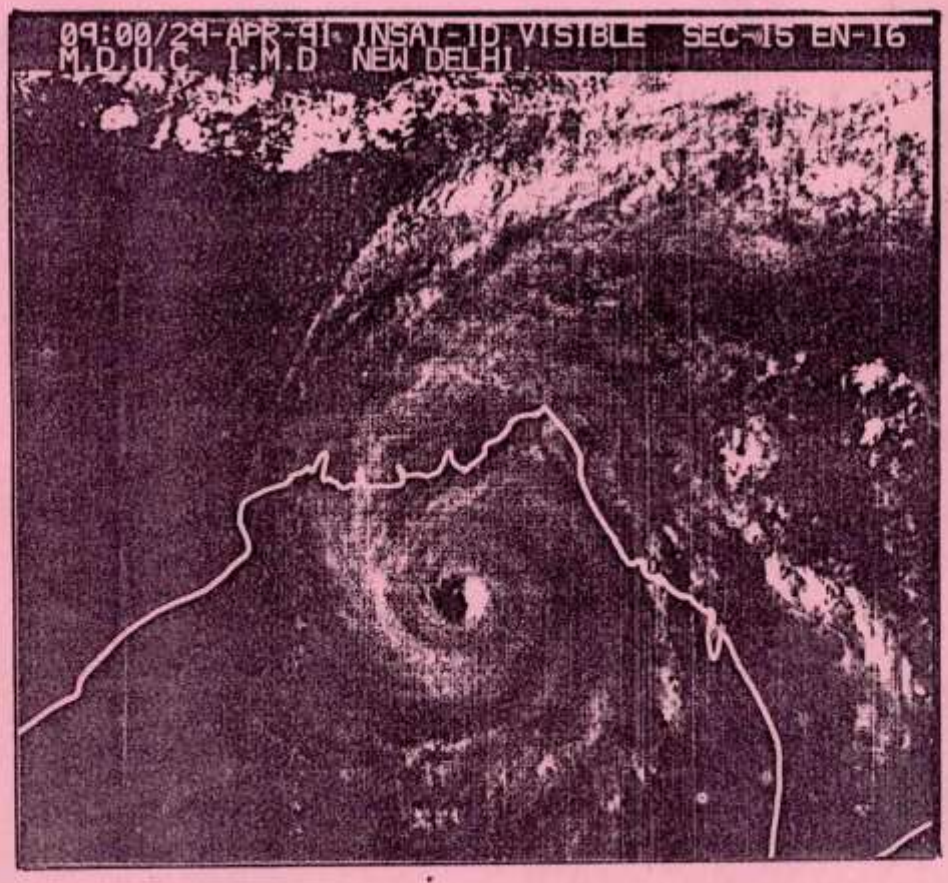
भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

REPORT ON CYCLONIC DISTURBANCES

(DEPRESSIONS AND TROPICAL CYCLONES)

OVER NORTH INDIAN OCEAN

IN 1991



REGIONAL SPECIALIZED METEOROLOGICAL CENTRE (RSMC) - TROPICAL CYCLONES
NEW DELHI

JANUARY 1992

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1. INTRODUCTION

This is a report on cyclonic disturbances (depressions and tropical cyclones) formed over the North Indian Ocean (the Bay of Bengal and the Arabian Sea) during the year 1991 prepared by RSMC - Tropical Cyclone, New Delhi. It may be recalled that the cyclonic disturbances over the North Indian Ocean as defined in the WMO Tropical Cyclone Operational Plan for the region (TCP-21) are as follows.

Weather system	Maximum wind speed
1. Low	Wind speed less than 17 kt (<31 kmph)
2. Tropical Depression	Wind speed between 17 and 33 kt (between 31 and 61 kmph)
3. Cyclonic storm	Wind speed between 34 and 47 kt (between 62 and 88 kmph)
4. Severe Cyclonic Storm	Wind speed between 48 and 63 kt (between 89 and 117 kmph)
5. Severe Cyclonic storm with a core of hurricane winds.	Wind speed 64 kt (118 kmph) or more

In India, the terms depression and deep depression are also used to indicate cyclonic disturbances with wind speed between 17 and 27 kt and 28 and 33 kt respectively corresponding to Beaufort Scale 5-6, and 7. The terms tropical storm , tropical cyclone or cyclone are used to indicate all classes of disturbances indicated under (3) to (5) above. However, in this report WMO terminologies only have been used to describe the intensity of the cyclonic disturbances.

Eight cyclonic disturbances formed over the North Indian Ocean during the year 1991, out of which five diturbances intensified into depressions and three into cyclones. All the disturbances developed over the Bay of Bengal and none over the Arabian Sea. This is the sixth consecutive year when no tropical storm formed in the Arabian Sea. This unique situation has occurred for the first time over the Arabian Sea during the last 101 years (1891-1991).

The first two cyclones formed during the pre-monsoon season (March-May) while the third formed during the post-monsoon season (October-December). Out of the five depressions, three formed during the monsoon season (June-September) and the remaining two in the post-monsoon season (October-December).

The tracks of all the cyclonic disturbances are shown in Fig.1. In Tables 1 to 3 the best track positions at 6 hourly interval alongwith other meteorological information for individual tropical cyclones are shown.

Detailed discussion on individual tropical cyclones and depressions are given in the following sections. The tropical cyclones are described in greater detail.

2. PRE-MONSOON SEASON CYCLONIC DISTURBANCES

2.1 Bangladesh Cyclone, 24-30 April, 1991

2.1.1 Life history of the cyclone (April, 1991)

The system originated as a depression over southeast Bay of Bengal near 9.5°N, 89.0°E on the afternoon of 24 April, 1991. The depression moved slowly in a north-westerly direction and intensified into a cyclonic storm by the evening of 25 April when it lay centred near 11.0°N, 88.0°E. The system apparently intensified under the influence of large scale low level wind surge across the equator during the above period. The objectively analysed winds of 0000 UTC of 25 April (Fig. 2) supports this view. Moving further westwards, the cyclone became severe by 26th evening and was centred near 11.5°N, 87.5°E. From 26th evening the severe cyclonic storm moved slowly in a northerly direction and at the same time intensified further. The system lay centred as a severe cyclonic storm with a core of hurricane winds near 14.5°N, 87.0°E, about 950 km south-south-west of Calcutta (42807) on 27th evening. Thereafter, the hurricane slowly recurved north-north-eastwards and intensified further. The system attained its peak intensity on the morning of 29 April when it was classified as T6.5 on the Dvorak's Scale (Fig.3) and was centred near 19.0°N, 89.5°E about 400 km south-south-east of Calcutta. At this time the central pressure of the cyclone was estimated as 920 hPa thus becoming one of the severest cyclonic storms in the Bay of Bengal. Continuing to move in a north-north-easterly direction and maintaining its hurricane intensity, the system crossed Bangladesh coast during the mid-night hours of 29-30 April, 1991 near about the time of high tide. Having moved further north-north-eastwards over land, the system weakened and lay as a depression over Tripura and adjoining States of India on the morning of 30 April. By the same evening, it further weakened and became unimportant.

2.1.2 Monitoring and tracking

The cyclone was continuously monitored and tracked with the help of INSAT cloud imageries and conventional meteorological observations from its formative stage over the southeast Bay of Bengal on 24 April, 1991 till its dissipation over the north-eastern States of the country on 30 April, 1991. The system came within the range of the Cyclone Detection Radars (CDRs) at Paradip (42976) and Calcutta (42807) on the east coast of India from 29th morning, although it remained more than 300 km away from the Indian coastline.

The Cyclone Detection Radars at Khepupara (41984), Chittagong (41977) and Cox's Bazar (41992) in Bangladesh tracked the cyclone from the evening of 29 April, when the system came within their surveillance range. The centre of the cyclone reported by the above CDRs in Bangladesh agreed well with those inferred from the INSAT cloud imageries.

2.1.3 Tidal waves / Storm surges

According to media reports tidal waves / storm surges of about 6 metre height hit the Bangladesh coast and islands off Chittagong at the time of landfall in the mid-night of 29 April, 1991. The landfall time of the cyclone nearly coincided with the time of high tide which was of the order of 5-1/2 metre high over this coast on this day.

2.1.4 Damage caused

As indicated earlier, it was one of the severest ever storm in this part of the globe. The cyclone, with associated wind speeds exceeding 220 kmph, lashed Bangladesh's most densely populated coastal areas and a dozen off-shore islands in the Bay of Bengal for about nine hours during the night of 29-30 April, 1991. Colossal damage to life and property was reported in the island and coastal areas of Bangladesh.

Incessant rains and squally winds in association with the cyclone also caused some loss of life and damage to property in Tripura and Mizoram States of India. Many houses collapsed and the telecommunication system in this area was disrupted by the cyclone during its dissipating stage. In terms of intensity and particularly the resultant devastation caused, this cyclone would be reckoned as one of the historical storms in the North Indian Ocean.

2.2 Bangladesh cyclone, 31 May - 2 June, 1991

2.2.1 Life history of the cyclone (May, 1991)

The system originated as a depression near 14.0°N, 90.0°E over southeast Bay of Bengal on the morning of 31 May, 1991. The depression moved in a north-north-westerly direction and intensified into a deep depression centred near 16.0°N, 89.0°E by the same evening. Moving further in a north-north-westerly direction, it intensified into a cyclonic storm on the morning of 1 June near 18.0°N, 88.5°E. It was classified as T2.5 based on the INSAT cloud imageries. On the morning of 1 June, the system curved in a north-north-easterly direction and further intensified. It attained its peak intensity of T3.0 on the 1st evening and was centred near 20.0°N, 89.5°E, about 300 km south-south-east of Calcutta. Continuing to move in a north-north-easterly direction and maintaining its peak intensity, the system crossed Bangladesh coast on the morning of 2 June, 1991. Moving further north-north-eastwards over land, the system lay as a deep depression over Tripura and adjoining States of India on the morning of 2 June. The system weakened further over the same area by 3 June, 1991. The INSAT-1D cloud imagery of the cyclone for 0800 UTC of 1 June, 1991 is shown in Fig. 4.

2.2.2 Monitoring and tracking

The system was tracked by INSAT-1D satellite and Cyclone Detection Radars (CDRs) besides the conventional observations. This system remained away from the surveillance range of Cyclone Detection Radars (CDRs) on the east coast of India during its life span. The Cyclone Detection Radars in Bangladesh tracked the cyclone from the night of 1st June when the system came within their range.

2.2.3 Tidal waves / storm surge

According to press reports tidal waves/storm surge of about 2-1/2 metre height hit the Bangladesh coast off Chittagong at the time of landfall in the early hours of 2 June, 1991.

2.2.4 Damages caused

According to Press reports this system also caused some damages in the coastal areas of Bangladesh due to heavy rainfall and squally winds. Wide spread rains accompanied with squally winds also lashed several areas of Mizoram State in northeast India during the dissipating stage of the cyclone. However, there were no reports of significant damages due to the cyclone over the Indian region.

3. MONSOON SEASON (JUNE-SEPTEMBER)

3.1 Deep Depression (27-31 July)

The system formed as a depression over north Bay of Bengal near 20.0°N, 89.5°E on the morning of 27 July, 1991. It intensified and crossed Orissa coast in India in the evening of 28 July. It attained a peak intensity of T2.0 at 1200 UTC on 28 July. The maximum sustained surface wind associated with the system was of the order of 30 kt from 1200 UTC of 28 July to 1800 UTC of 30 July. Moving west-north-westwards across the central parts of India the depression dissipated over East Rajasthan and neighbourhood on the evening of 31 July, 1991. The depression enhanced the monsoon activity over the northern and central parts of India during this period.

3.2 Depression (22-26 August)

The system developed from the remnant of Typhoon 'FRED' which crossed south Myanmar coast and emerged into the East Central Bay of Bengal on 20 August, 1991. It concentrated into a depression over northwest Bay on 22 August and crossed north Orissa coast near Balasore (42895) in India on the afternoon of the same day. Moving further northwestwards over land, the system dissipated over the plains of West Uttar Pradesh on the evening of 26 August, 1991.

The depression caused good monsoon rainfall activity over the northern and central parts of India during the above period. This system generated widespread rainfall over greater parts of north India. Heavy rainfall also occurred at a few places over East Rajasthan. The maximum sustained surface wind associated with the system was of the order of 25 kt.

3.3 Depression (21-22 September)

The depression developed from a pre-existing system in the lower tropospheric levels over west central Bay of Bengal on 21 September, 1991. It crossed north Andhra Pradesh coast in India near Kakinada (43189) in the early hours of 22nd and weakened over the northern parts of Andhra Pradesh on the same day. The highest intensity of the system based on the satellite classification was T1.5. The maximum sustained surface wind speed associated with the system was 25 kt. The system was short-lived and caused heavy rainfall at a few places in Andhra Pradesh.

4. POST MONSOON SEASON (OCTOBER-DECEMBER)

4.1 Depression (12-14 October)

A depression formed over West-Central Bay of Bengal with its centre near 18.0°N, 87.0°E on the evening of 12 October during the withdrawal phase of the southwest monsoon. The system moved in a north-easterly direction and crossed West Bengal - Bangladesh coast on 14th morning. It weakened over Bangladesh and neighbourhood on the same evening. Under its influence, fairly widespread rainfall with heavy to very heavy falls occurred at a few places over the northeastern States of India.

4.2 Depression (28-30 October)

The system in its incipient stage was first observed as a low pressure area over the south Bay of Bengal on 27 October. It concentrated into a depression over southwest Bay on 28th morning near 10.5°N, 82.5°E. The depression crossed north Tamilnadu coast in India between Cuddalore (43329) and Madras (43279) in the morning of 29 October and dissipated over South Interior Karnataka by 30th evening. Under its influence, winter monsoon activity was enhanced over southern parts of the peninsular India. Heavy to very heavy rainfall occurred at many places over Tamilnadu, South Interior Karnataka and Kerala.

4.3 Karaikal Cyclone (11-15 November)

4.3.1 Life history of the cyclone (November, 1991)

The system developed from the remnant of the Pacific tropical storm 'THELMA' which emerged as a low pressure area into the Andaman Sea on 10th November. It concentrated into a depression over the southeast Bay of Bengal on the evening of 11 November and lay centred near 11.0°N, 87.5°E. Moving initially in a westerly direction, it intensified into a deep depression

over southwest Bay of Bengal on 13th morning and rapidly intensified into a cyclonic storm by the same evening when it was centred near 11.0°N, 83.0°E. Moving further in a westerly direction the cyclonic storm crossed Tamilnadu coast in India between Nagapattinam (43347) and Cuddalore (43329) near Karaikal (43346) in the early hours of 15 November, 1991. After crossing the coast, the system retained its cyclonic storm intensity and lay centred at about 30 km west of Cuddalore at 0300 UTC of 15 November. Thereafter, it weakened and slowly moved in a northwesterly direction and lay centred as a depression close to Vellore (43303) on 15th evening. The system further weakened and became unimportant on 16 November, 1991. The INSAT-1D cloud imagery of 0800 UTC of 14 November, 1991 is shown in Fig. 5.

4.3.2 Monitoring and tracking

The cyclone was monitored and tracked with the help of INSAT-1D cloud imageries, Cyclone Detection Radars and conventional meteorological observations from its formative stage over the sea on 11 November till its dissipation over the land on the 16th. Over the sea area, when the cyclone was far away from the coast, it was mainly tracked by the satellite cloud imageries and available ships' observations in the cyclone field. From the evening of 13 November, as the system approached the coast and came within the range of the Cyclone Detection Radars at Karaikal (43346) and Madras (43279) on the Tamilnadu coast in India, it was continuously tracked by these radars till its landfall.

First indication of the cyclone formation was observed in the INSAT-1D cloud imageries of 11th evening. Continuous intensification of the system was indicated by the satellite pictures till the evening of 13th November, when it attained the intensity of T2.5 on the Dvorak's scale. The cyclone further intensified and attained its peak intensity of T3.0 on 14th morning. Same intensity of the cyclone was maintained till the time of its landfall over Tamilnadu coast in India on 15 November, 1991.

Hourly radar fixes of the cyclone centre were given by the Cyclone Detection Radars at Karaikal and Madras in Tamilnadu coast from 0900 UTC of 13th till 0600 UTC of 15 November 1991. As the cyclone was only of a moderate intensity, the "eye" of the storm was not very well defined. Both the CDRs reported "open eye" in their hourly observations from 0300 UTC to 1600 UTC of 14 November, except at 14/0500 UTC when circular closed 'eye' was reported by CDR Karaikal. The radar fixes of the cyclone from CDRs Karaikal and Madras were in good agreement with the centres derived from the INSAT-1D cloud imageries. The radar photograph of the cyclone for 0500 UTC of 14 November, 1991 is shown in Fig. 6.

4.3.3 Damage caused

Coastal districts of the State of Tamilnadu in India experienced the greatest impact of the cyclone. According to press reports seven districts in Tamilnadu, mainly over the coastal regions, were affected by this cyclone. Considerable damages to standing crops and properties were also reported from these districts mostly due to inundation caused by heavy rainfall and floods.

Nine districts were affected in Andhra Pradesh. The districts of Prakasam, Nellore, Chittoor and Cuddapah suffered relatively more damage compared to Guntur, Krishna, Anantapur and East and West Godavari districts. Damages to properties and standing crops were considerable mainly in Nellore and Prakasam districts of south Coastal Andhra Pradesh. Some loss of lives was also reported from Tamilnadu and Andhra Pradesh. Media reports indicated that 300 people lost their lives in Tamilnadu and Andhra Pradesh.

5. TRACK PREDICTION BY MODELLING

Climatology, Persistence, the combination of Climatology and Persistence (CLIPER), Analogue and Statistical models are run at the RSMC New Delhi for track forecasting of the cyclonic disturbances in the north Indian Ocean. The forecast positions of the systems are verified with respect to the best tracks. The analogue technique is used only for the track prediction of tropical cyclones while the other techniques are used for all classes of cyclonic disturbances. At present, the statistical technique is not run in operational mode. Tables 4 and 5 show the forecast position errors in respect of tropical cyclones by analogue method and those for all the cyclonic disturbances by Climatology, Persistence and CLIPER models respectively.

The analogue technique is run for obtaining 12, 24 and 36 hours forecast positions of individual tropical cyclones. The forecast position errors were computed by analogue method at different time projections for three tropical cyclones formed over the North Indian Ocean during 1991. Table 4 shows that the forecast errors in April and May cyclones were comparatively larger than the November cyclone, which was mainly due to the fact that both the April and May cyclones were recurving storms. The forecast errors for the November tropical cyclone by the analogue technique exhibited a reasonable forecast skill.

6. DYNAMICAL PARAMETERS ASSOCIATED WITH CYCLONIC DISTURBANCES

6.1 Vertical wind shear

Vertical shear of the zonal winds between 200 and 850 hPa over the Indian Ocean and adjoining areas were computed in respect of cyclones and depressions. These were calculated by utilizing the winds at 850 and 200 hPa from the land stations and 5 deg. latitude/longitude grid point winds available over oceanic areas from the European Centre for Medium Range Weather Forecasting (ECMWF), U.K.The vertical wind shear values between 200 and 850 hPa for 1200 UTC of 27 April, 1991 in respect of the Bay of Bengal cyclone of 24-30 April, is shown in Fig. 7 as an example. The system had attained cyclonic storm intensity on 26 April and further intensified on 27 April, 1991.

On 26 April, the vertical wind shear was nearly zero over the storm centre. To the north of the centre there was strong anticyclonic vertical shear, while to the south cyclonic shear was present. This is a feature normally seen in the formative stage of a cyclone. The vertical wind shear pattern remained nearly similar on 27 April when the system attained the mature stage. On this day the anticyclonic shear to the north of the cyclone centre considerably increased and showed large horizontal gradient, while the cyclonic shear to the south of the centre showed a significant decrease. The above vertical wind shear pattern suggested the occurrence of considerable horizontal temperature gradient over the region to the north of the centre than to the south. The large anticyclonic wind shear to the north is attributed to stronger westerly winds at 200 hPa prevailing over this region.

Similar patterns of vertical wind shear between 200 and 850 hPa were also observed in association with the other two Bay cyclones of May and November, 1991.

The pattern of vertical shear of the zonal winds between 200 and 850 hPa over the Indian Ocean and adjoining land areas in respect of the depressions in the months of July and August during the southwest monsoon season (June-September) 1991 was significantly different from that of the cyclones. Strong easterly (negative) vertical wind shear was present over the north Indian Ocean and adjoining areas on the above days, which inhibited further intensification of the depression into a cyclonic storm.

The vertical shear showed considerable increase towards the south of the depression centre with the highest values occurring over the central parts of the Bay of Bengal. This feature is attributed to the existence of the tropical easterly jet stream at about 200 hPa in the latitudinal belt of 10^{0} - 15^{0}N over the Bay of Bengal during the monsoon months.

6.2 Vergence Field

The horizontal distribution of vergence around the Bay of Bengal cyclone of April, 1991 and its neighbouring areas for 0000 UTC of 28 April (mature stage) at 850, 500 and 200 hPa is presented in Fig. 8 (a) to (c) only to highlight the order of magnitude of these values in its mature stage. Similar computations for other days were also made.

Both the low level convergence and high level divergence in the cyclone field progressively increased from 26 to 28 April. In general the distribution of convergence and divergence in association with the system were typical of an intense tropical cyclone. The maximum low level convergence occurred near the cyclone centre on 28 April, 1991 when the system was in its most intense stage (severe cyclonic storm with a core of hurricane winds).

The patterns of horizontal distribution of vergence in association with the May and November cyclones were nearly similar to those of the April cyclone. However, the values of low level convergence and high level divergence associated with these two cyclones were comparatively much

smaller in magnitude than those of the April cyclone. This feature is attributed to the fact that the April, 1991 cyclone was of a very high intensity (T6.5), whereas the other two cyclones were only of a moderate intensity (T3.0).

The distribution of vergence around the monsoon depressions was significantly different from that of the cyclones. It is seen that the convergence occurred far away from the depression centre at a distance of about 500-600 km to the west of the system. This feature is typical of monsoon depressions. The INSAT satellite cloud imageries also showed distinctly a dense convective cloud mass located on the western side of the depression centre on all the days.

Maximum high level divergence occurred in the forward sector of the system along its direction of movement. Similar patterns of horizontal distribution of vergence were seen in association with the monsoon depression of 22-26 August, 1991.

6.3 Vorticity Field

Relative vorticity of tropical cyclones and depressions averaged at 2^{o}, 4^{o} and 6^{o} radii around the centre for standard isobaric levels on different dates were computed.

As mentioned before, the April, 1991 cyclone had the highest intensity (T6.5) as compared to other systems forming over the North Indian Ocean during the year 1991, the relative vorticity profiles in respect of this cyclone are only presented in this report.

Fig. 9 shows the relative vorticity profiles averaged over 4^{o} radius around the cyclone centre for 0000 UTC of 26, 27, 28 and 29 April, 1991. Level to level increase in the relative vorticity from 26 to 29 April is evident from the figure, thus indicating the ongoing intensification of the system during this period. The vorticity showed a decrease in the upper tropospheric levels and became anticyclonic above 200 hPa.

6.4 Vertical velocity

Computations of vertical velocity over the north Indian Ocean and adjoining areas were made in respect of the cyclones and depressions and these are briefly described in the following paragraphs.

Fig. 10 (a) to (c) illustrate the horizontal distribution of vertical velocity at 850, 500 and 200 hPa around the April 1991 cyclone and its neighbouring areas for 0000 UTC of 28 April. Strong upward motion is seen near the centre of the cyclone and downward motion in its forward and rear sectors on this day. Such patterns of vertical motion field are normally seen in association with intense tropical cyclones. One distinct feature evident from these diagrames and from those of 26th (not shown) is that the upward vertical motion near the cyclone centre considerably increased from the initial stage of the cyclone on 26 April to its mature stage on the 28th.

The horizontal distribution of the vertical motion field in respect of the May and November, 1991 cyclones showed nearly similar features as those of the April, 1991 cyclone. However, the order of magnitude of the vertical velocity in May and November cyclones was much smaller as compared to that of the April cyclone.

In association with the monsoon depressions, maximum upward motion was found to occur far away from the centre on the western side of the depression which nearly coincided with the area of maximum low level convergence associated with the system. Downward motion occurred both to the north and south of the depression centre.

7. DISSEMINATION OF WARNINGS

The cyclone warnings were disseminated to the general public, Government officials and other user organisations in India through high priority telegrams, T/P, telephone and telex. The electronic and print media were also extensively used for this purpose. Cyclone warnings in local languages were communicated directly to the coastal population likely to be affected by the cyclone through the satellite based communication system known as Disaster Warning System (DWS). This system, which is in operation in the coastal areas of Tamilnadu and Andhra Pradesh in India for the past 3-4 years, proved to be very dependable and effective during 1991 cyclone season also. There was great appreciation by the Governmental authorities and Media in India about the quality of cyclone warning service rendered by the India Meteorological Department.

8. CO-OPERATION AMONG PANEL COUNTRIES

RSMC New Delhi continued to issue 'Tropical Weather Outlook' for the North Indian Ocean and adjoining land areas daily as a routine to the Member countries of the Panel. During the 1991 cyclone season, the Regional Specialized Meteorological Centre (RSMC), New Delhi issued frequent tropical cyclone advisories alongwith observations to the concerned Member countries of the WMO/ESCAP Panel on Tropical Cyclones. During the two cyclones of the pre-monsoon season, RSMC New Delhi received observations of the Cyclone Detection Radars in Bangladesh which were helpful in tracking the system. Six-hourly surface observations of coastal stations in Myanmar were also received from the National Meteorological Service of Myanmar during the above two cyclones.

As mentioned earlier, the Bangladesh cyclone of April 1991 was a devastating one causing widespread loss of life and property in Bangladesh. During this cyclone, RSMC-Tropical Cyclone, New Delhi closely monitored the system with INSAT satellite and other observational tools and issued frequent cyclone advisories to the Bangladesh Meteorological Department. In fact the WMO Eleventh World Meteorological Congress (May 1991) noted with appreciation the great value of the frequent advisories provided by

RSMC New Delhi to support the National Meteorological Service of Bangladesh in issuing very good forecast and early warnings on this cyclone.

9. CONCLUSIONS

In 1991, eight cyclonic disturbances formed in the Bay of Bengal, out of which three were tropical cyclones and five were depressions. The first two cyclones formed during the pre-monsoon season (March-May) and crossed Bangladesh coast, while the third one formed during the post-monsoon season (October-December) and crossed Tamilnadu coast in India.

The cyclone of April 1991, which crossed Bangladesh coast on 29 April between Hatia and Chittagong, was the most devastating cyclone of the year. It caused considerable loss of life and property in Bangladesh. During this cyclone, RSMC-Tropical Cyclones, New Delhi issued tropical cyclone advisories to the Bangladesh Meteorological Department at frequent intervals. These advisories were fully utilised by the Bangladesh Meteorological Department in issuing advance warnings on this cyclone. The other cyclone which also crossed Bangaldesh coast on 2 June, 1991 was of a moderate intensity. This system helped in the northward progress of southwest monsoon over the northeastern States of India.

The last cyclone of the year 1991 crossed the Tamilnadu coast in India on 15 November, 1991 and caused considerable damage to standing crops and properties in the coastal districts of Tamilnadu and south Andhra Pradesh. However, due to timely and adequate warnings issued by the India Meteorological Department and effective action taken by the State Governments, more than a lakh people from the coastal areas were evacuated to safer places, thus minimising the loss of life considerably.

The depressions of the southwest monsoon season (June - September) sustained good monsoon activity in the Panel area, whereas the depressions of the post-monsoon season enhanced the winter monsoon activity over the peninsular India.

[Pokhriyal/Feb.wmo91/]

TABLE 1: BEST TRACK POSITIONS ALONGWITH OTHER PARAMETERS OF SEVERE CYCLONIC STORM WITH A CORE OF HURRICANE WINDS, 24 - 30 APRIL, 1991.

TIME (UTC)	CENTRE POSITION LAT. (deg.N)	LONG. (deg.E)	T. NO.	MIN. SURFACE PRESSURE (hPa)	MAX. WIND (kt)	OUTER MOST CLOSED ISOBAR (hPa)	ΔP (hPa)	SIZE OF THE STORM'S OUTERMOST ISOBAR (deg.Lat.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
APRIL								
24 00	8.5	89.0	-	1002	-	1004	2	5
06	9.0	89.0	-	1002	-	1004	2	5
12	9.5	89.0	1.5	1002	25	1006	4	6
18	10.0	89.0	1.5	1002	25	1006	4	6
25 00	10.5	89.0	1.5	1002	25	1006	4	6
06	11.0	88.5	2.0	1000	30	1006	6	6
12	11.0	88.0	2.5	996	35	1004	8	7
18	11.0	88.0	2.5	998	35	1006	8	7
26 00	11.0	87.5	3.0	994	45	1004	10	9
06	11.0	87.5	3.5	991	55	1006	15	10
12	11.5	87.5	3.5	987	55	1002	15	10
18	11.5	87.0	3.5	991	55	1006	15	10
27 00	12.0	87.0	3.5	989	55	1004	15	10
06	13.5	87.0	4.5	974	77	1004	29.4	10
12	14.5	87.0	4.5	972	77	1002	29.4	10
18	14.5	87.0	4.5	974	77	1004	29.4	10
28 00	15.0	87.2	4.5	972	77	1002	29.4	10
06	16.0	87.8	5.5	952	102	1004	51.6	10
12	16.5	88.0	5.5	950	102	1002	51.6	10
18	17.5	88.5	6.0	934	115	1000	65.6	10
29 00	18.5	89.0	6.5	920	127	1000	80.0	10
06	20.0	90.0	6.5	922	127	1002	80.0	10
12	20.5	90.5	6.5	918	127	998	80.0	10
18	22.0	91.5	6.5	920	127	1000	80.0	10
30 00	23.7	92.7	-	994	30	1000	6	6
06	25.5	94.5	-	996	15	998	2	5

TABLE 2: BEST TRACK POSITIONS ALONGWITH OTHER PARAMETERS OF CYCLONIC STORM, 31ST MAY - 2ND JUNE 1991.

TIME (UTC)		CENTRE POSITION LAT. (deg.N)	LONG. (deg.E)	T. NO.	MIN. SURFACE PRESSURE (hPa)	MAX. WIND (kt)		OUTER MOST CLOSED ISOBAR (hPa)	ΔP (hPa)	SIZE OF THE STORM'S OUTERMOST ISOBAR (deg.Lat.)
(1)		(2)	(3)	(4)	(5)	(6)		(7)	(8)	(9)
MAY										
31	00	13.5	90.5	-	1000	-	del	1002	2.0	5
	06	15.0	89.5	1.5	998	25	D	1002	4.0	6
	12	16.0	89.0	2.0	996	30	DD	1004	6.0	6
	18	16.5	88.7	2.0	996	30		1002	6.0	6
JUNE										
1	00	17.0	88.5	2.5	994	35		1002	7.0	7
	06	19.0	89.0	2.5	994	35		1002	8.0	7
	12	19.5	89.5	3.0	990	45	CS	1000	10.0	8
	18	20.0	89.5	3.0	992	45		1002	10.0	6
2	00	22.5	91.0	3.0	990	45		1000	10.0	6
	06	25.0	93.0	-	996	25	D	1002	6.0	6
	12	25.5	94.5	-	1000	15	NML	1002	2.0	3

TABLE 3: BEST TRACK POSITIONS ALONGWITH OTHER PARAMETERS OF CYCLONIC STORM 11 - 15 NOVEMBER, 1991.

TIME (UTC)		CENTRE POSITION LAT. (deg.N)	LONG. (deg.E)	T. NO.	MIN. SURFACE PRESSURE (hPa)	MAX. WIND (kt)	OUTER MOST CLOSED ISOBAR (hPa)	△P (hPa)	SIZE OF THE STORM'S OUTERMOST ISOBAR (deg.Lat.)
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
NOVEMBER									
11	00	10.0	91.5	-	1008	- del	1010	2	4
	06	10.5	90.0	-	1008	-	1010	2	5
	12	11.0	87.5	1.5	1006	25	1010	4	5
	18	11.0	87.5	1.5	1006	25	1010	4	5
12	00	11.0	87.0	1.5	1006	25	1010	4	6
	06	11.0	86.5	1.5	1004	25	1008	4	6
	12	11.0	86.0	1.5	1004	25	1008	4	6
	18	11.0	85.0	1.5	1004	25 D	1008	4	7
13	00	11.0	84.5	1.5	1004	25	1008	4	7
	06	11.0	83.5	2.0	1004	30 DD	1010	6	7
	12	11.0	83.0	2.5	1000	35	1008	8	7
	18	11.0	82.0	2.5	1000	35	1008	8	7
14	00	11.0	81.0	2.5	1000	35	1008	8	8
	06	10.5	80.5	3.0	1000	45 CS	1010	10	8
	12	11.0	80.5	3.0	998	45	1008	10	8
	18	11.2	80.0	3.0	998	45	1008	10	8
15	00	11.5	79.7	2.5	1000	35	1008	8	7
	06	12.0	79.3	-	1002	30 DD	1008	6	6
	12	12.5	79.0	-	1000	25 D	1004	4	5
	18	12.5	78.5	-	1002	15 WML	1004	2	4

TABLE 4: 12, 24 AND 36 HOUR FORECAST POSITION ERRORS FOR INDIVIDUAL TROPICAL CYCLONES OVER THE BAY OF BENGAL BASED ON ANALOG FORECST MODEL.

TROPICAL CYCLONES	FORECAST ERRORS (KM)		
	12 HOUR	24 HOUR	36 HOUR
24 - 30 April, 1991	190	290	80
31 May-2 June, 1991	300	-	-
12-16 November, 1991	160	170	100
AVERAGE	217	230	90

TABLE 5: 12, 24, 36 AND 48 HOUR FORECAST POSITION ERRORS FOR TROPICAL CYCLONES AND DEPRESSIONS IN THE BAY OF BENGAL AND THE ARABIAN SEA IN 1991 BASED ON CLIMATOLOGY, PERSISTENCE AND CLIPER MODELS.

Tropical Cyclone/ Depression	12 hour			24 hour			36 hour			48 hour		
	A	B	C	A	B	C	A	B	C	A	B	C
1. 24-30 April	-	118	-	-	238	-	-	372	-	-	534	-
2. 31 May-2 June	-	193	212	-	465	586	-	926	-	-	1266	-
3. 27-31 July	109	138	117	205	312	240	311	537	406	440	752	589
4. 22-26 August	107	91	84	167	183	150	232	332	252	291	556	381
5. 21-22 Sept.	126	71	96	238	167	198	-	-	-	-	-	-
6. 12-14 October	-	-	-	-	-	-	-	-	-	-	-	-
7. 28-30 October	66	55	59	109	124	102	124	191	149	175	275	225
8. 12-16 Nov.	89	77	64	201	153	160	298	205	191	321	335	222
Average:	99	106	105	184	235	239	241	427	249	307	620	354

A - Climatology; B - Persistence; C - Average (CLIPER)

MEANING OF THE SYMBOLS USED IN FIGURES

	Sea level position of depression/cyclone (with wind speed up to 63 kt)
	Sea level position of severe cyclonic storm with a core of hurricane winds (wind speed 64 kt or more)
—	Convergence in vergence field
+	Divergence in vergence field
	Downward vertical velocity
	Upward vertical velocity

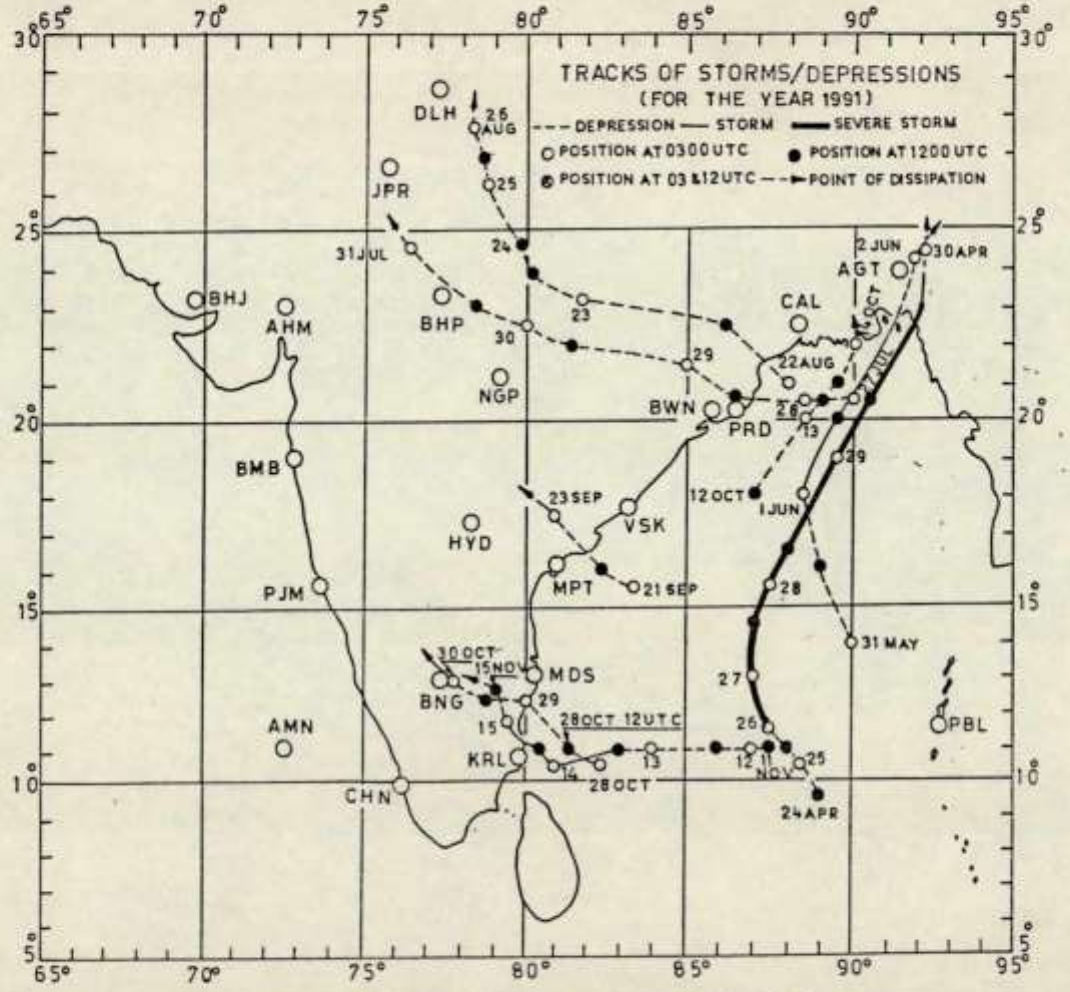

FIG. 1: **TRACKS OF CYCLONES AND DEPRESSIONS OF 1991**

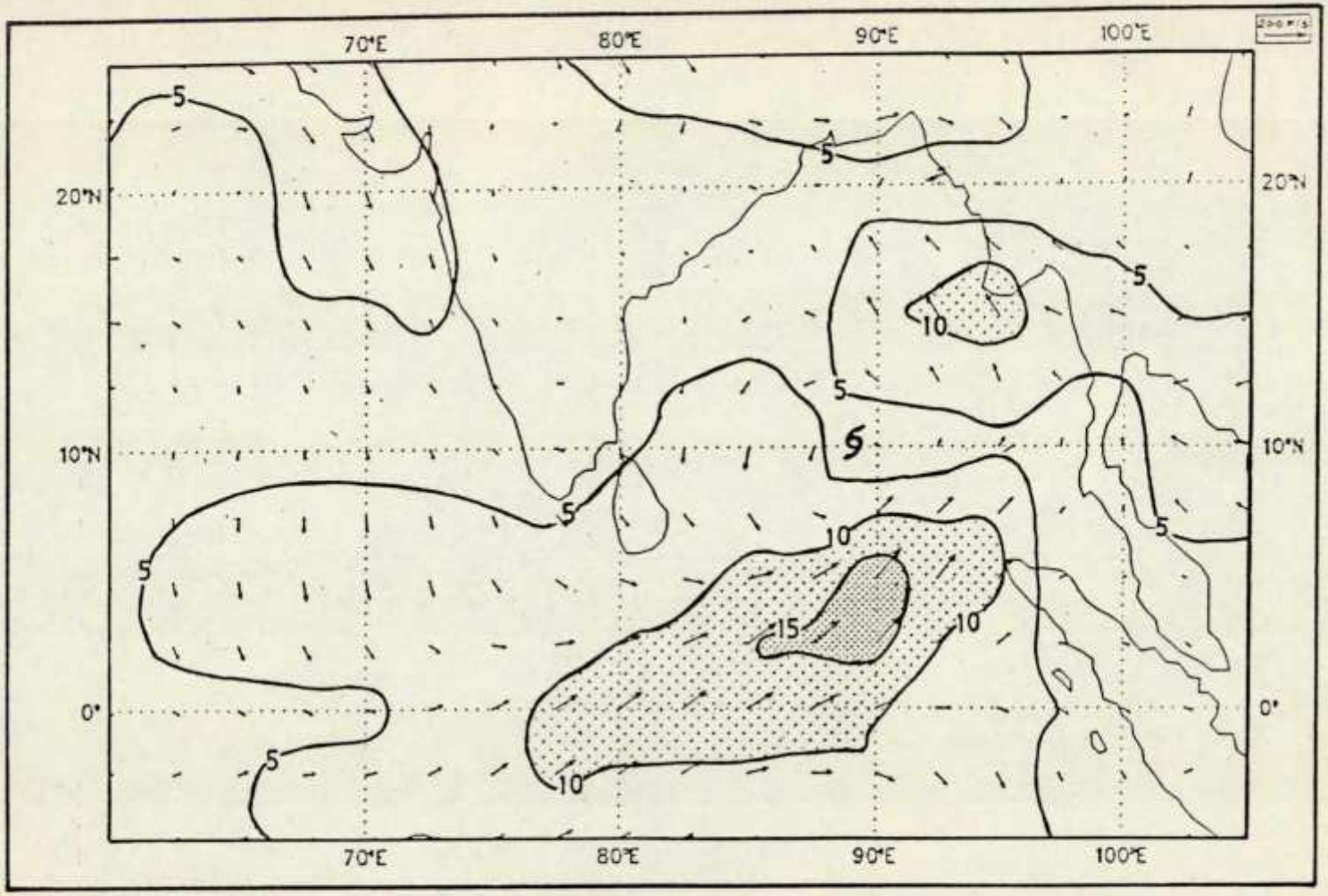

FIG. 2: ISOTACH ANALYSIS OF 850 hPa FOR 0000 UTC OF 25 APRIL, 1991 (UNIT: ms^{-1})

FIG. 3: INSAT-1D SATELLITE IMAGERY - 0900 UTC OF 29 APRIL, 1991

FIG. 4: INSAT-1D SATELLITE IMAGERY - 0800 UTC OF 1 JUNE, 1991

FIG. 5: INSAT-1D SATELLITE IMAGERY - 0800 UTC OF 14 NOVEMBER, 1991

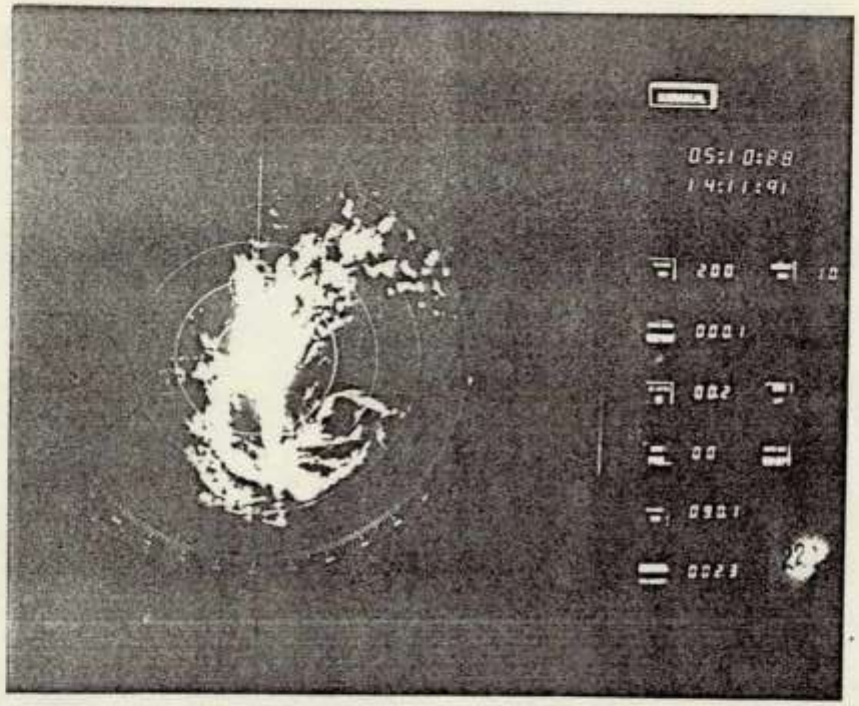

FIG. 6: RADAR PICTURE OF CYCLONE - 0500 UTC OF 14 NOVEMBER, 1991

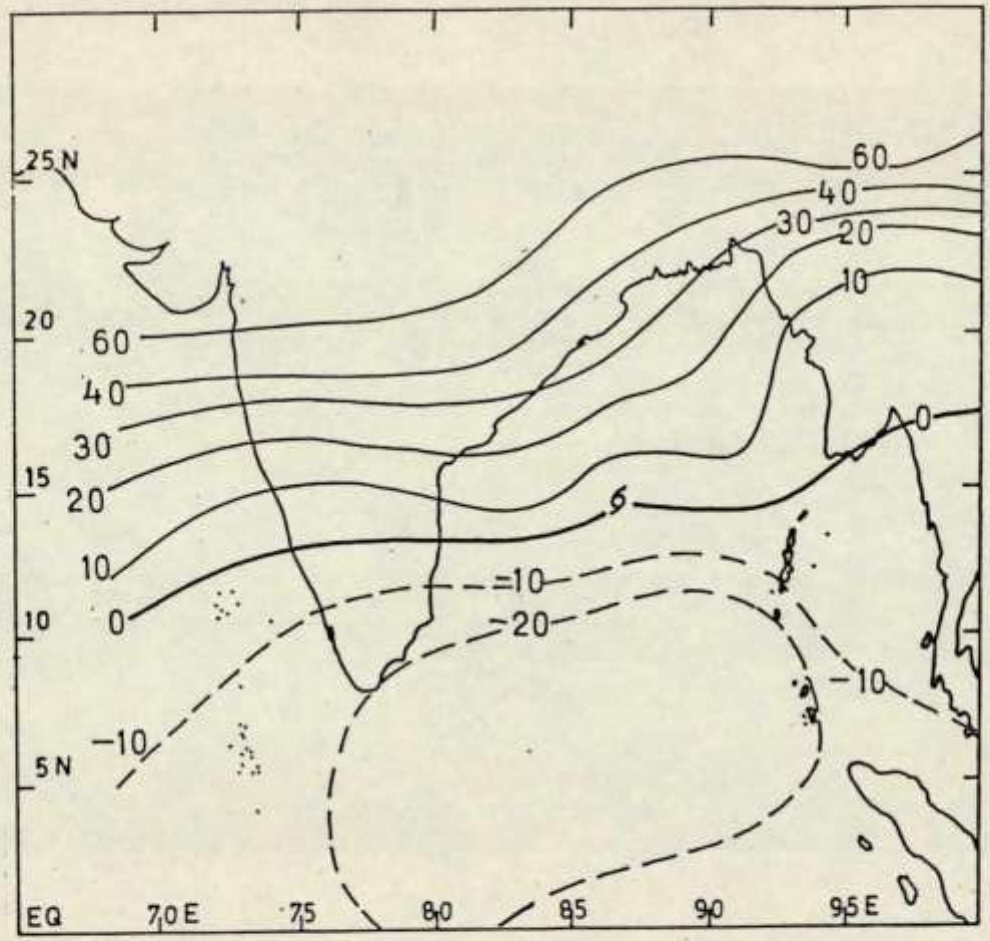

FIG. 7: VERTICAL SHEAR OF ZONAL WIND BETWEEN 850 AND 200 hPa AT 1200 UTC OF 27 APRIL, 1991 (UNIT: Knot 650 hPa^{-1})

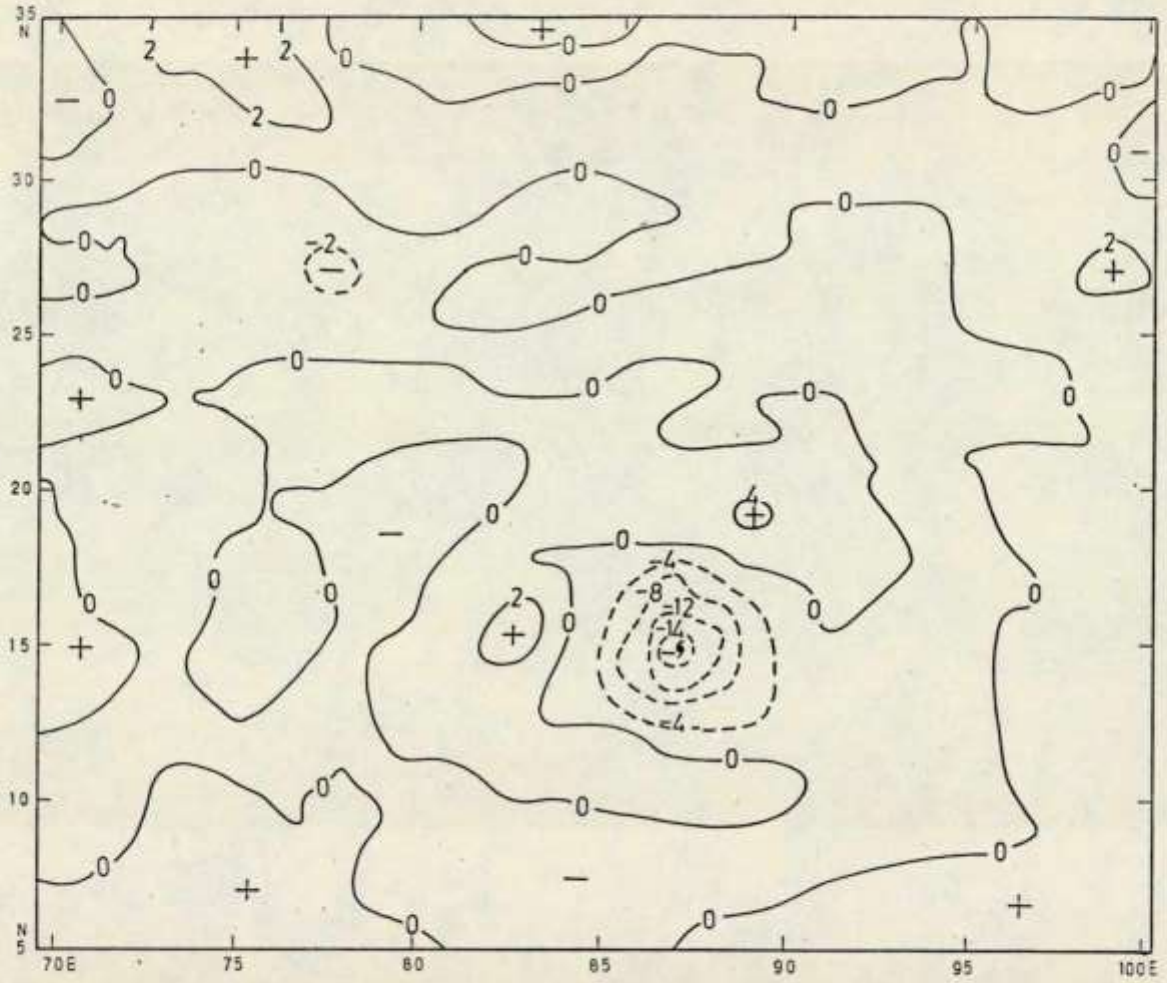

FIG. 8(a): VERGENCE AT 850 hPa - 0000 UTC OF 28 APRIL, 1991 (UNIT: 10^{-5} SEC^{-1})

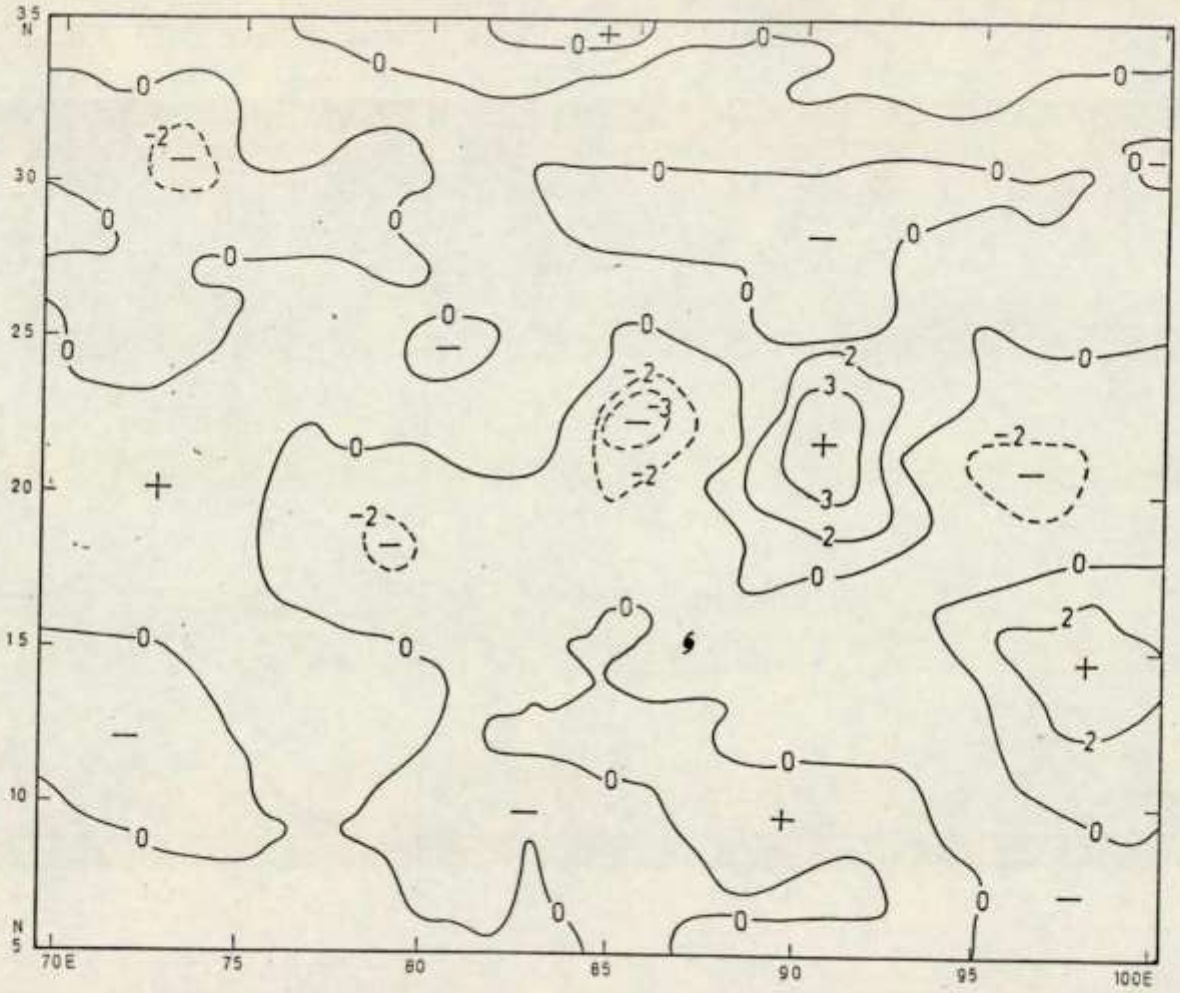

FIG. 8(b): VERGENCE AT 500 hPa - 0000 UTC OF 28 APRIL, 1991 (UNIT: 10^{-5} SEC^{-1})

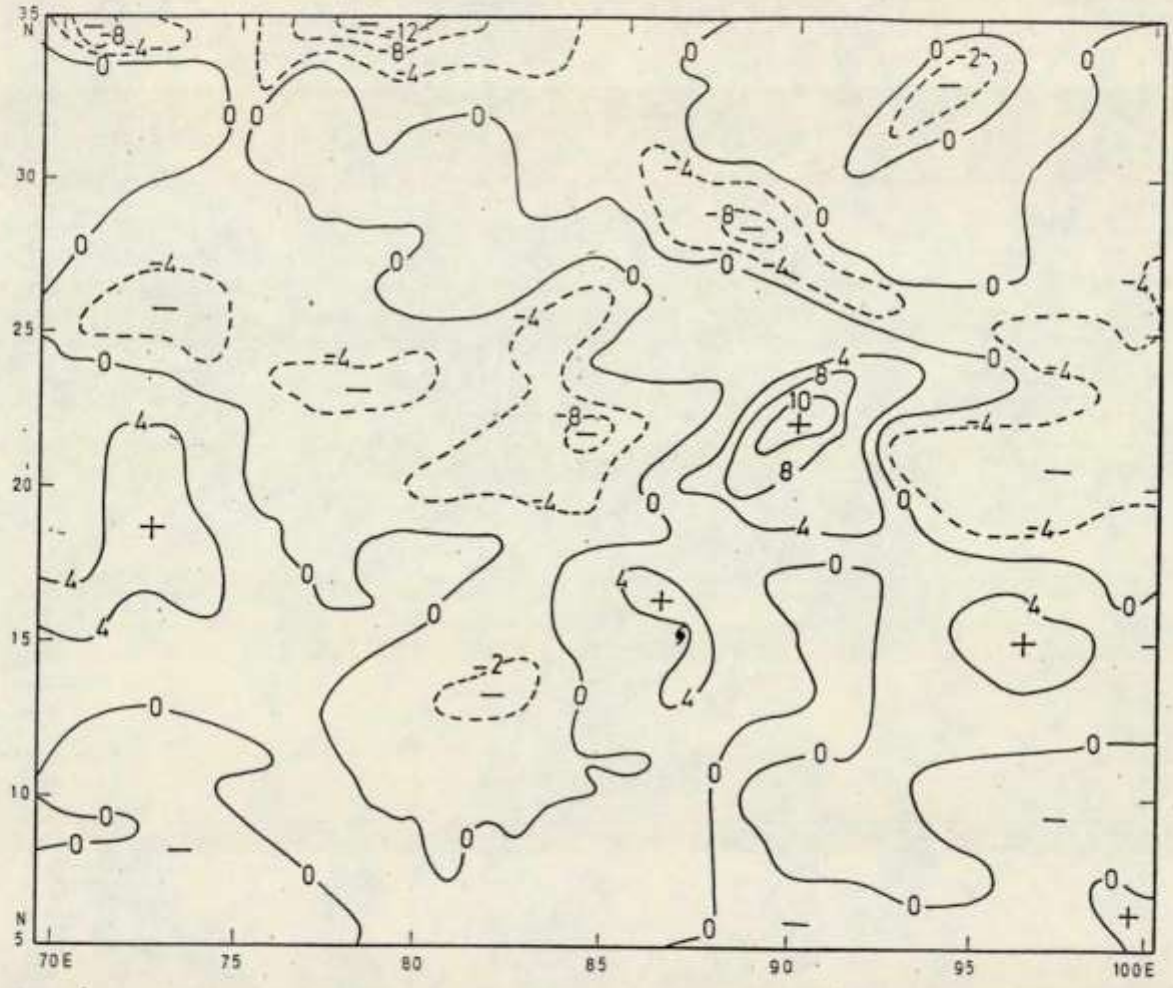

FIG. 8(c): **VERGENCE AT 200 hPa - 0000 UTC OF 28 APRIL, 1991 (UNIT: 10^{-5} SEC^{-1})**

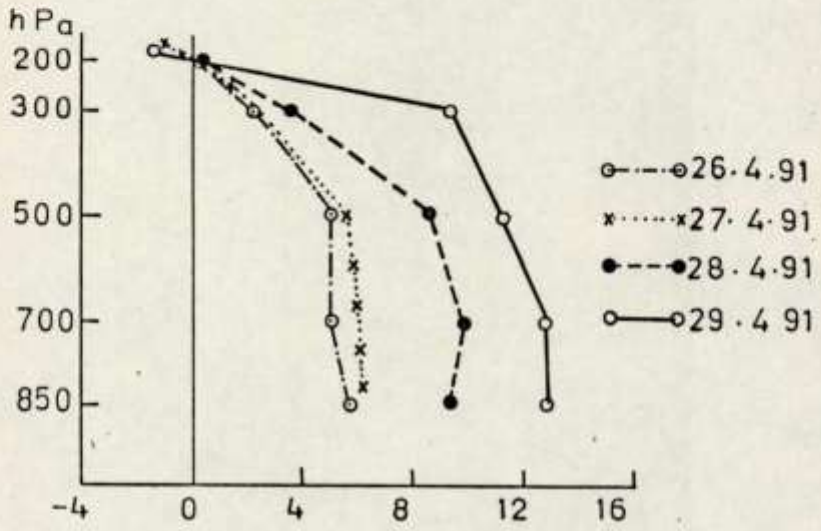

FIG. 9: RELATIVE VORTICITY PROFILES AVERAGED WITHIN 4° RADIUS OF CYCLONE CENTRE FOR 0000 UTC OF 26, 27, 28, AND 29 APRIL, 1991 (UNIT: 10^{-5} sec^{-1})

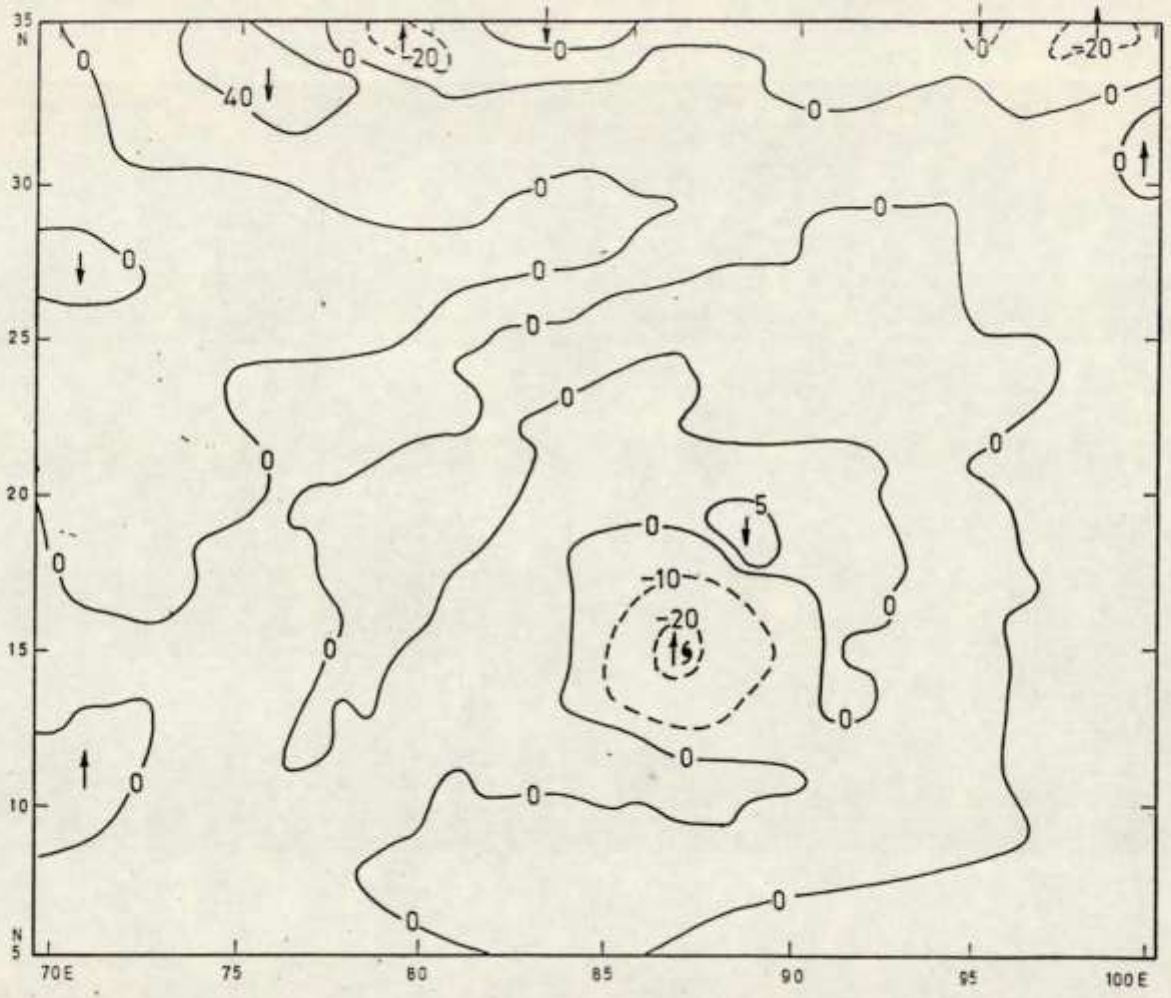

FIG. 10(a): VERTICAL VELOCITY FIELD AT 850 hPa - 0000 UTC OF 28 APRIL, 1991 (UNIT: 10^{-3}hPa SEC^{-1})

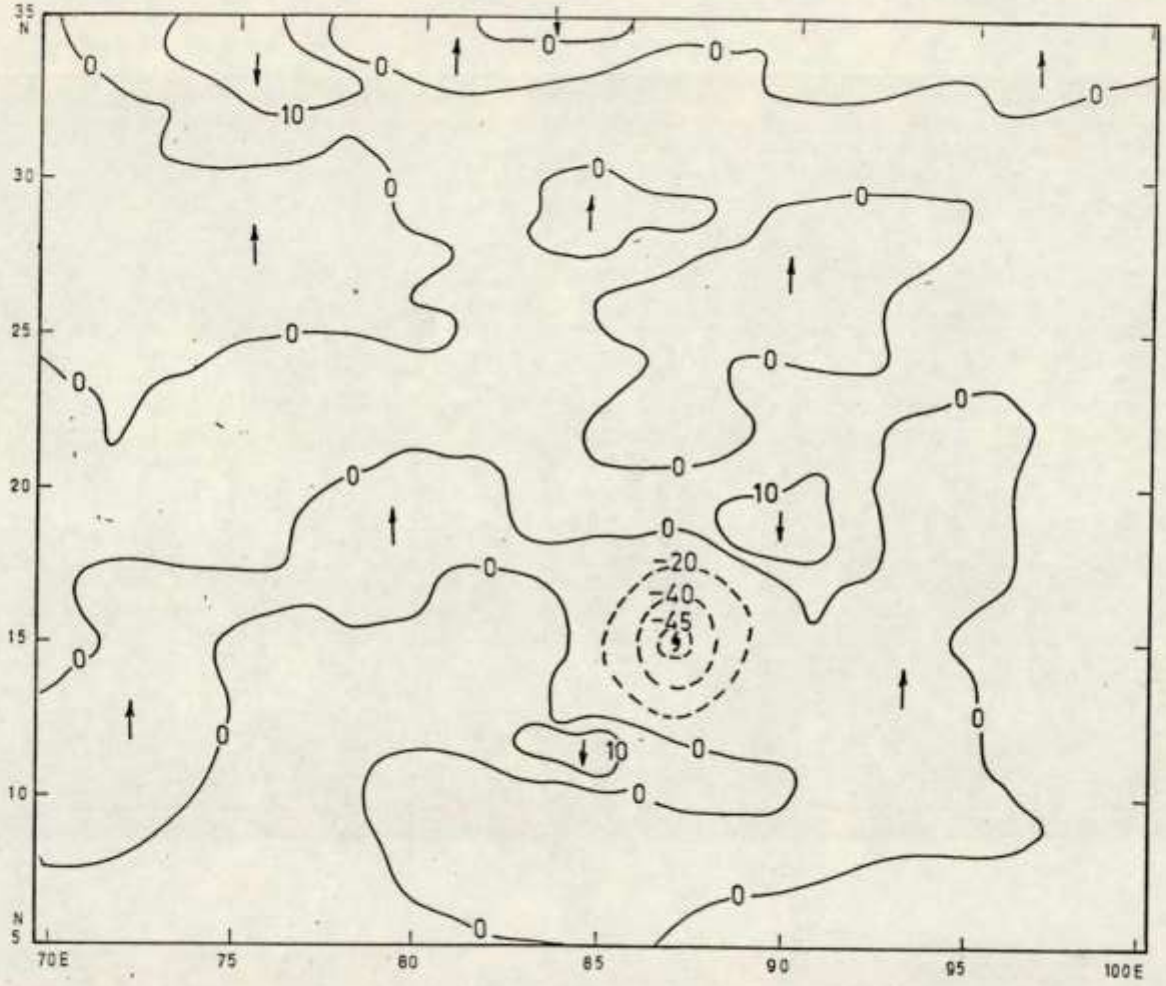

FIG. 10(b): VERTICAL VELOCITY FIELD AT 500 hPa - 0000 UTC OF 28 APRIL, 1991 (UNIT: 10^{-3}hPa SEC^{-1})

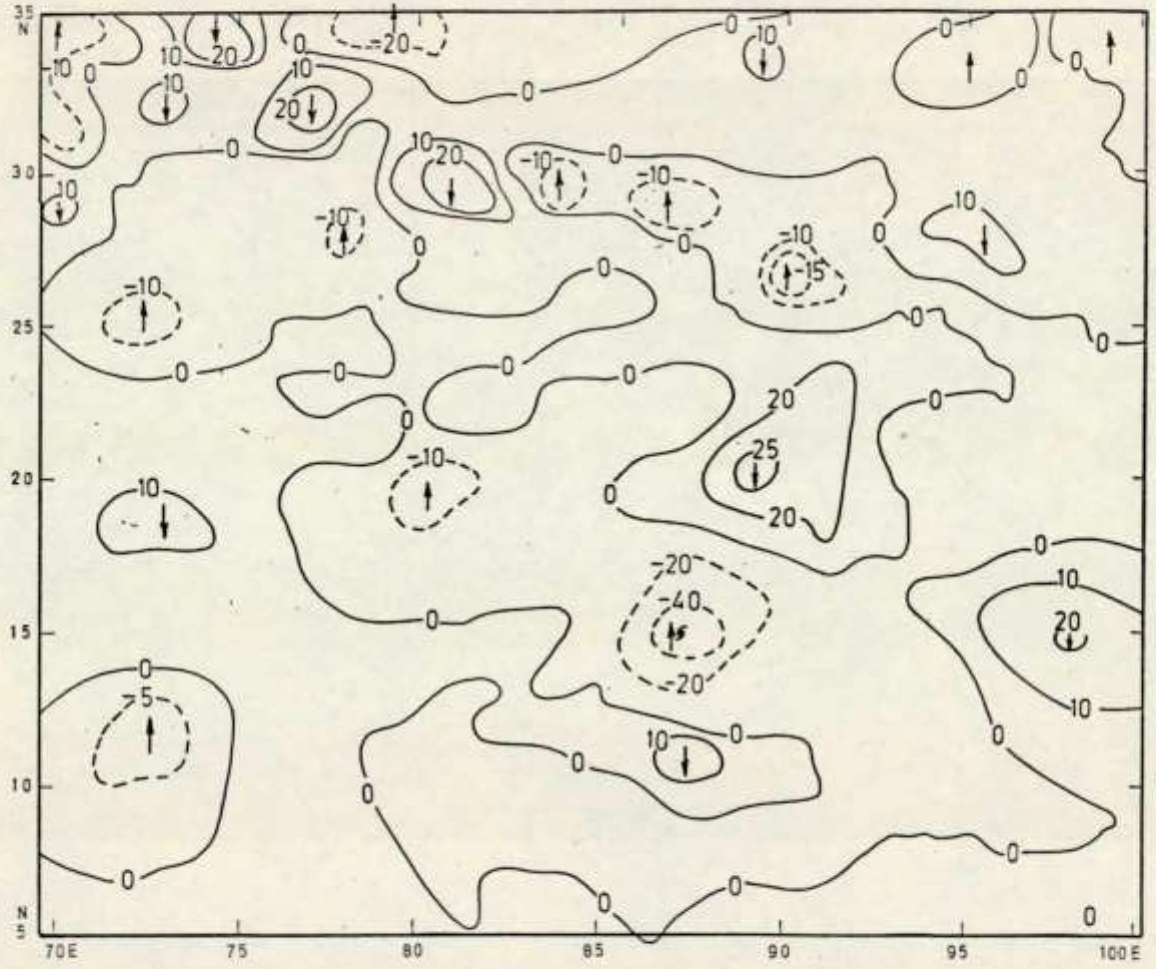

FIG. 10(c): VERTICAL VELOCITY FIELD AT 200 hPa - 0000 UTC OF 28 APRIL, 1991 (UNIT: 10^{-3}hPa SEC^{-1})