विश्लेषण से पता चलता है कि आरंभिक उत्पत्ति का जनन गहन स्तरी संवहनी मेघ गुच्छों के मध्य अपेक्षाकृत मेघ मुक्त क्षेत्र में घटित होने वाली तिरछी विपुवतीय महोर्मियों और यांत्रिकी अवतलन द्वारा होता है। उच्च समुद्र सतह तापमान और उचित निम्नोष्णकटिबंधीय व्यवस्थापन द्वारा परवर्ती तीव्रीकरण का समर्थन किया गया। इससे पता चलता है कि अमिल की आरंभिक गति β प्रभाव और परवर्ती गति इसकी वायुमंडलीय स्टीयरिंग धारा द्वारा संचालित हुई। इसकी गति की दिशा में नये संवहनी मेघ गुच्छ वृद्धि का प्रेक्षण किया गया और गति की दिशा में परिवर्तन के दौरान इसकी गति घीमी पड़ जाती है, या कुछ समय के लिए यह स्थिर रह जाती है। इसकी तीव्र अवस्था के दौरान पश्चिमी और दक्षिण-पश्चिमी दिशा में शूक खांचे की उपस्थिति और इसके जीवन के परवर्ती भाग की ओर सहयोजित मेघ गुच्छ उत्तरी पूर्वाभिमुख के दीर्घीकरण से, उपोष्ण पश्चिमी प्रवाह के साथ इसकी बढ़ती हुई अंतरक्रिया का पता चलता है। यह अन्ततः समुद्र के ऊपर इसके क्षय की ओर ले गया, जहाँ पर समुद्र सतह तापमान भी अपेक्षाकृत कम था।

ABSTRACT. A satellite study of an unusual tropical cyclone is made to investigate its genesis, intensification, movement and the decay over sea. Dvorak technique has been applied for its intensity analysis. Satellite cloud imagery analysis indicates that initial genesis was spawned by cross equatorial surges and mechanical subsidence occurring in the relatively cloud free area between deep layer convective cloud masses. Subsequent intensification was favoured by high sea surface temperature and suitable synoptic settings. It appears that initial movement of the vortex was guided by β -effect and subsequent movement by its environmental steering current. New convective cloud mass growth was observed in the direction of its movement and during change of its direction of movement, its speed became slow or it remained stationary for some time. Presence of dry slot in western and southwestern side in its intense stage and elongation of associated cloud mass northeastwards towards the later part of its life indicate its increasing interaction with subtropical westerly flow. This finally led to its dissipation right over sea where sea surface temperature was also relatively less.

1. Introduction

Development of cyclonic storm over Bay of Bengal in the months of January and February, being the winter season, is very rare. From 1891 till date, only four cyclonic storms and one severe cyclonic storm formed over Bay of Bengal in the month of January and that too in the first half of this month and only one in early February. This was responsible for our taking the study of the Bay of Bengal cyclone of 29 January to 4 February 1987. Further this cyclone attained hurricane intensity over a good part of its life cycle. No aircraft or other conventional data were available in the storm field except the cloud imagery from INSAT-1B satellite. Of late, satellite images were being increasingly utilised for tropical cyclone analysis and forecasting. Dvorak's technique which is being applied worldwide, calls for identification of initial pattern of vortex, which can assume a number of shapes depending upon environmental conditions in which it is embedded. Tropical cyclone development is described in terms of day to day changes

in the cloud pattern of the storm and its environment. The initial formation of the vortex over south Bay of Bengal and adjoining Indian Ocean took place on 29 January 1987 and it attained the strength of a cyclonic storm (T 2.5) on 30 January. The system showed steady intensification and by 1 February, it attained the peak intensity of T 4.0, when it displayed a banding type of eye. It started weakening in the late night hours of 2 February and attained a minimum cyclonic storm intensity on 3 February morning. It dissipated completely over the sea on 4 February. Initially, it moved slightly northward and subsequently in a westerly and north-westerly direction until 00 UTC of 1 February. Thereafter it started recurving and changed its course of movement to a north/northeasterly direction. Fig. 1 shows the track of the storm. The main objective of this study is to investigate the process of its genesis, subsequent development, formation of large feeder band and banding type of eye, direction of its movement and ultimate decay over sea area using satellite imagery.

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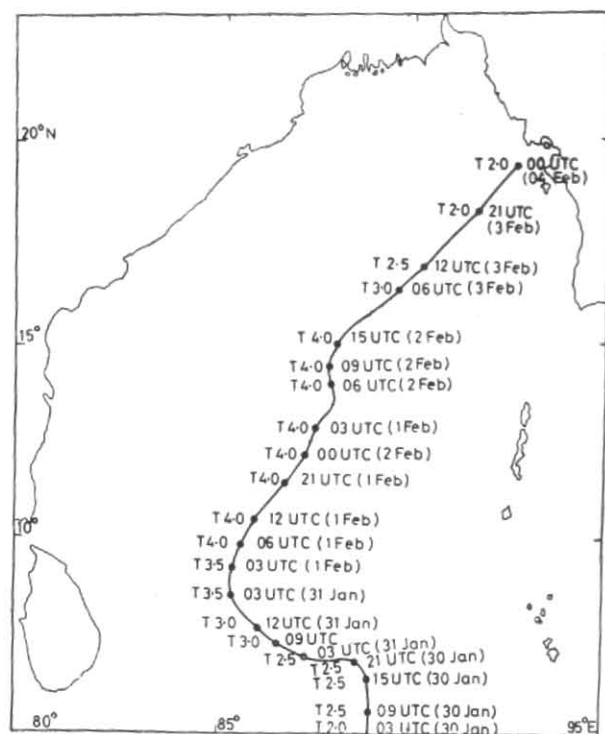


Fig. 1. Satellite track of tropical storm from 29 January to 4 February 1987

The least understood aspect of a tropical cyclone is how the relatively weak initial vortex extending through most of the troposphere is formed from a tropical disturbance with only very weak cyclonic circulation. This very early stage in tropical storm formation process is termed as 'cyclone genesis'. It goes without saying that the birth of a tropical cyclone is a significant event. By contrast, the question of cyclone intensification or growth of an already formed tropospheric cyclone is much better understood. Very few tropical disturbances or cloud clusters develop closed circulation extending through most of the troposphere. Typically their vortex circulations are confined to a shallow layer. Little tropospheric warming or surface pressure fall is observed. On the other hand, a weak cyclone which extends throughout the troposphere must, from hydrostatic consideration, possess an upper tropospheric warm core and a deep-layered central pressure decrease. This type of deep tropospheric vortex or cyclone appears to be almost as rare as the severe cyclonic storm or hurricane that forms only from this latter type of system. It is not well understood why one cloud cluster grows and another does not.

Frictional convergence appears to play a minor role in early cyclogenesis and intensification process. Direct cumulus cloud induced enthalpy changes due to condensational process, are probably too small to explain the enthalpy increases needed for initial cyclone genesis and intensification. Cumulus cloud induced enthalpy changes occur primarily as a result of clouds return flow subsidence and adiabatic compression. Cumulus convection typically produces positive enthalpy changes only in the upper troposphere, where subsidence warming is often greater than cloud re-evaporation cooling. At

lower levels cloud re-evaporation is typically as large or larger than subsidence warming and small enthalpy decreases usually occur. Thus cyclone genesis appears to require a dynamically and or mechanically forced subsidence mechanism which occurs adjacent to or between convective regions. To be effective this dynamically forced subsidence must occur in an environment of small tropospheric vertical wind shear. In addition, it is necessary that the disturbance exists in an environment of large low level horizontal wind shear.

Dynamically forced subsidence due to strong upper level convergence occurs in hurricane eye (Gray and Shea 1973) and mechanically forced subsidence occurs in mid-latitude squall lines. Such dynamically forced subsidence can be quite strong in selective situations occurring in tropics. Mechanically driven subsidence typically occurs in clear area or partially cloudy areas adjacent to region of deep convection. If sustained in conditions of weak tropospheric vertical wind shear for a period of 3-6 hours, it can result in significant concentrated local warming and pressure decrease.

In the light of these discussions, we have explained as to how the initial cyclogenesis took place in Sec. 2. Intensification of a tropical vortex is not as intriguing as its genesis. Extensive numerical modelling of cyclone intensification has already been accomplished with reasonable success. Since the size, shape and structure of satellite observed cloud pattern of tropical cyclone reveals its intensity and also indicates its direction of movement, these aspects have been discussed in Secs. 3 and 4. Finally, explanation for its rapid decay, even when it was over sea, is presented in Sec. 5.

2. Genesis

To understand the genesis of any tropical disturbance, one requires detailed information on all aspects mentioned above. Practically no information other than satellite data is available in the genesis region. Strips of infrared images from INSAT-1B from 26 to 29 January 1987, are shown in chronological order in Fig. 2 (a). This period represents the embryonic phase of the cyclone. At 00 UTC of 26 January, the Southern Hemispheric Equatorial Trough (SHET) was active around 5° S from 60° E to Sumatra island. In association with a low pressure system, a region of active and persisting convective area lay over southwest Bay of Bengal and adjoining Indian Ocean, southeast of Sri Lanka from 26th itself. The cross equatorial flow towards this low pressure began on 27 January when SHET became inactive. Though conventional data are sparse, this is supported by southwesterly flow over Sumatra and west of it as seen from 00 UTC, 850 mb chart of 27th (Fig. 3). Cloud Motion Vectors (CMVs) derived through INSAT data have also been plotted.

A weak trough in the upper air westerlies also lay off southeast coast of India. By 06 UTC of 28th, another deep convective cloud cluster developed southeast of the pre-existing system over southwest Bay of Bengal and at 1800 UTC of the same day, it is clear that curved convective cloud clusters became well organized around a comparatively clear area. On 29th this organisation steadily became more prominent, and from 09 UTC, the cloud pattern rapidly evolved into a distinct pattern of a vortex. From 09 UTC of 29th cirrus

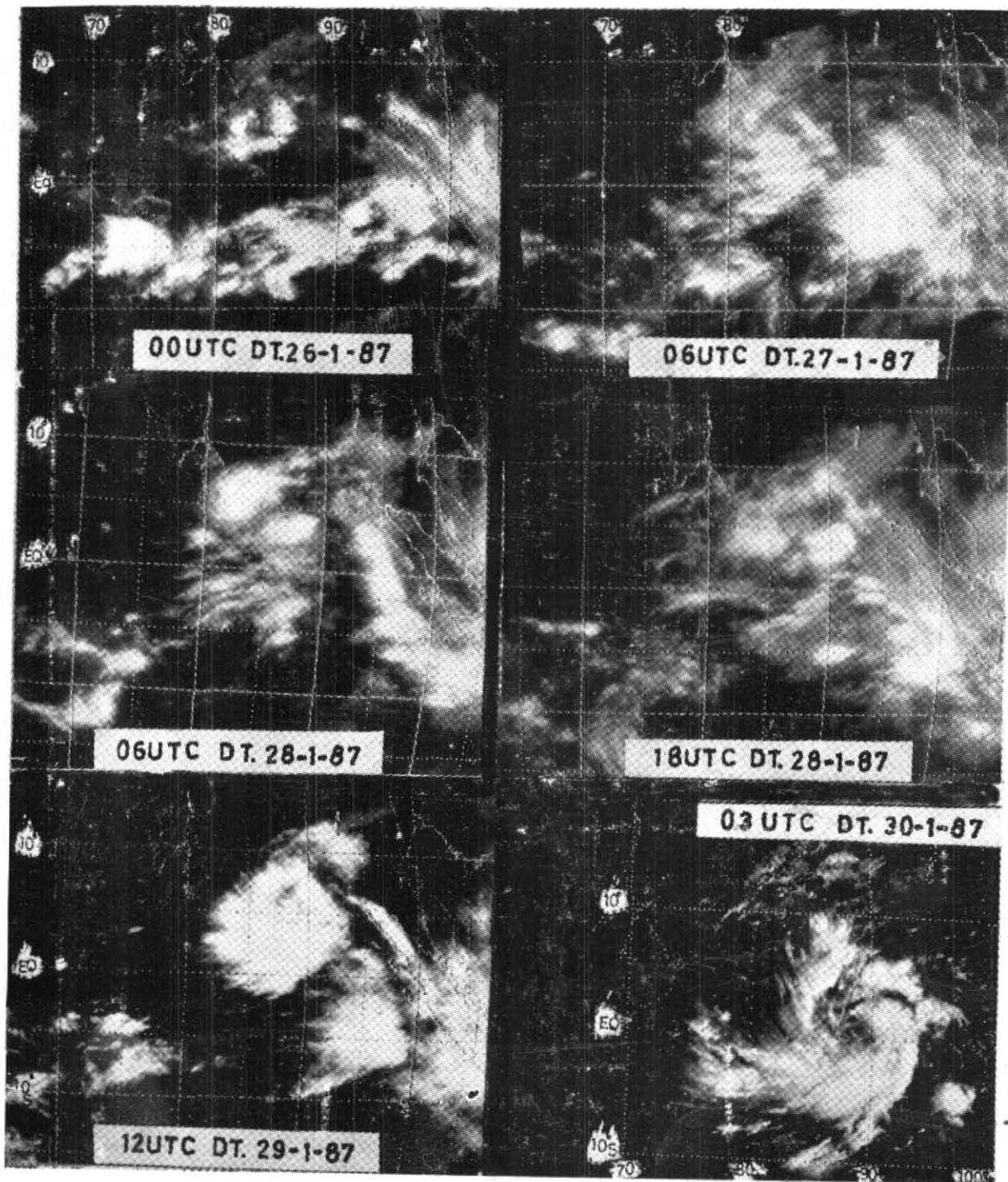


Fig. 2(a). Strips of full disc INSAT-1B IR imagery during embryonic stage

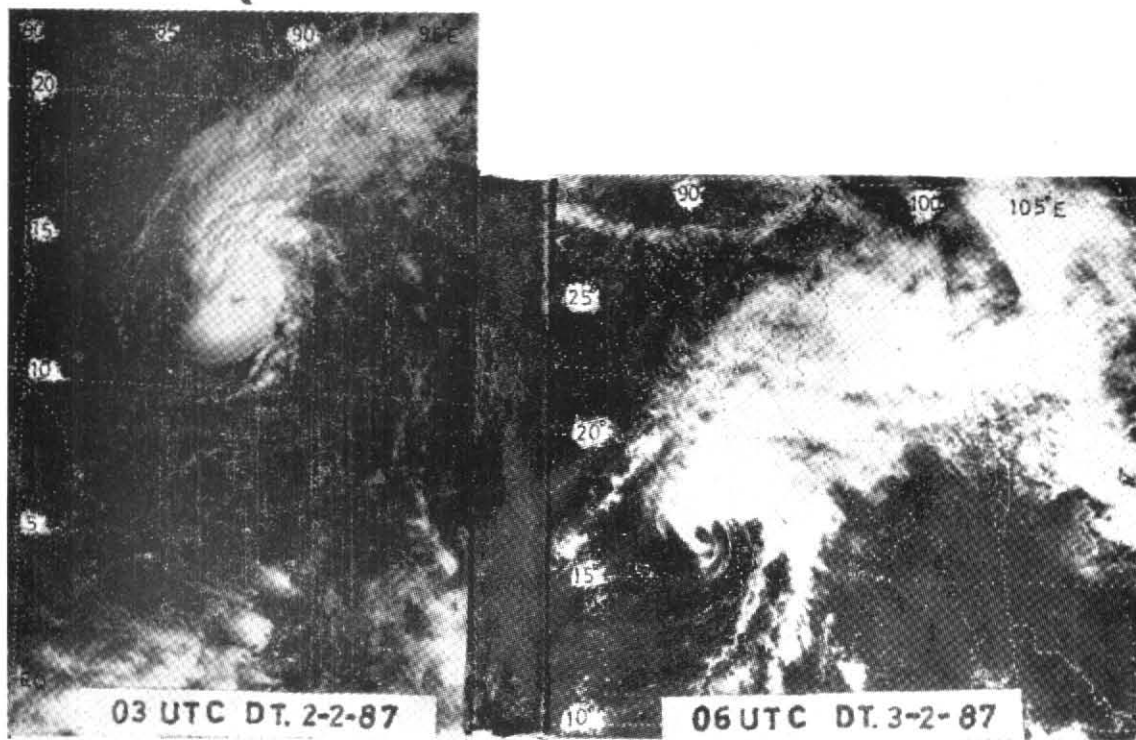
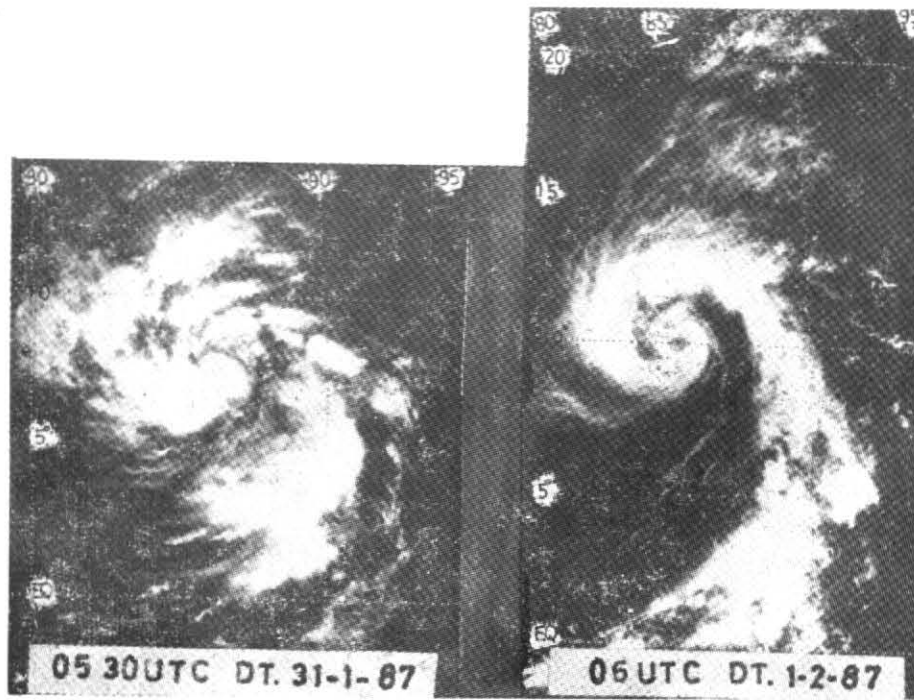


Fig. 2(b). Strips of full disc INSAT-1B VIS imagery during intensification stag.

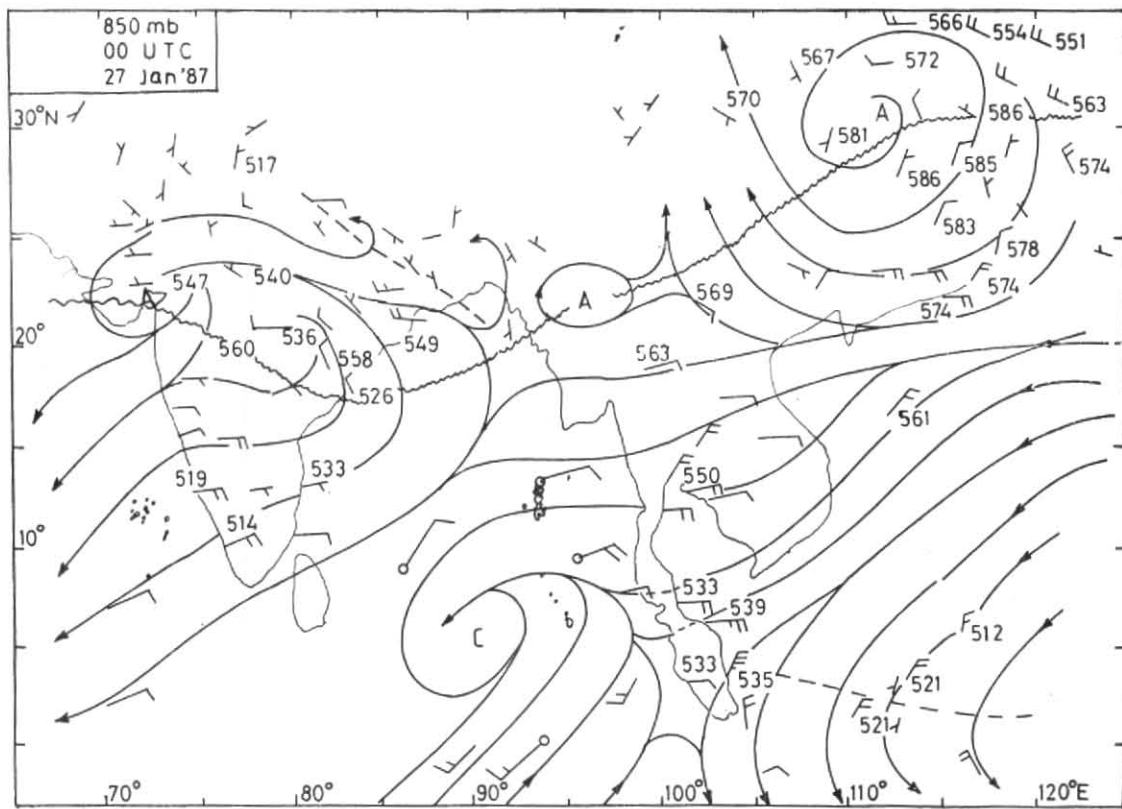


Fig. 3. 850 mb (hPa) 00 UTC of 27 January 1987

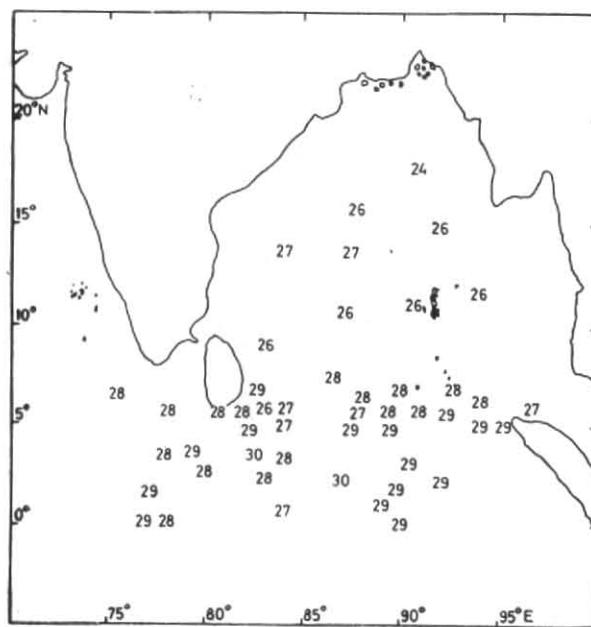


Fig. 4. Sea surface temperature ($^{\circ}$ C) over Bay of Bengal from 26 January to 5 February 1987

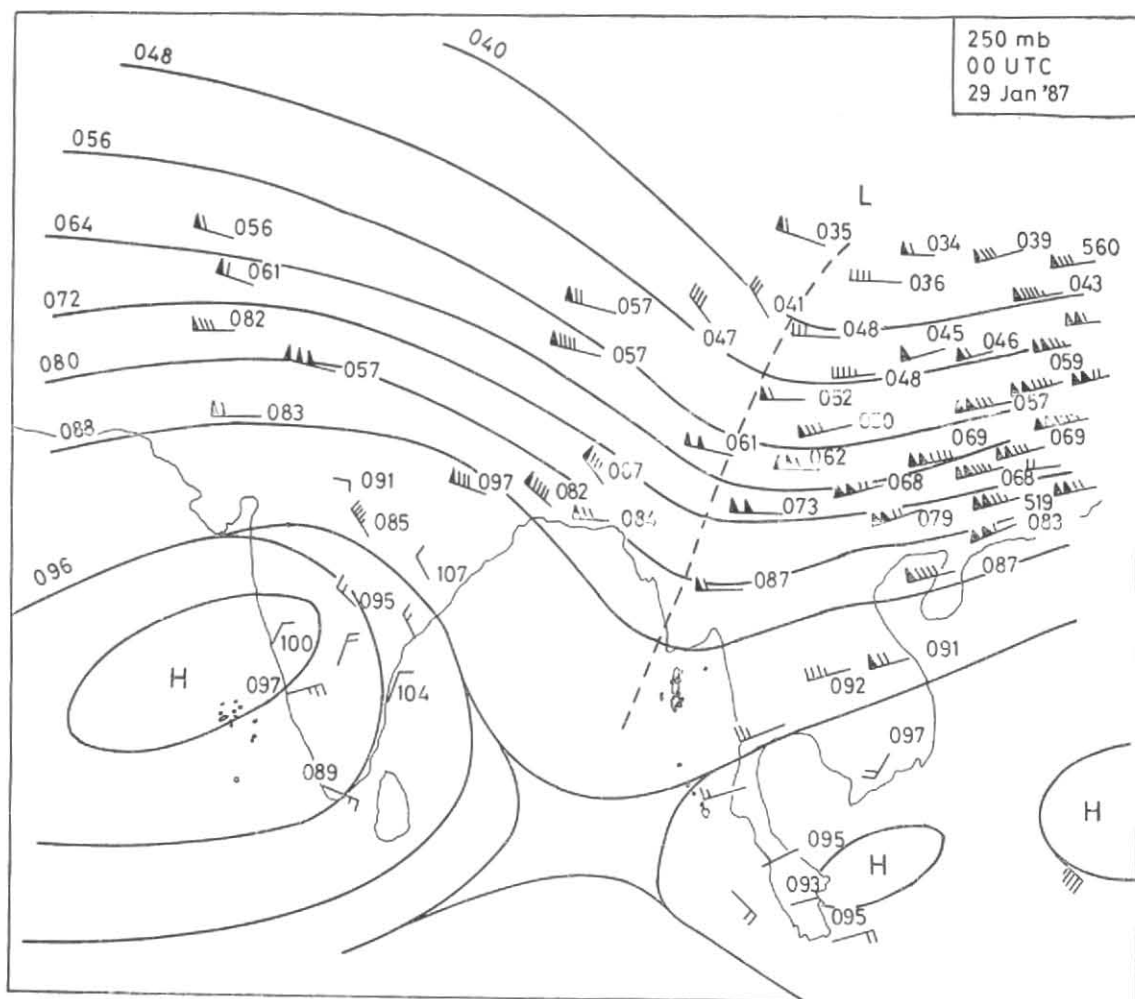


Fig. 5. 250 mb (hPa) 00 UTC of 29 January 1987

outflow was taking place from almost all quadrants from the convective clouds which indicated that the system was situated below an upper tropospheric anticyclonic flow, which is considered favourable for intensification of the vortex. Convective cloud bands and lines associated with the system were seen curving more around the centre of circulation, which became better defined on the 30 January.

The low pressure system southeast of Srilanka persisted for a longer period. The sea surface temperature in that region was of the order of 28°C (Fig. 4) and the area of low pressure system lay below upper air col region (Fig. 5). There was no large vertical wind shear and the air mass was sufficiently conditionally unstable. In spite of these favourable conditions, vortex did not

form over that low pressure system. It formed southeast of it. It is interesting to know the reasons that lead to this kind of development. A large amount of satellite cloud information on tropical disturbances of western Atlantic and Pacific indicates that the location of the centre of newly forming tropical cyclone is not typically within the disturbances active convective region (Fett 1966, Oliver and Anderson 1969, Dvorak 1975, Erickson 1977), instead the centre occurs (a) within the clear region just to the west or northeast of the convective cloud mass, (b) in the clear region between two different disturbance clusters or (c) between active convective regions in the same cluster. At 09 UTC of 29th it is clear that the genesis of the vortex falls in the category (c) above. As discussed early in the previous section, such a condition is favourable for forced subsidence in the small

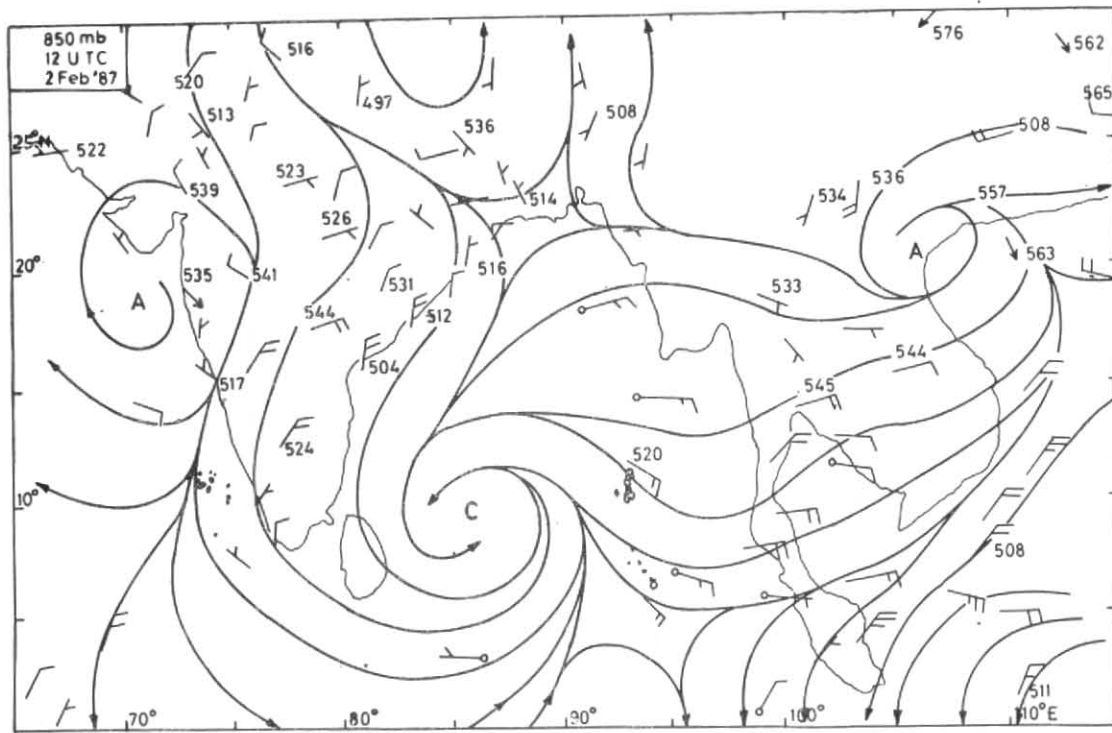


Fig. 6. 850 mb (hPa), 12 UTC of 1 February 1987

central region causing adiabatic compression and warming. This situation makes the vortex circulation extend to the upper tropospheric levels.

The increase of low level cyclonic wind shear in this case can be attributed to the 'Equatorial Burst Band surge' from the southern hemisphere in the region of pre-existing trough of low pressure. This is seen along 5° S on 26 January. A large scale flow from southern hemisphere pushes north deforming SHET on 28 January. During the pushing stage, the band can move far to the north (Anderson *et al.* 1974). At this time vortices tend to form along the ITCZ cloud band, where wind shear and cyclonic relative vorticity are greatest and this is what happened on 29 January 1987.

3. Intensification and movement

Since the depressions which develop into tropical storms usually do so within 36 hours after formation (Dvorak 1975), the system should be in an area of divergence which would enhance the outflow mechanism of developing depression, while the depression itself would be far away from jet axis to avoid excessive wind shear (Weldon 1979) Fritz *et al.* (1966) noted the importance of cloud mass location relative to the tropical wave axis or depression centre as well as the importance of

other environmental factors at this stage of development. If unfavourable thermodynamic and environmental conditions such as below normal sea surface temperature or large area of subsidence tend to persist, it would cause continued non-development of depression. The single most important criterion for development in the case is the position of the convective cloud mass relative to the depression centre, which is in the relatively cloud-free area. The high level flow pattern strongly influences the appearance of the cloud mass on the satellite pictures but the cloud mass to north/north/east of wave axis or depression and the feeder band emanating from a southerly quadrant are favourable for intensification. Fig. 2 (b) shows the satellite imagery from 30 January to 3 February 1987. From 03 UTC visible picture of 30 January, it is evident that deep layered curved convective band with inner sharp boundary formed around the system centre covering eastern and southeastern sector of the system. The radius of curvature of the inner edge was small with well defined boundaries. The system's centre was more or less cloud-free, except some low and medium clouds. Cirrus outflow was very clear from southwest to northwest sector. All these factors were indicative of development. At this time, the system was classified as T 2.0. At 06 UTC (figure not shown) convective area increased to the northwest sector of the system. Cirrus outflow extended further to the northeast sector of the system. This showed further intensification, when the intensity

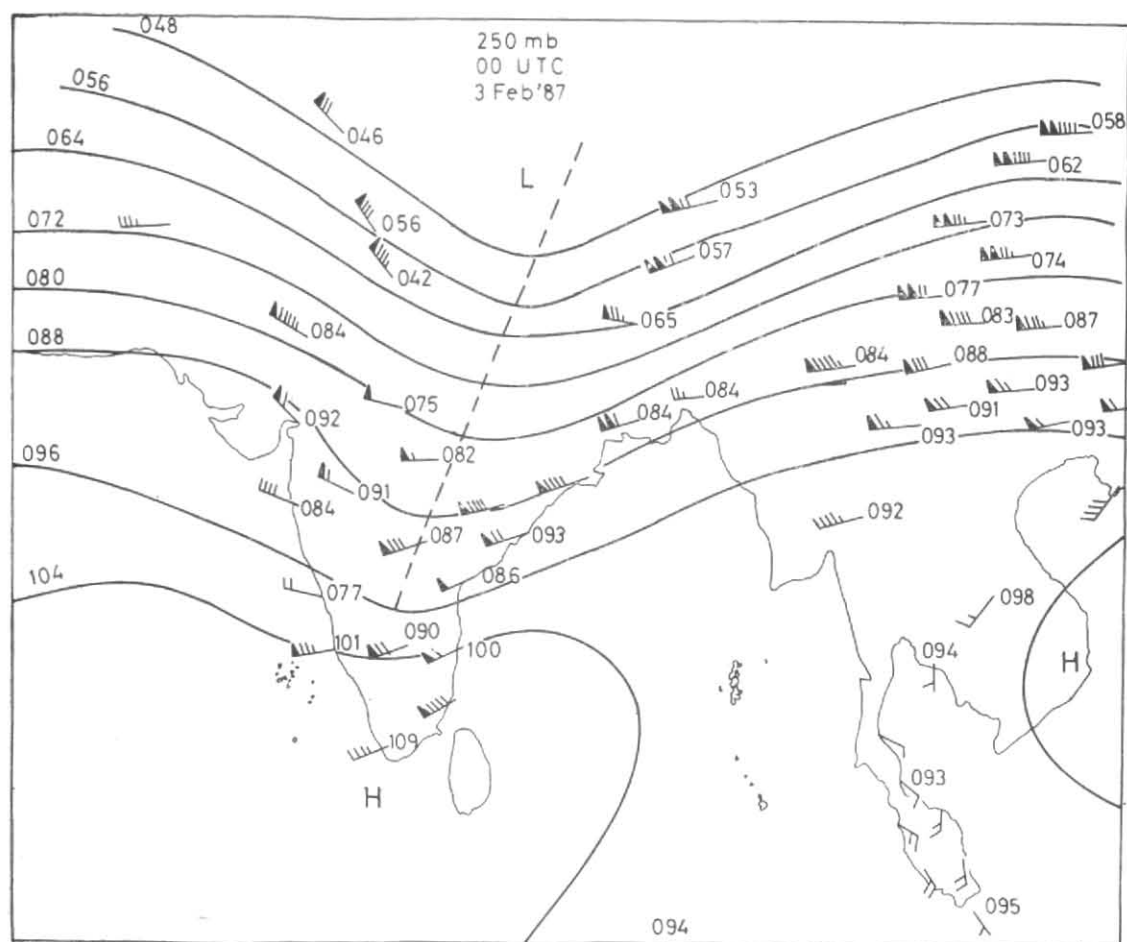


Fig. 7. 250 mb(hPa), 00 UTC of 3 February 1987

was T 2.5. The tropical storm growth as observed in changes in central pressure measurements, like that in cloud pattern does not occur in a steady manner but in surges. The amplitude of fluctuations is largest in pre-storm stage of development, which was observed in this case also.

In the initial stage, up to 12 UTC of 30 January, the vortex moved northwards and remained practically stationary for sometime before starting to move in a north-westerly direction. Between 03 and 09 UTC of 30 January a new convective area started to develop towards north-west sector of the system. New development took place in the direction to which the vortex subsequently moved and before changing the direction of movement it remained practically stationary for sometime.

After 12 UTC of 30th, the system started to move in a westerly direction. During subsequent period the vortex was situated in the upper tropospheric col region as supported by conventional chart (Fig. 5)

and the sea surface temperature in this area was of the order of 28°C enabling the vortex to intensify in a steady manner. At 0530 UTC of 31 January, it was classified as T 3.0. At 09 UTC (figure not shown) a feeder band extended from equator to the northwest sector of the system through east and northeast which is a very good sign for further development as discussed earlier. It was classified as T 3.5 at 21 UTC when the feeder band extended only up to the northern side of the system and towards western side, it became weak. This indicated that the vortex would change its course of movement from northwesterly direction to northerly direction. At 06 UTC of 1 February, a very strong and broad feeder band encircled completely around the system centre and formed a banding type of eye. At this stage it reached its peak intensity of T 4.0. From northern side, middle and high level clouds extended to northeasterly direction because of westerly flow far north. After this, it maintained its course of movement in a north-northeasterly direction and also its intensity T 4.0,

up to 21 UTC of 2 February. On 2 February, the system had a ragged type of eye embedded in deep-layered convective clouds having no prominent feeder band.

4. Comma shape cloud mass and banding type of eye

Perhaps, the most frequently observed pattern of a tropical cyclone is a comma cloud pattern which starts as a curved band as seen in the satellite imagery. The curved band pattern type is the primary development used in Dvorak 1984 technique. This pattern is observed when a storm is developing in an environment of average vertical wind shear. The evolution of comma vortex in tropical storm and its dependence on environmental flow has not been investigated extensively. Anthes and Hoke (1975) stated that nearly stationary band found in their hurricane model may be related to the confluence zone which developed in the initially circular vortex in their barotropic experiments. Apparently, the β -effect produced a preferred location where the confluence pattern can be induced. Jones (1977) hypothesized that these bands are a result of the interaction between a vortex and its environmental steering current. The work of Tuleya and Kurihara (1981) revealed that high wind side region of disturbance is favourable for the formation of the tail of comma pattern. With β -effect an amorphous depression evolves with little evidence of comma type structure in the case of easterly flows. However, for westerly winds, a more vigorous disturbance develops with a distinct comma shape.

So far as this system is concerned, the distinct comma cloud system was seen only on 31 January and 1 February, which indicates a vorticity maximum at the centre of circulation and another vorticity filament along the curved band which is also called comma tail. The relatively larger size of banding eye is controlled by the onslaught of dry air surging inside and creating a dry slot. The long tail of the comma is the feeder or the principal spiral band (Willoughby *et al.* 1984) that separates the inner core from the outer circulation and forms in the baroclinic environment. As shown in Fig. 6, the relative flow induces convergence on the upwind side of the core region to form a principal band that extends around the poleward side of the cyclone. Band development is inhibited on the divergent down wind side of the cyclone core.

5. Weakening and dissipation over sea

The first indication of weakening of this storm became evident at 03 UTC of 2 February, when the convection got eroded to the west of the centre and the

centre and the feeder band got cut-off. Due to the westerly jet stream north of the system, the cirrus extended far northeast over north Burma. With the passage of time, the cloud pattern also got deformed northeastward suggesting its increasing interaction with upper air westerly flow and northeast movement (Fig. 7). Finally, since the sea surface temperatures over Bay decreased appreciably from south to the north, all these unfavourable factors finally led to its complete decay right over sea by 4 February.

6. Conclusions

Following conclusions can be drawn from this study:

(i) Equatorial burst band surge from the southern hemisphere into a pre-existing low pressure area increased cyclonic shear which led to enhanced convection.

Mechanically and dynamically induced subsidence aloft from convective cloud tops led to compressional heating over a localized comparatively cloud-free area which favoured the vortex to extend to middle and upper troposphere thus leading to initial cyclogenesis.

Genesis was also favoured by weak vertical wind shear and warm sea surface temperature.

(ii) Further intensification was favoured by suitable upper air conditions, warm sea surface temperature and by the high energy air fed into the storm's circulation along the feeder band from equator.

(iii) New convective cloud mass growth was observed in the direction of the movement and before recurving or changing its direction of movement, the speed of movement became slow or it remained stationary for some time.

(iv) The changes in the shape of cloud pattern are highly correlated with the change in the direction of movement and gave good signals for its movement.

(v) Deformation of cloud pattern towards its end suggested its increased interaction with the westerlies and dry and cold air penetration into the cloud are a leading to its rapid decay. Low sea surface temperature also might be one of the causes for its rapid weakening right over the sea.

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