Important synoptic features during INDOEX IFP-99

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INDOEX IFP-99 was undertaken as part of the international experiment in the Indian Ocean to take observations pertaining to aerosols, radiation, cloud physics and other related meteorological parameters. The important-aim of the INDOEX was to quantify radiative forcing due to natural and anthropogenic aerosols and their feedback on regional and global climate systems. Since prevailing circulation features transports aerosols, it is essential that important synoptic patterns during the expedition phase, i.e. 20 January to 10 March 1999 be examined. Based on the synoptic features it was noticed that cross-equatorial flow in lower levels from western Arabian Sea to southern Indian Ocean was significantly higher than the eastern Arabian Sea. Two cyclonic storms, one in the south Bay of Bengal during 1–3 February and another in the south Indian Ocean during 4–13 March were observed. Significant changes in the cross-equatorial flow in the lower/upper tropospheric levels and ITCZ locations were noticed.

INDIAN Ocean Experiment Intensive Field Phase-1999 (INDOEX IFP-1999), and its Indian component over the Arabian Sea and the south Indian Ocean were undertaken by ORV *Sagar Kanya* from 20 January 1999 to 11 March 1999, covering the longitudinal belt 50°E to 90°E. The international team deployed research aircraft equipped with highly specialized instruments, research vessel *Ron Brown* and European Space Agency satellite *METEOSAT* to take observations related to aerosols and cloud physics. The French Group took constant pressure balloon observations to study the air parcel trajectories emanating from the West Coast of India. The important aim of the INDOEX is to quantify the radiative forcing due to natural and anthropogenic aerosols and its feedback on regional and global climate. The region comprising Arabian Sea and Indian Ocean was selected for observational programme because the polluted air from Indian Sub-continent, south-east Asia and southern China was expected to be carried equator-wards by north-east trades of the Northern Hemisphere. Northeast trades while crossing the equator in this longitudinal belt would meet the pristine air of the southeast trades of the Southern Hemisphere. Since the prevailing wind circulation is expected to transport aerosols into the general area of ITCZ, that is located in the Southern Hemisphere during this time of the year, the radiative forcing due to clouds and aerosols together may undergo changes on a seasonal as well as climatic scale.

Godbole and Ghosh[1] based on the analysis of aerological data along meridionals 55°E and 65°E, from 23 May to 28 May, during MONEX-1973 showed the existence of broad zone of equatorial westerlies to the south of Inter-Tropical Convergence Zone (ITCZ) in the Northern Hemisphere. Easterlies to the north of ITCZ were warm and dry while westerlies to its immediate south were cool and moist. They also found another trough in Southern Hemisphere, which extended from surface to 500 hPa and had poleward inclination. Asnani[2] reviewed the work on ITCZ in various parts of the world, giving wind, temperature, moisture and distribution of some of the diagnostics such as divergence, vorticity, etc. in its neighbourhood.

Objective of the study

The objective of the present study is to study flow features which are associated with the important synoptic systems that affected the south Bay of Bengal, south Arabian sea and Indian Ocean relevant to the interest of INDOEX IFP-99.

Data

The study is based on the daily analysis of National Centre for Medium Range Weather Forecasting (NCMRWF) charts of 925, 850, 500 and 200 hPa levels, zonal section of vertical circulation along the equator, forward and backward trajectories. India Meteorological Department (IMD) charts of Northern Hemisphere Analysis Centre (NHAC), INSAT visible and Infra red cloud imageries, daily INSAT OLR charts at 2.5° × 2.5°, associated rain

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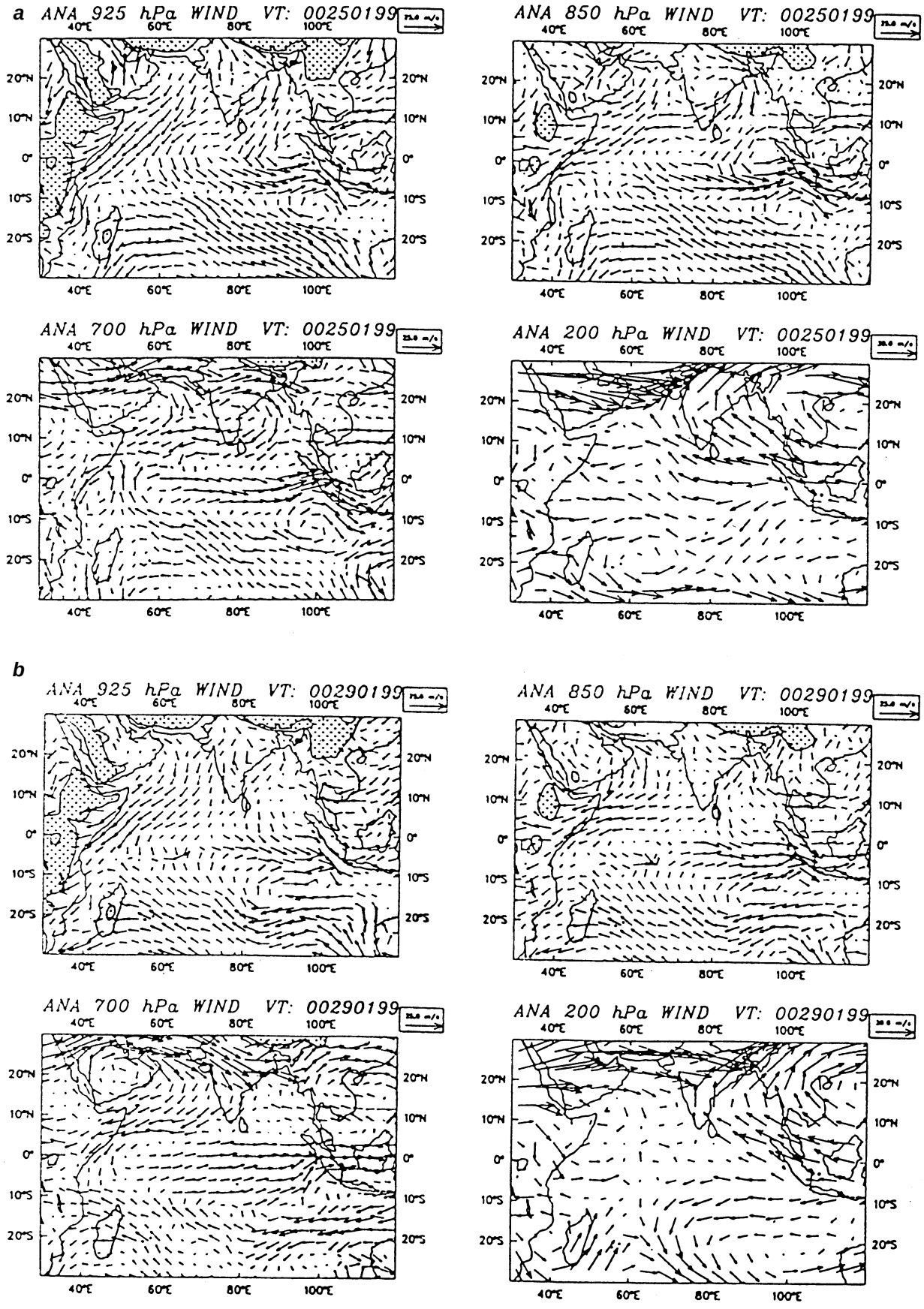


Figure 1. NCMRWF Wind analysis at 0000 UTC. ***a***, 25 January 1999; ***b***, 29 January 1999.

fall analysis, satellite-derived cloud motion vectors and Regional Specialised Meteorological Centre (RSMC), New Delhi analysis and forecast charts at various levels have also been used.

Synoptic features – Leg A

ORV *Sagar Kanya* sailed from Goa on 20 January 1999, and returned on 11 March 1999. The ship track and its approximate locations on different days is as shown in Figure 1 of the Introductory Note. The following important synoptic features were observed on Leg A (Goa–Port Louis).

ITCZ

From 20 to 29 January 1999, Northern Hemisphere Equatorial Trough (NHET) or ITCZ (N) as well as Southern Hemisphere Equatorial Trough (SHET) or ITCZ (S) existed simultaneously. The SHET was continuously active and the belt between equator to 10.0°S had continuous convective activity. A tropical disturbance, probably a depression was located in the Indian Ocean close to 12°S/107°E on 22 January 1999. The depression moved west-south-westwards and on 30 January it was close to 19.5°S/83.0°E. Thereafter it weakened gradually and became unimportant. The ship was close to ITCZ (N) on 25 January 1999 and passed through ITCZ (S) on 28/29 January 1999. The flow pattern at 925, 850, 700 and 200 hPa on 25 January and 29 January is given in Figure 1. The visible INSAT pictures at 0600 UTC of 25 January and 29 January are given in Figure 2.

Based on the above examination of weather charts and other meteorological parameters between 20 and 29 January 1999 the following conclusions can be drawn:

(i) ITCZ (N) and ITCZ (S) were more active east of 80°E, i.e. South Bay of Bengal and eastern part of south Indian Ocean.

(ii) Low level flow pattern (925 hPa) indicated that cross-equatorial flow from western Arabian Sea (West of 60°E)

a

b

Figure 2. INSAT picture (VIS) at 0600 UTC. ***a***, 25 January 1999; ***b***, 29 January 1999.

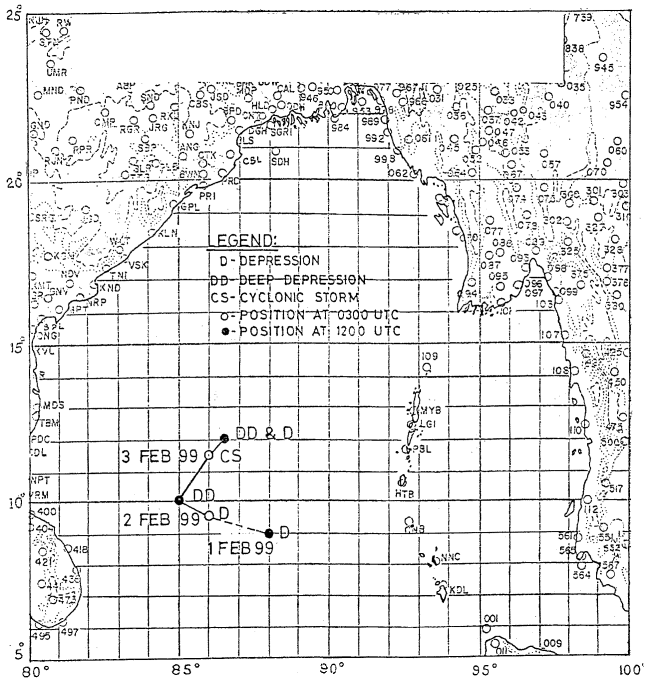
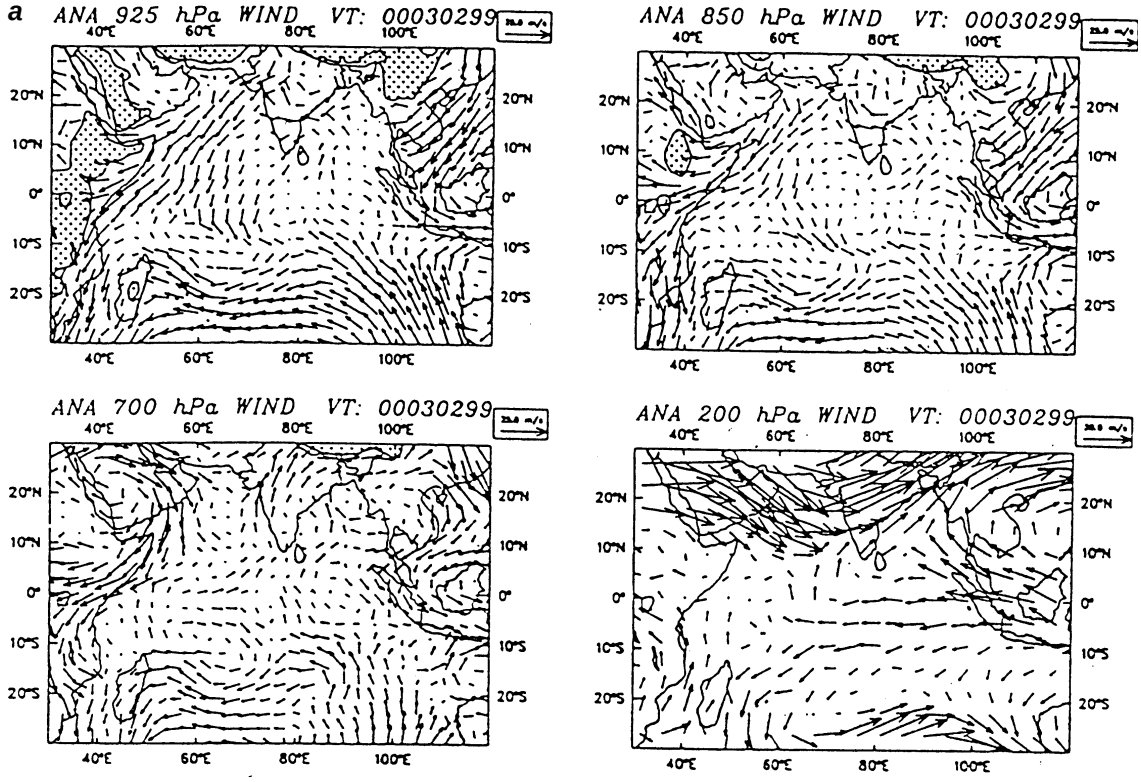


Figure 3. Bay of Bengal cyclonic storm, 1–3 February 1999.

to south Indian Ocean was significantly higher than over the eastern Arabian Sea. Similarly significant cross-equatorial flow was observed in the western parts of Bay of Bengal.

(iii) Low level winds to the south of ITCZ (N) were usually westerlies and appear to be of northern hemispheric origin. The ITCZ (S) appears to be between monsoonal westerlies and south-east trades of the southern hemisphere. From the wind fields, both the ITCZ (N) and ITCZ (S) appear to be nearly vertical.

(iv) In the upper levels at 200 hPa, cross-equatorial flow from south Indian Ocean to Bay of Bengal was signifi-



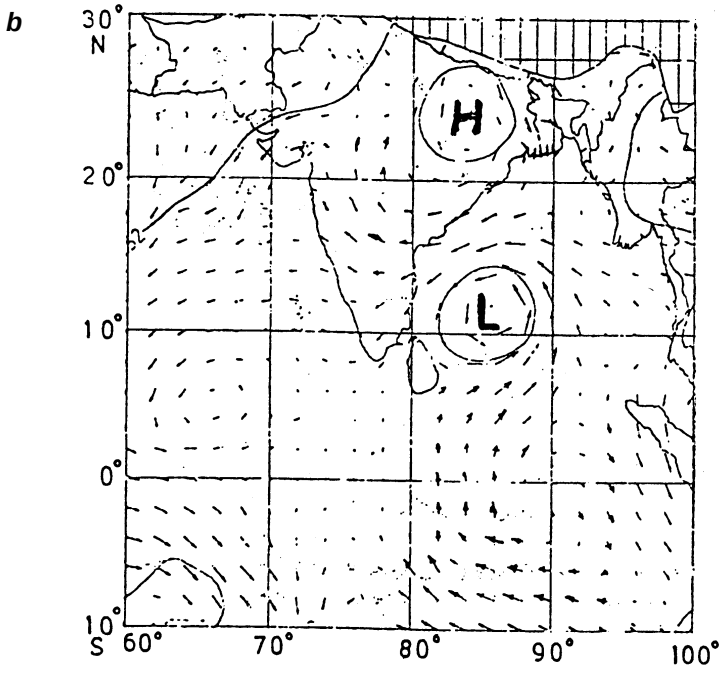


Figure 4 ***a***, NCMRWF Wind analysis at 0000 UTC on 3 February 1999; ***b***, RSMC (IMD) Wind analysis at 0000 UTC on 3 February 1999.

cantly higher, while in the Arabian Sea side it was rather weak.

Cyclonic storms

(i) A broad low pressure prevailed over southern parts of Bay of Bengal on 31 January in which 1008 hPa isobar covered most of the area south of 15°N latitude. Within this broad low there was a relatively well-marked low pressure area with central pressure of 1006 hPa over southeast Bay of Bengal and neighbourhood. The surface winds were of the order of 10–15 knots from the southwest. However the persistent convection which was associated with this configuration gave rise to a depression on 2 February. This system eventually intensified further into a cyclonic storm at 0300 UTC of 3 February when it was located around 11.5°N/86.0°E. Hereafter this vortex came under the increasing influence of stronger middle and upper tropospheric westerly flow and got sheared off. Since 1891 this has been the third significant vortex seen in Bay of Bengal during 1st week of February. Though it was seen in the Limited Area Model (LAM) analysis, it was not very well captured in the NCMRWF analysis charts.

(ii) A depression on 1 February 1999, lay centered close to 12.5°S/70.5°E in the south Indian Ocean. Moving west-south-westwards on 3 February its position was 19.0°S/65.0°E and on 5 February it was located close to 22.0°S/50.5°E. It had become unimportant after crossing south Mozambique on 8 February 1999. The positions are extracted from the INSAT imagery and did not tally exactly with the NCMRWF analysis.

(iii) Another tropical disturbance was located close to 8.0°S/67.0°E on 3 February 1999. On 5 February, the tropical disturbance lay close to 10.0°S and 60.0°E and was possibly a tropical depression. On 8 February it lay in the Mozambique Channel close to 15.0°S and 47.0°E. Simultaneously in the north Arabian Sea a trough at 200 hPa lay close to 75°E.

The track of the above systems along with corresponding INSAT pictures and flow patterns are given in Figures 3 to 8. Composite OLR chart and rainfall analysis for 4 February 1999, are shown in Figures 9 and 10, indicating the presence of highly organized vortex in the south Bay of Bengal. The large-scale precipitation estimate as per Arakin[3] technique indicates a broad region of convective precipitation of 1 to 2 cm, which includes a maxima of 2.5 cm.

The following important observations are made:

- In the Bay of Bengal, particularly in the western parts, significant flow from Southern Hemisphere across the equator is taking place in the lower troposphere on 3 February 1999 while on 5 February the direction is reversed.
- The monsoonal westerlies in the south Indian Ocean are not noticed on 3 or 5 February 1999 and both the ITCZ (N) and ITCZ (S) are suppressed.
- At 200 hPa, in the Arabian Sea the cross-equatorial flow depends upon the location and the amplitude of the mid-latitude westerly trough of Northern Hemisphere over India.

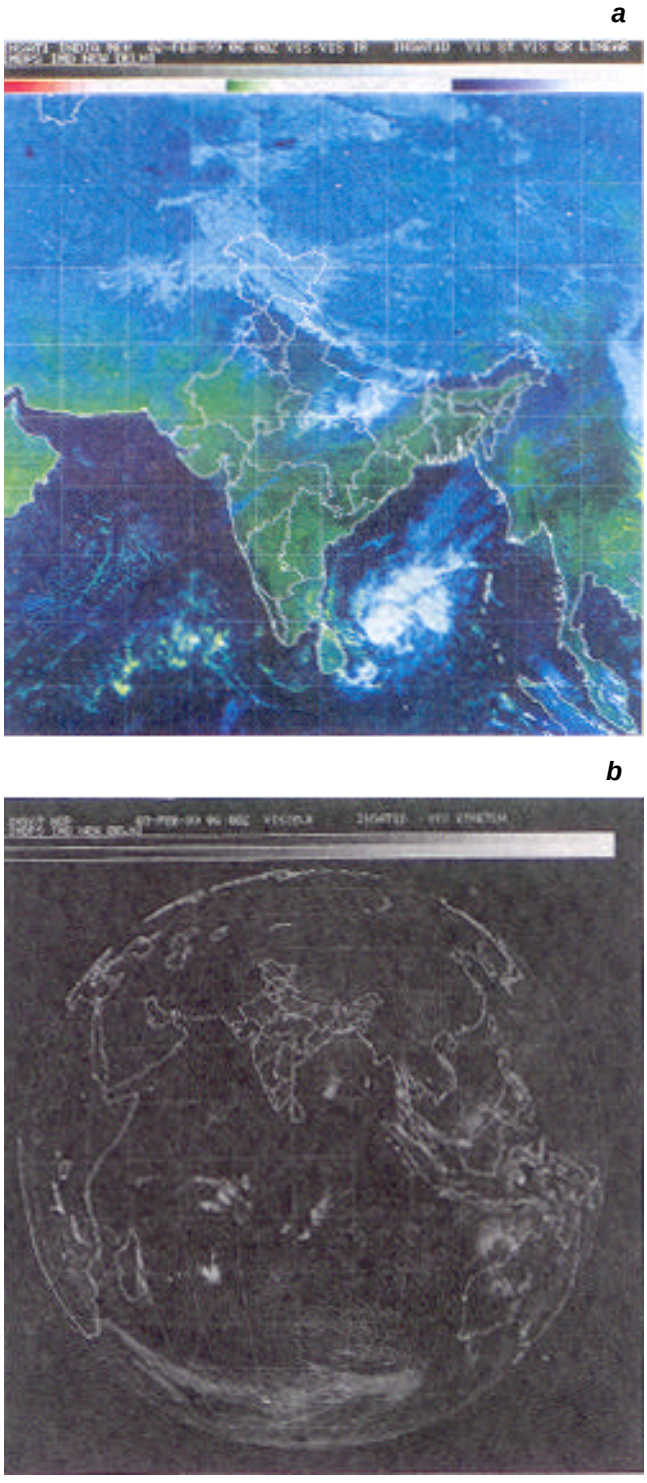


Figure 5. INSAT picture (VIS). ***a***, 2 February 1999 at 0600 UTC; ***b***, 3 February 1999 at 0900 UTC.

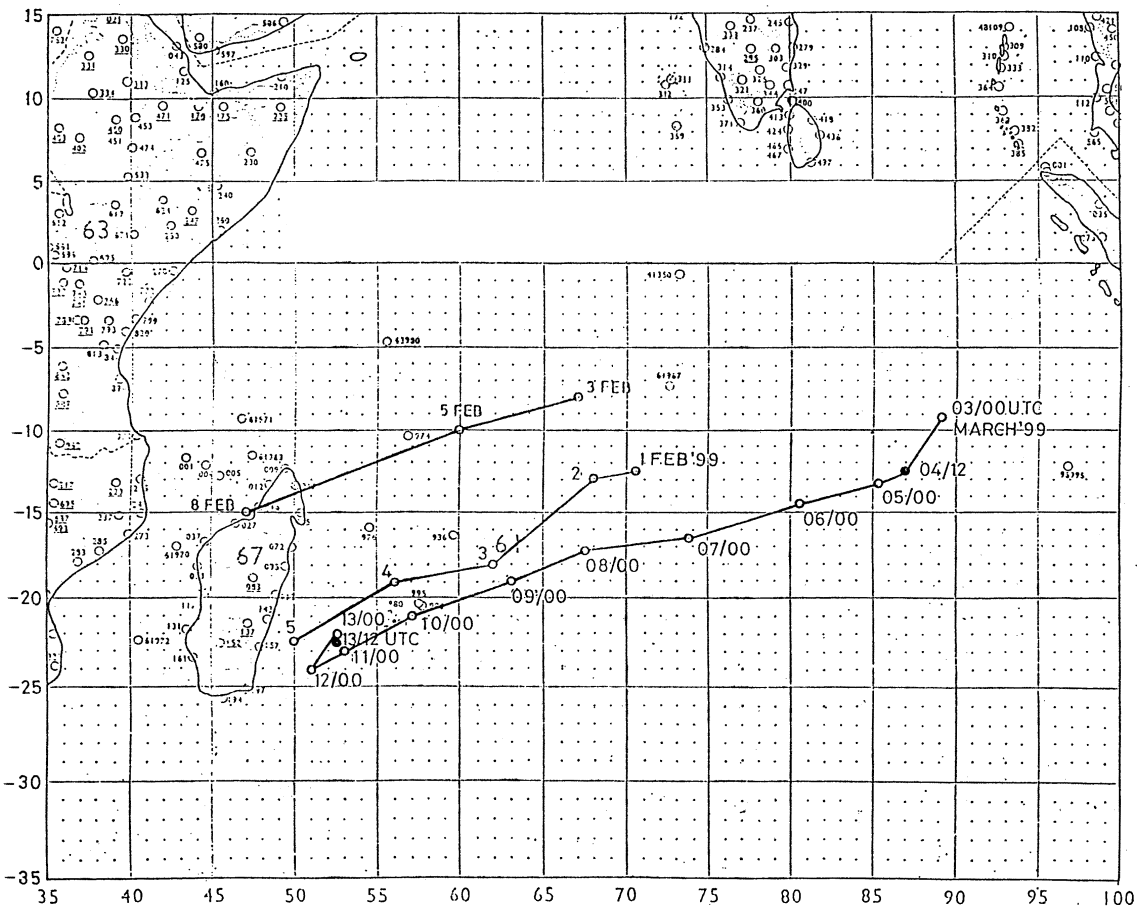


Figure 6. Track of tropical depressions and a tropical storm DAVINA in the south Indian Ocean.

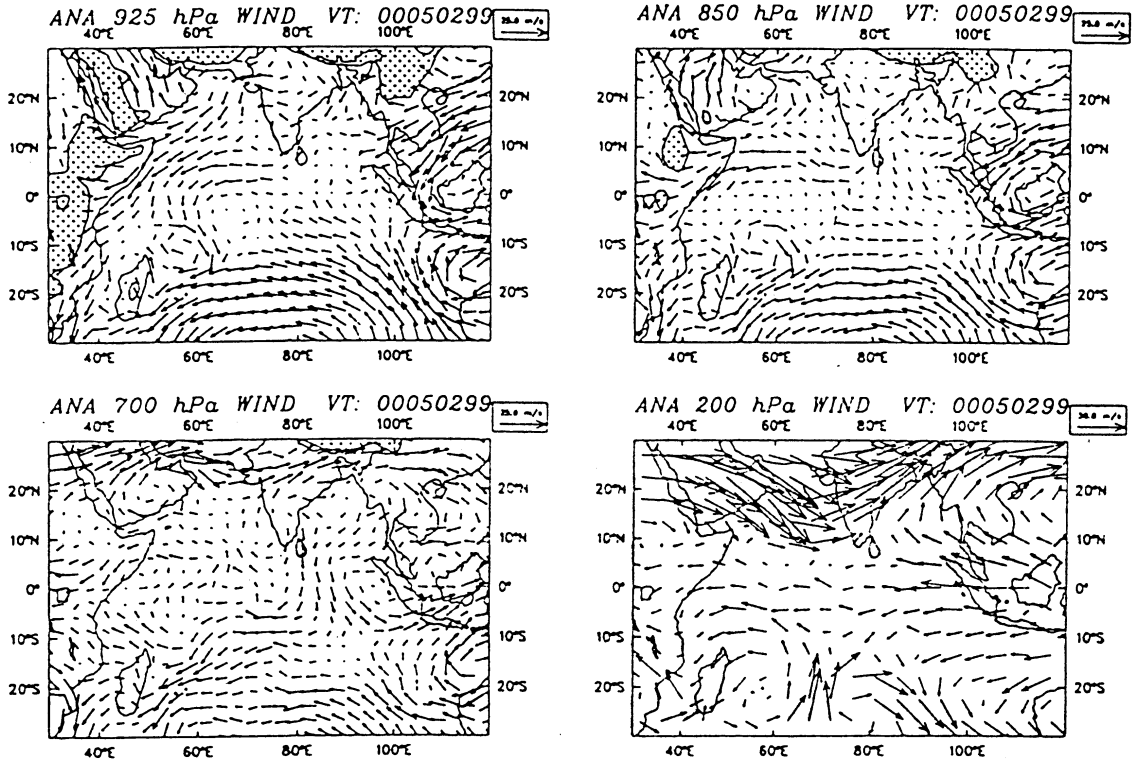


Figure 7. NCMRWF Wind analysis at 0000 UTC on 5 February 1999.

Synoptic situation on Leg B

Cyclonic circulation in the Bay of Bengal and ITCZ (S)

On 17 February 1999, a low-level cyclonic circulation was noticed at 850 hPa in the south Bay of Bengal. It moved across Sri Lanka and south Tamil Nadu on 19 February and finally emerged in the Arabian Sea on 22 February and became unimportant on 24 February. On the same day ITCZ (S) was observed close to 7.5°S. The INSAT picture for 22 February 1999 is shown in Figure 11.

Figure 8. INSAT picture (VIS) at 0600 UTC on 5 February 1999.

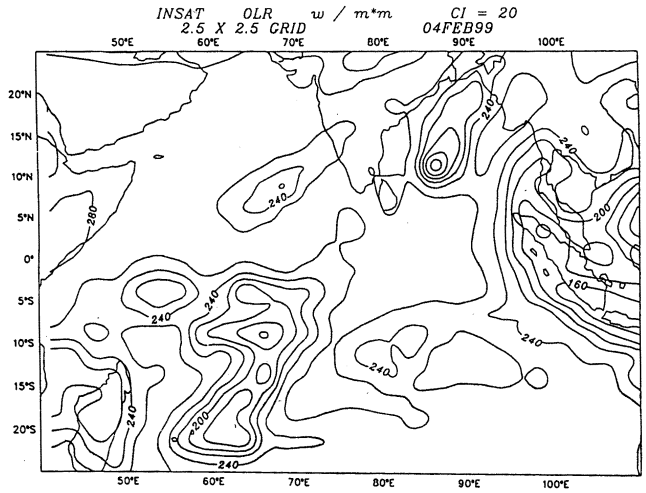


Figure 9. OLR analysis (24 h) on 4 February 1999.

Tropical storm in the Indian Ocean

A tropical disturbance was noticed on 1 March 1999 close to 8.0°S/92.0°E. It became a depression and lay close to 9.5°S/89.0°E. It became a cyclonic storm on 4 March 1999, and lay centered at 1200 UTC close to 12.5°S/ 87.5°E with intensity T3.0. The storm was named 'DAVINA'. It moved west-southwestwards and intensified gradually to the stage of T5.0 on 8 March when it was close to 17.0°S/67.5°S. Thereafter it showed signs of weakening. On 10 March 1999, it was located close to 22.0°S/56.
It became unimportant on 14 March. NCMRWF analysis at 0000 UTC and satellite picture at 0600 UTC for 8 March 1999 are presented in Figures 12 and 13.

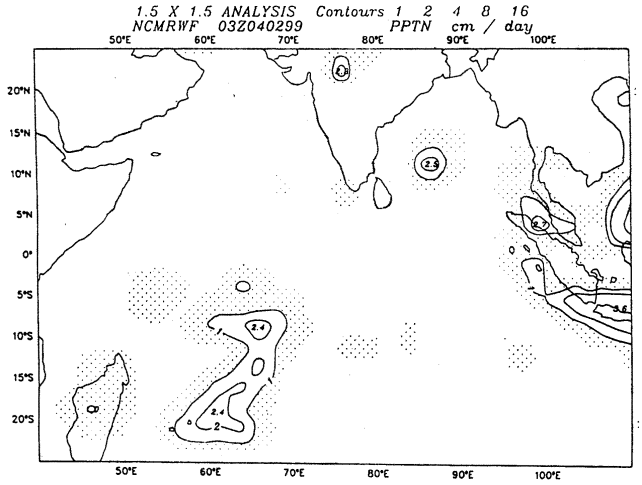


Figure 10. Rainfall analysis (24 h) at 0300 UTC on 4 February 1999.

Figure 11. INSAT picture at 0600 UTC (VIS) on 22 February 1999.

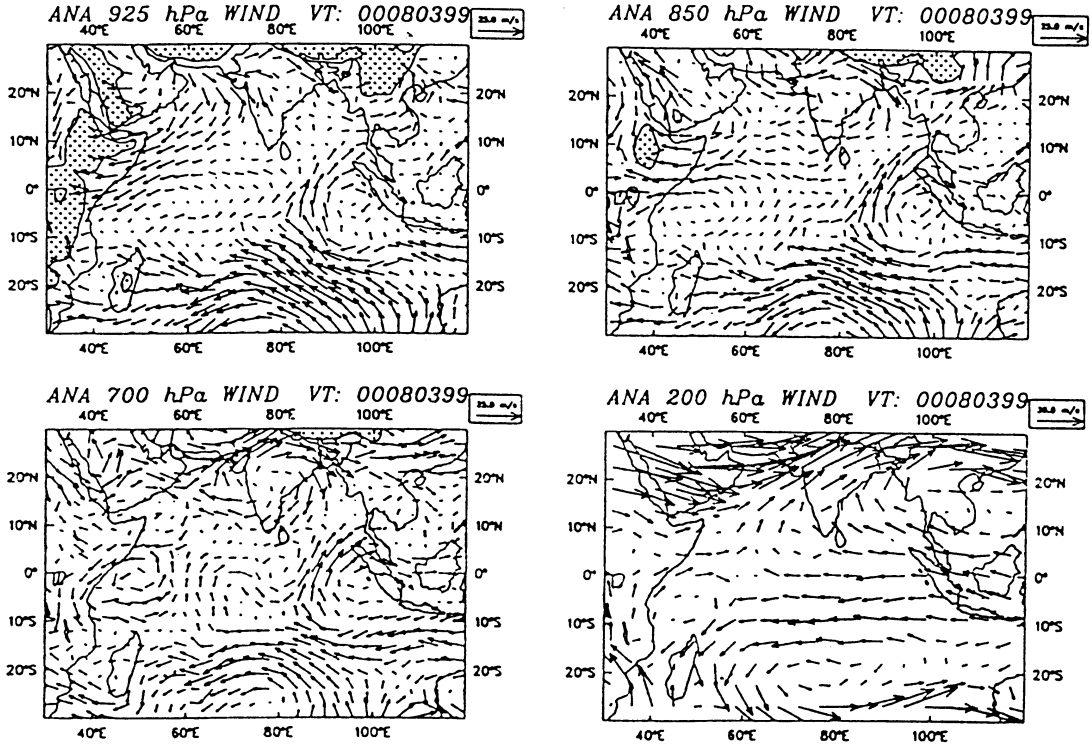


Figure 12. NCMRWF analysis at 0000 UTC on 8 March 1999.

Figure 13. INSAT picture (VIS) at 0600 UTC on 8 March 1999.

The following observations were made:

(i) The low-level cross-equatorial flow in the Arabian Sea is reduced compared to the earlier situations.
(ii) ITCZ (S) during the intensification stage of cyclonic storm in the south Indian Ocean became diffused.
(iii) At the upper levels, at 200 hPa the cross-equatorial flow, particularly in the Arabian Sea has increased.

Conclusions

ITCZ (N) and ITCZ (S) during the INDOEX IFP-99 were more active to the east of 80°E. From 20 January to 29 January 1999, both the ITCZ (N) and ITCZ (S) were observed simultaneously. The cyclonic storm in the Bay of Bengal in February 1999 was a rare phenomenon and it was the third significant vortex since 1891. Cyclonic circulation's in the low levels were observed on many days in the south Bay and were associated with convective clouds and precipitation. In the Indian Ocean a number of vortices possibly depressions could be discerned from the INSAT cloud imagery but only the important ones in relation to ORV *Sagar Kanya* track have been described. The monsoonal westerlies were observed in the Indian Ocean, between the two ITCZ positions. However during the presence of strong vortices, the ITCZ positions became diffused.

The cross-equatorial flow from Arabian Sea into the Indian Ocean is significantly higher (say up to 850 hPa) in the western Arabian Sea off the coasts of Somalia and Kenya than in the eastern Arabian Sea off Kerala and Karnataka coast.

In the Bay of Bengal, low-level cross-equatorial flow from the Bay into the Indian Ocean is significant in the western Bay, particularly off Tamil Nadu and Sri Lanka coast.

In the presence of synoptic systems such as lows/depressions/cyclonic storms, either in the Bay, or Indian Ocean within the equatorial belt of 15°N to 15°S, significant variations in the low-level cross-equatorial flows take place and the position of ITCZ becomes diffused.

In the upper troposphere at 200 hPa, cross-equatorial flow from the Indian Ocean into the Bay is significantly higher than in the Arabian Sea. Under the influence of deep amplitude troughs in the mid latitude westerlies at 200 hPa over the Indian sub-continent, some interesting variations in the cross-equatorial flow amongst Arabian Sea, Bay of Bengal and Indian Ocean are observed.

With the availability of glass-sonde, aircraft and ship data collected during INDOEX IFP-99, the re-analysis of wind field and other meteorological fields by NCMRWF would better represent the synoptic features, particularly in the Indian Ocean.

1. Godbole, R. V. and Ghosh, S. K., *TELLUS*, 1975, **XXVI**, 125–131.
2. Asnani, G. C., *Trop. Meteorol*., 1993, **I**, 19–134.
3. Arakin, P. A., *Mon. Wea. Rev*., 1979, **107**, 1382–1387.

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