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On the development of the cyclonic storms and their rainbands during October-December 1987

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सार — लेखक ने 1987 की मानसूनोत्तर ऋतु के दौरान बने चार चक्रवातीय तूफानों का अध्ययन किया है। सभी प्रणालियां एक समान वायुमंडलीय व्यवस्था में बनी जिनके परिणामस्वरूप पोषक मेघ बैंडों का विकास हुआ।

ABSTRACT. The author has studied four cyclonic storms that formed during the post monsoon season of 1987. All the systems developed in similar atmospheric settings leading to the development of feeder cloud bands.

1. Introduction

In 1987 four depressions/cyclonic storms developed between October and December. Their life history and tracks are shown in Fig. 1. All developed under similar atmospheric settings. Their development leads us to explain the formation of feeder bands associated with cyclonic storms. These cyclonic storms developed in the Bay of Bengal close to the coast. The land observations over India and INSAT-1B satellite imageries were used to study their development. A few selected charts and satellite imageries were used to explain the transition that took place in atmospheric circulation and the development of the cyclonic storms and their feeder bands.

2. Cyclonic storm of 13-19 October 1987

A cyclonic circulation extending up to the mid-troposphere was observed over north Andaman Sea on 10 October. It was embedded in an east-west equatorial trough up to 3.6 km. It descended to form a low pressure area over the Andaman and Nicobar Islands and their neighbourhood on 13 October. This happened when an upper air westerly trough was located along 75° E between 500 and 200 hPa. Moving westwards, the low pressure area concentrated into a depression over central and adjoining south Bay on 14th. At this hour, a cyclonic circulation was seen over the Arabian Sea, embedded in the equatorial trough at 0.9 km a.s.l. This circulation disappeared at 12 UTC when the northerlies around the anticyclone swept across the Indian subcontinent between 0.6 and 4.5 km a.s.l. (Fig. 2). The cloudiness over the Arabian Sea began to dissolve at its northern fringes, but later reorganised itself into a curved band, feeding the Bay of Bengal depression. The warm moist southerlies to the east, and cold and dry northerlies to the west provided a baroclinic atmosphere that was conducive for the intensification of depression. The southerly feed to the depression subsequently strengthened and seemed to merge with the air from the northeast, forming a northeast-southwest oriented feeder band. The depression moved northwestward and intensified into a cyclonic storm over west central Bay centred at 0300 UTC of 15 October near 14° N, 84° E. At 850 hPa with the sweep of northerlies, the temperatures had fallen by 2° to 4° C over Peninsular India between 00 UTC of 14 October and 00 UTC of 15 October.

The NE-SW band was intense. Sometimes we had the impression that two cyclonic centres are present close to each other. This could be due to the presence of a secondary vortex at 12 UTC on 14th at 0.9 km, and its subsequent merger with the main vortex. The cirrus outflow bands emanated from the southern portion of the storm and extended 5° to 10° ahead of the storm between 12° N and 28° N. This was in response to an upper air westerly trough along 70° E at 00 UTC of 15th. The westerly trough in turn retrogressed, deepened and extended further south to 8° N in response to this outflow. The cyclonic storm moved northwestward, crossed the south Andhra coast on the morning of 16th and weakened into a depression. The moist southerlies swept the country in its wake extending right up to Jammu & Kashmir and gave widespread rainfall throughout India. The system became unimportant at 12 UTC of 19th.

3. Cyclonic storm of 30 October to 4 November 1987

In Fig. 3 an east-west oriented equatorial trough with two embedded cyclonic circulations, one over southwest Bay off Sri Lanka & south Tamil Nadu and another over the Maldives-Lakshadweep area was observed

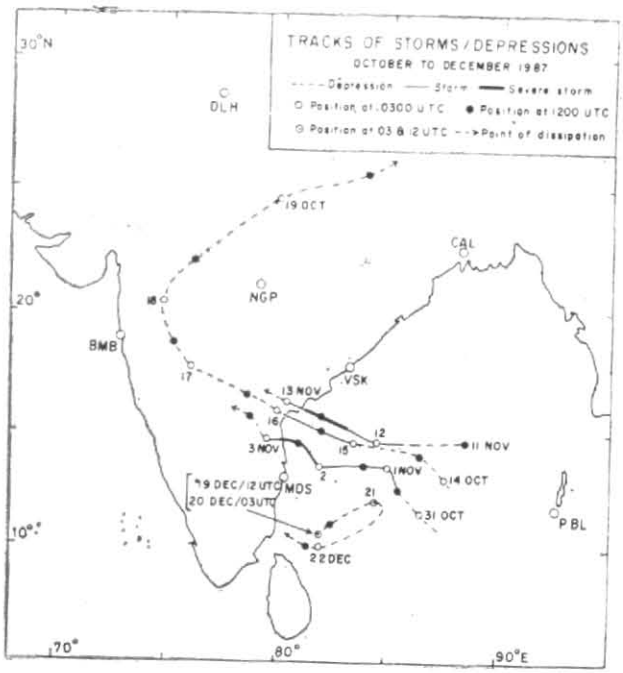

Fig. 1. Life history and tracks of cyclonic storms/depressions during October-December 1987

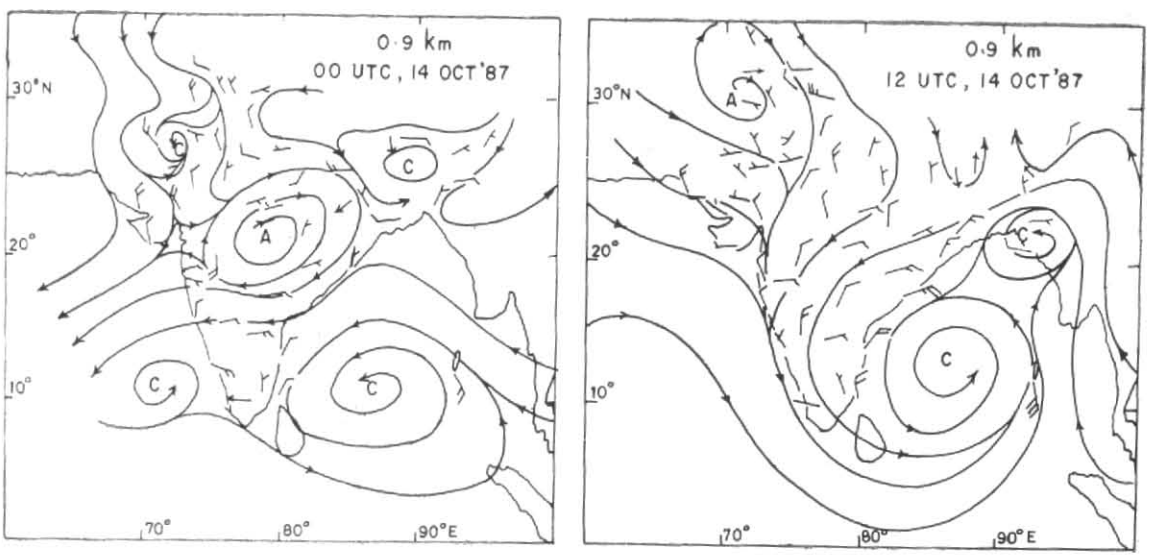

Fig. 2. Change in circulation at 0.9 km a.s.l. leading to the development of a depression on 14 October 1987

on 850 hPa at 00 UTC of 29 October 1987. The winds to the north of this trough consist of tropical maritime easterlies. However, at 00 UTC of 30 October, these easterlies were replaced by continental northeasterlies around the subtropical anticyclone over Gujarat and neighbourhood. The temperatures fell over Peninsular India with the sweep of these northeasterlies. The warm moist southerlies over the south Bay of Bengal and cold dry northeasterlies or northerlies over Peninsular India provided a baroclinic atmosphere to the east and west of the Bay circulation. As a result, a low pressure area developed over south central Bay on 30 October. The baroclinic contrast increased on 31 October leading to the intensification of the system into a cyclonic storm. Moving westwards it further intensified into a severe cyclonic storm on 2 November. Thereafter, moving westnorthwestward, the system crossed south Andhra coast around 00 UTC of 3 November.

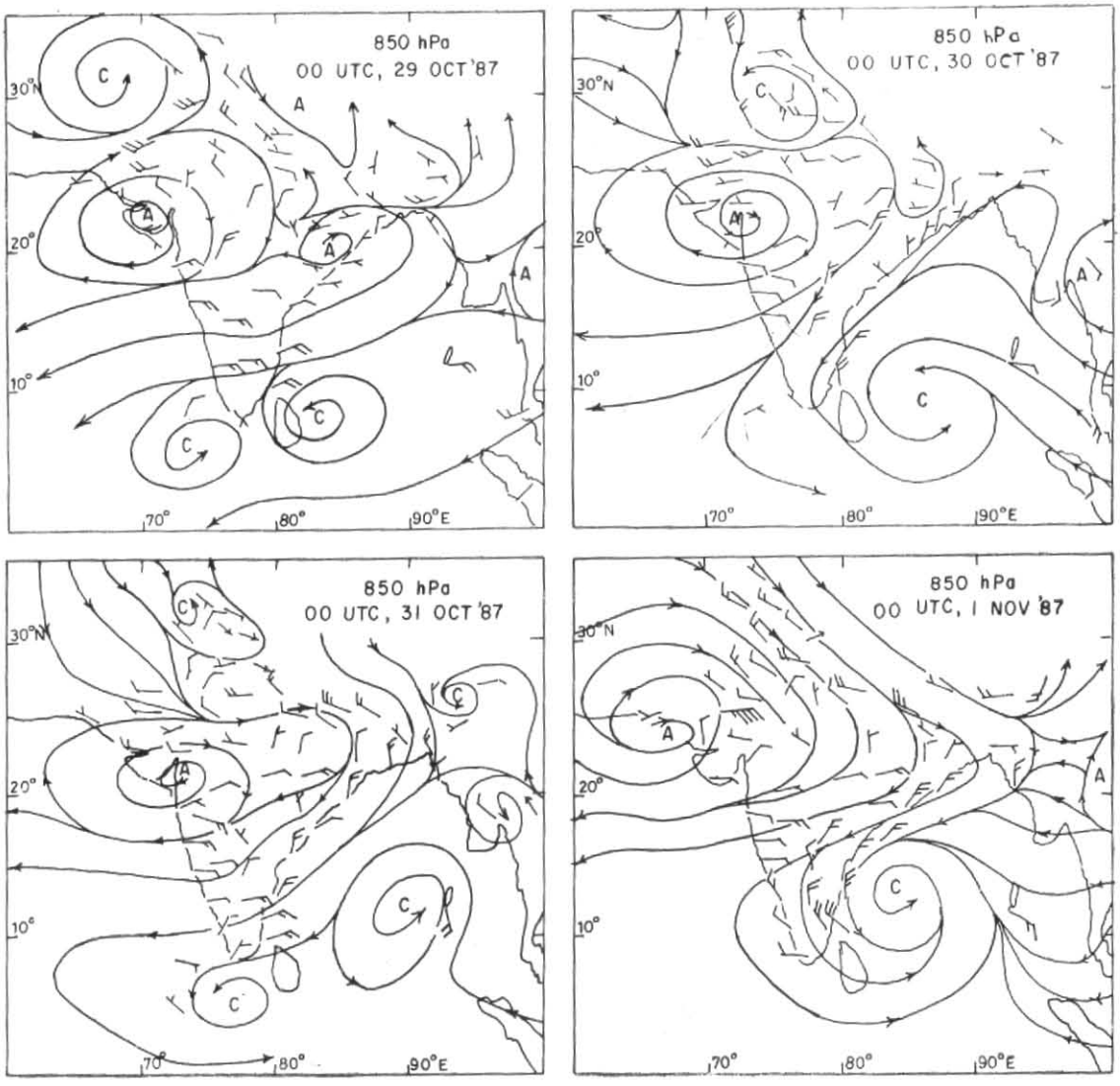

Fig. 3. Change in circulation at 850 hPa leading to the development of a cyclonic storm on 31 October and a severe cyclonic storm on 1 November 1987

In Fig. 6, on the satellite pictures the cloudiness was aligned east-west on 30 October. Two types of feeder bands were observed for this cyclonic storm on 31 October : (1) bands from the northeast generated from the cyclonic recurvature of southerlies over the Bay of Bengal and (2) the curved feeder bands from the Arabian Sea which merged with the cyclonic storm from the south. They developed in the baroclinic environment provided by moist westerlies to the south and dry northeasterlies to the north. This change in the field of cloudiness was observed in the southward displacement of the Lakshadweep cyclonic circulation at 850 hPa on 00 UTC of 31 October.

The outflow cirrus bands on 2 November were observed to emanate from the south of the cyclonic storm. They extended in the shape of an anticyclonic arc 5° ahead of the storm between 12° N and 28° N. This was in response to the upper air westerly trough. This trough in turn deepened and the southwesterlies strengthened. After crossing the coast on 3rd morning the system successively weakened into a cyclonic storm, a depression and a well marked low pressure area over north interior Karnataka and neighbourhood by 4th morning. This system was responsible for the advent of northeast monsoon rain over Tamil Nadu on 30 October. The low emerged into east central Arabian Sea on 5th and lay off Konkan and Goa coast. It moved away westward by 6th.

4. Cyclonic storm of 9-14 November 1987

In Fig. 4 three cyclonic circulations were observed at 700 hPa level on 11 November: one over the south-east Bay and Andaman Sea, the second off Tamil Nadu

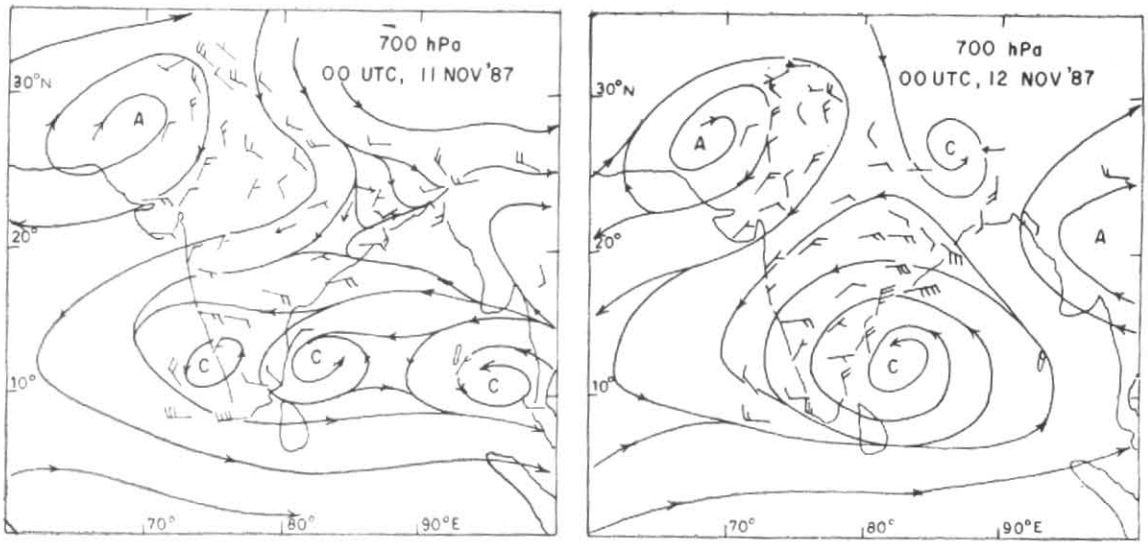

Fig. 4. Change in circulation at 700 hPa leading to the development of a cyclonic storm on 12 November

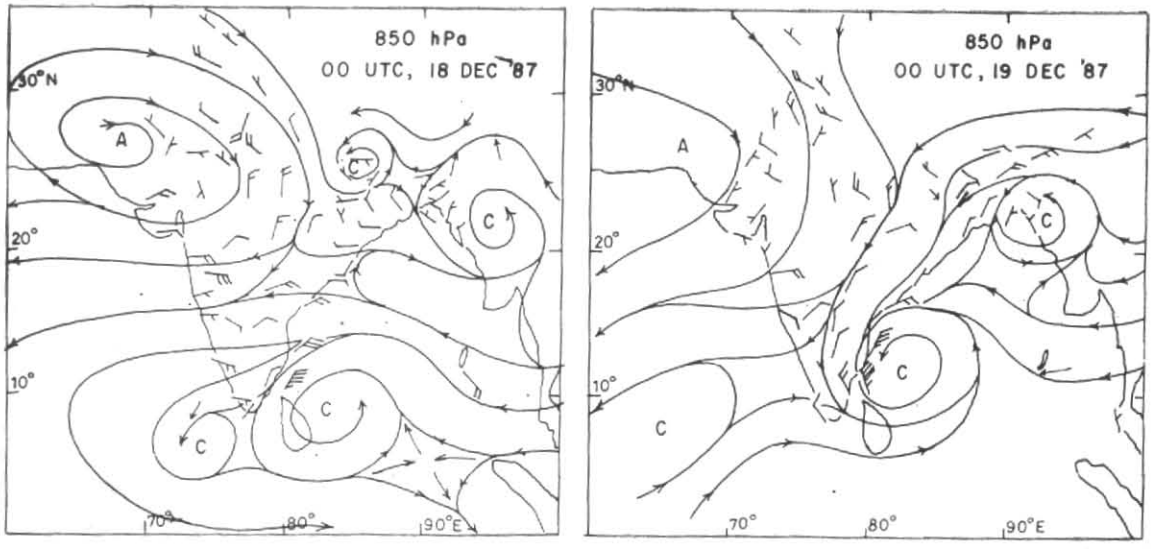

Fig. 5. Change in circulation at 850 leading to the development of a depression on 19 December 1987

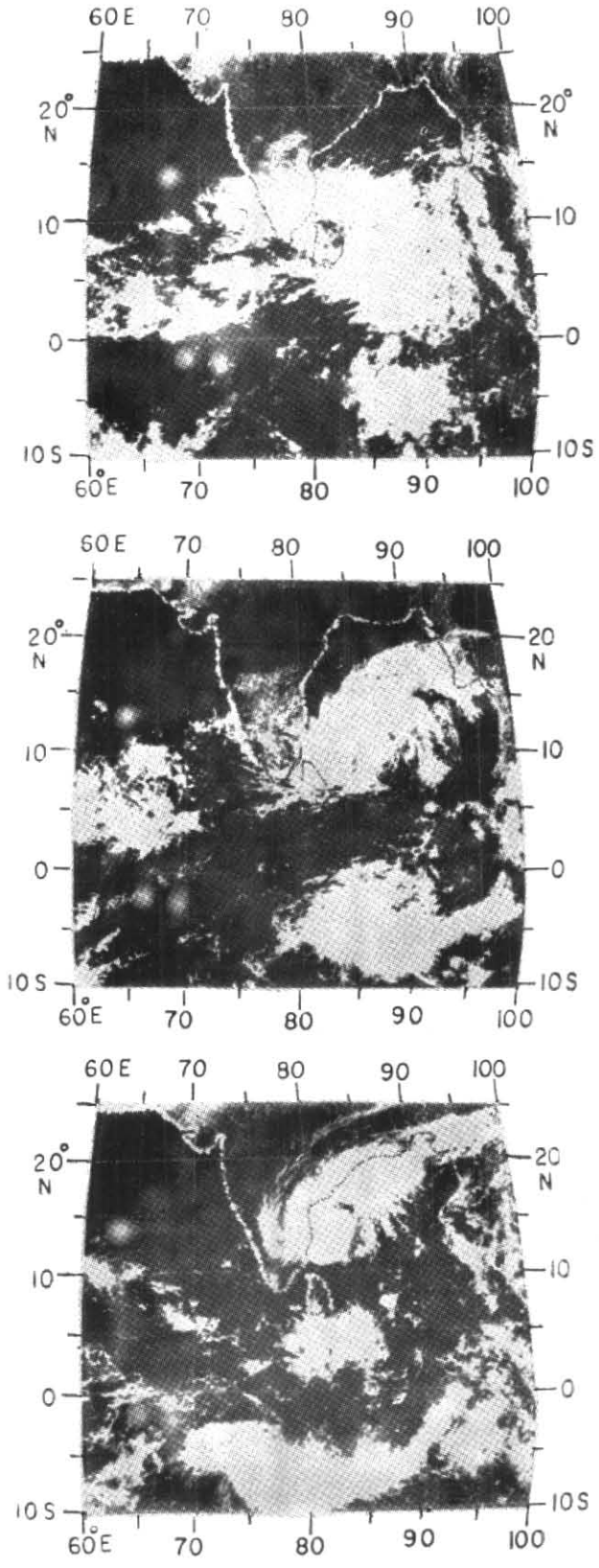

Fig. 6. Satellite cloud imageries depicting the development of a cyclonic storm and the associated rainbands on 30 and 31 October and severe cyclonic storm on 2 November 1987

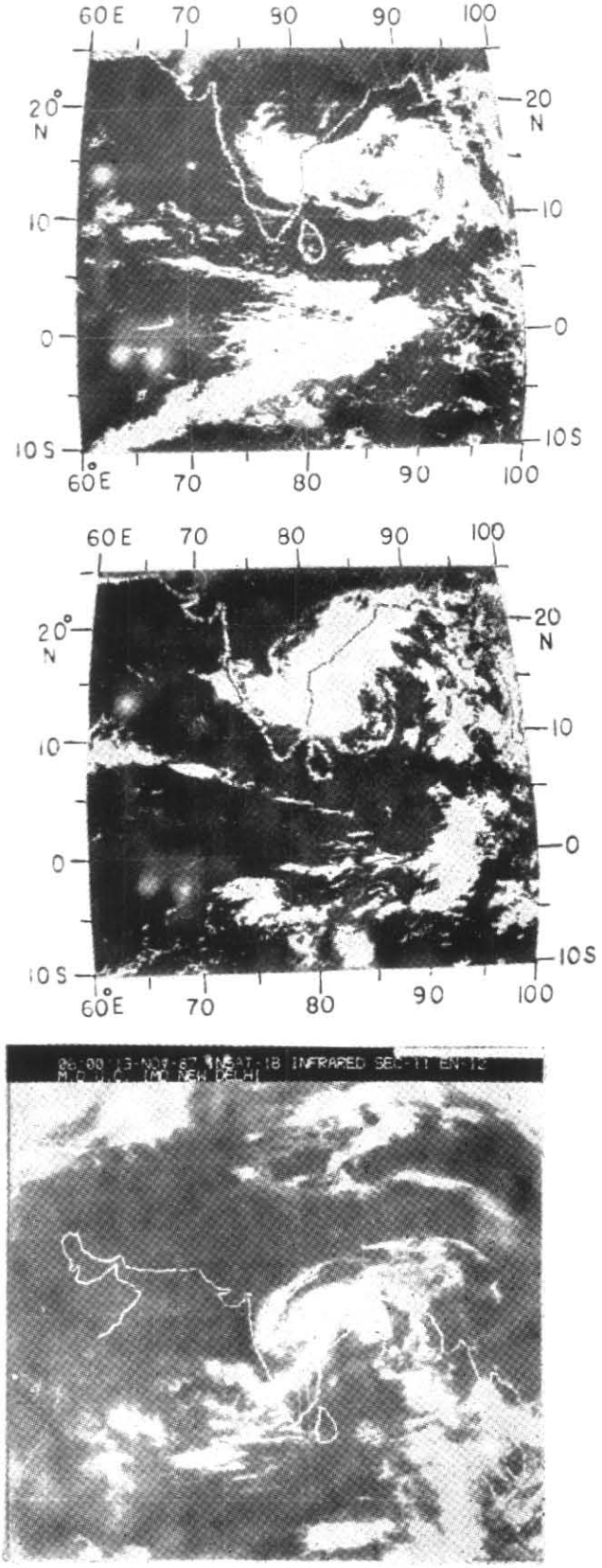

Fig. 7. Satellite cloud imageries depicting the development of a cyclonic storm and the associated rainbands on 11-12 November and outflow bands on 13 November

coast and the third over east central Arabian Sea and coastal Karnataka. Of these circulations the first one was associated with a low pressure area on sea level. This low rapidly concentrated into a deep depression in the afternoon of 11 November over central and adjoining southeast Bay. In Fig. 7 on the satellite imagery at 06 UTC of 11 November the cloud bands from SH and the Arabian Sea converge towards the eastern cluster in the Bay of Bengal.

The system intensified into a cyclonic storm in the early hours of 12 November, when the cloud patch associated with the depression and the cloud patch off Tamil Nadu coast merged and lay at 0600 UTC over west central Bay. At 00 UTC of 12 November the cyclonic circulation over east central Arabian Sea and adjoining central Karnataka became less marked. This coincided with the appearance of northerlies over Peninsular India. These northerlies were of mixed origin; namely, (*i*) continental northerlies coming around the subtropical anticyclone over Gujarat and neighbourhood and (*ii*) maritime northeasterlies forming part of the circulation around the cyclone. This suggests that the intensification of the cyclonic storm took place in a baroclinic atmosphere similar to the two earlier cases. On the satellite imagery, the feed from the southern hemisphere extends deep northward into the Bay of Bengal, recurves cyclonically and develops into the feeder bands for the cyclonic storm in its northeast sector. The feeder bands over the Arabian Sea have developed in the presence of continental northerlies. The system intensified further into a severe cyclonic storm in the evening of 12 November. It crossed south Andhra coast near Machilipatnam in the morning of 13th and weakened into a depression. On the infrared satellite imagery at 06 UTC of 13th, outflow bands are seen emerging from the southern portion of the storm. They extend both northeast and southward suggestive of rapid dissipation into a low pressure area on 14th morning. It became insignificant by the 14th evening.

5. Depression of 13-23 December 1987

An east-west equatorial trough can be seen at 850 and 700 hPa at 00 UTC of 16, 17, 18 & 19 December. On 16, 17 and 18 December the flow to the north of this trough is mainly easterly of tropical origin. The Bay system was a well marked low pressure area at mean sea level on these days. On 19 December the flow over Peninsular India is mainly northerly of mid-latitude origin (Fig. 5). Subsequently the Bay system concentrated into a depression over southwest Bay on the evening of the 19th. The baroclinic environment was similar to those discussed for the earlier systems. At this time the depression came under the influence of a mid-latitude upper air westerly trough, and as a result recurved and began moving eastward. It further intensified into a deep depression on the evening of 21st. On the satellite imageries the cloudiness was aligned east-west on 16 December. On 19 December the bands converging into the depression from northeast over the Bay of Bengal and from the south over the Arabian Sea showed a structure similar to the ones discussed in the first three cases. After the mid-latitude westerly trough moved off eastward its influence ended and the system began moving westward. It weakened into a depression on 22nd. Moving further westward it crossed Tamil Nadu coast near Nagapatinam in the morning of 23rd and weakened into a low pressure area over Tamil Nadu.

6. Discussion and conclusions

We have studied four depressions/cyclonic storms that formed in the Bay of Bengal during the post monsoon season of 1987. We discussed the development of cloud bands which formed around them. All the four formed (1) by concentration of existing systems embedded in east-west oriented equatorial troughs and (2) at the time of their concentration into depressions or cyclonic storms, the warm maritime southerlies, with their origin in the southern hemisphere, extended deep into the northerly latitudes to the east of these systems. The development of convective clouds and release of latent heat during the northward traverse of these southerlies warm them further. The appearance of northerlies over Peninsular India took place around the subtropical anticyclone over Gujarat and neighbourhood. The cold continental northerlies extended deep into the equatorial latitudes to their west. This provided the baroclinic atmosphere needed for the development of these systems.

The cyclonic cloud bands developed over northeast and the southwest sectors of the cyclonic storms. From satellite data on cloud top temperatures, the convection in the northeastern band was well organised and intense. Its intensity was next to convection in the wall cloud region of the cyclonic storm (Barnes and Stossmeister 1986). This happened because the southerlies in the lower tropospheric levels traversed northward leading to an increase in the Coriolis parameter (f). When these southerlies recurved cyclonically to merge with the cyclonic storm their relative vorticity (ζ) also increased.

For adiabatic motion, the potential vorticity of a given parcel of air is conserved in the absence of friction. We put :

$$(\zeta + f)\frac{\partial \theta}{\partial p} = \text{Constant} \qquad (1)$$

From Eqn. (1) we see that the static stability ($\partial\theta/\partial p$) must change in a sense opposite to the absolute vorticity. Thus, for an increase of ($\zeta + f$) in the northeast sector of the cyclonic storm, the parcel of air becomes increasingly unstable (Krishnamurti 1987). This leads to strong vertical motion and release of greater latent heat, increased moisture convergence and intensification of convective feeder bands. This also suggests that the maximum inflow into the cyclonic storms took place in their northeast sector. The feeder bands in the southwest sector were relatively weak and were composed of medium clouds.

The outflow of cirrus clouds, which was observed 5° to 10° ahead of the cyclonic storm in their mature stage, emerged in the southwest sector of the cyclonic storm. This may be in response to the maximum inflow in the northeast sector. The outflow of cirrus was responsible for strengthening of westerlies and deepening of westerly troughs to the north of the cyclonic storms. It also helped the strengthening of easterlies and the formation of easterly troughs to their south (Singh 1985, 1987). The deepening of westerly troughs may in turn be responsible for the recurvature of cyclonic storms.

The maximum outflow was observed when the cyclonic storms crossed the coast and started dissipating. The increased outflow was due to the increased frictional convergence in the lower levels and less vertical motion after landfall. The dissipation starts due to the cut-off of moisture supply from below (Gray 1982). These outflow bands extended from 10° N over Peninsular India to 28° N over northeast India. At this time the southerlies swept the Indian sub-continent in the lower tropospheric levels. Under these conditions widespread rainfall occurred over India for the first cyclonic storm. The rainfall was widespread over the Peninsular India for the other three systems as well.

A few tentative explanations have been given on the development of cyclonic rainbands from the study of four cyclonic storms of the post monsoon season of 1987. The structure of these rainbands will be another fascinating study, which can be carried out with the help of satellite mapping of temperature and moisture at different levels and also from RS/RW observations falling within their range.

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