REPORT ON CYCLONIC DISTURBANCES (DEPRESSIONS AND TROPICAL CYCLONES) OVER NORTH INDIAN OCEAN IN 1990

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INTRODUCTION

This is a report on cyclonic disturbances (depressions and tropical cyclones - as defined in WMO TCP-21) formed over North Indian Ocean and adjoining land areas during the year 1990. The definitions of cyclonic disturbances over the North Indian Ocean as included in the above WMO TCP-21 are given below:

	Weather System	Maximum wind speed
1.	Low	Wind speed less than 17 kt.
2.	Tropical depression	Wind speed between 17 and 33 kt. (31 and 61 kmph)
3.	Cyclonic storm	Wind speed between 34 and 47 kt. (62 and 88 kmph)
4.	Severe cyclonic storm	Wind speed between 48 and 63 kt. (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 term 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. The term Tropical Cyclone or Cyclone is used to indicate all classes of disturbances indicated under (3) to (5).

There were 10 cyclonic disturbances over the North Indian Ocean in 1990. Out of these 10 cyclonic disturbances, only one disturbance (depression) formed over the Arabian Sea and the remaining cyclonic disturbances formed over the Bay of Bengal.

Eight out of the ten cyclonic disturbances were depressions and two were tropical cyclones. Out of the two cyclones, one formed during the pre-monsoon season (March-May) and other during the post-monsoon season (October-December) in the Bay of Bengal. This is the fifth consecutive year when there was no cyclonic storm in the Arabian Sea. Out of eight depressions, four formed during the monsoon season (June-September) and 4 during the post-monsoon season over the Bay of Bengal. Out of 4 depressions of the post-monsoon season, 3 formed in the Bay of Bengal and one in the Arabian Sea.

On an average, 16 cyclonic disturbances and 6 tropical cyclones form annually over the North Indian Ocean. During the past 10 years, the corresponding figures are about 9 and 3.

The tropical cyclone which formed over the Bay of Bengal in the month of May was a severe cyclonic storm with a core of hurricane winds (hereafter also called hurricane) while the one which formed in the month of December was a severe cyclonic storm. The May cyclone is one of the most intense tropical cyclones formed in the past over the Bay of Bengal in the month of May. This system crossed Andhra Pradesh coast in India in the evening of May 9, 1990 about 40 km southwest of Machilipatnam (43185) causing considerable damage to properties and loss of human lives. The tropical cyclone which formed in the month of December, however, weakened into a depression over the North Bay of Bengal before crossing coast near Cox's Bazar (41992) in Bangladesh in the night of 18-19 December, 1990. The tracks of these cyclonic disturbances are shown in Fig.1.. In Table 1 to 10, the best track positions of these disturbances at 6 hourly intervals alongwith other meteorological information for individual tropical cyclones and depressions with intensity T 1.0 and above (on Dvorak's scale) are shown.

Detailed discussions on individual tropical cyclones and depressions are given in the following sections. While doing so, the tropical cyclones are dealt in more detail as they only cause large scale damage to the properties and loss of lives.

2. PRE-MONSOON SEASON CYCLONIC DISTURBANCES

2.1 Machilipatnam Cyclone, May 4-9, 1990

2.2 Life history of the cyclone (May, 1990)

The system originated as a depression over the southwest Bay of Bengal on the night of 4-5 May, 1990. It concentrated into a deep depression by 5th morning and was centred near Lat. 10.0^{o}N Long 85.0^{o}E, about 600 km. southeast of Madras (43279). Moving initially in a westerly direction it intensified into a cyclonic storm by 1000 UTC the same day and lay with its centre about 500 km. southeast of Madras. Moving further in a northwesterly direction it became severe and attained hurricane intensity and lay on the morning of 6th May near Lat. 10.5^{o}N Long. 83.5^{o}E, which is about 450 km. southeast of Madras. Continuing the drift towards northwest the hurricane was centred near Lat 11.0^{o}N Long.

82.2°E, which is about 300 km. southeast of Madras on 7th morning. Thereafter it took a north-north-westerly course and lay about 150 km northeast of Madras on the morning of 8th May 1990. Moving slowly further to the north and intensifying continuously it crossed south Andhra Pradesh coast of India near the mouth of the river Krishna as a severe cyclonic storm with a core of hurricane winds at about 1330 UTC of May 9, 1990. After crossing the coast the system moved in a north-westerly direction and lay centred as a cyclonic storm near Gannavaram (43181) on 10th morning. Thereafter, it moved in a northerly direction and weakened further over land by 11th evening. A chart showing the locations of various stations referred in the description of this cyclone is shown in Fig. 2.

2.3 Monitoring and tracking of cyclone

The cyclone was continuously monitored with the help of INSAT-IB cloud imageries from its formative stage till its dissipation over the land. Over the sea area it was mainly tracked by the satellite cloud imageries from 4 to 6 May, 1990. From the evening of May 6, when the cyclone came within the Range of cyclone detection radars (CDR), it was tracked by the CDRs at Madras (43279), Machilipatnam (43185) and Visakhapatnam (43149) till its landfall over Andhra coast on 9th evening. Frequent surface observations and six-hourly rawin ascents were also taken by the coastal observatories located over Tamil Nadu and Andhra Pradesh during the cyclone period in order to help tracking the cyclone.

First indication about the formation of the cyclone was observed in the INSAT-IB cloud imageries of 4th night. Continuous intensification of the system was indicated by the satellite pictures till the morning of 8th May when the cyclone attained its peak intensity (Fig. 3) of T 6.5 on Dvorak's scale. The maximum sustained winds associated with the cyclone at this stage were estimated to be of the order of 127 kts (235 km per hour). The cyclone showed signs of slight weakening in the cloud configuration before the time of landfall on 9th evening. The intensity of the cyclone at the time of landfall was estimated as T5.5 with associated maximum sustained winds of the order of 102 kt. (about 190 km per hour).

The "eye" of the storm was first seen by the Cyclone Detection Radar (CDR) at Karaikal (43346) at 1800 UTC of May 6, 1990 when the cyclone was centred at a distance of about 340 km. from the station. Hourly radar fixes of the "eye" were given by Karaikal radar from 0000 UTC of 7th till 0900 UTC of 8th May. CDR Madras tracked the cyclone from 1500 UTC of 6th to 1500 UTC of 9th May. The radar observation of 1400 UTC of 9th May reported distinct "eye" even after the cyclone had crossed the coast and was located over land about 30 km. southwest of Machilipatnam. At 1500 UTC, however, the "eye" had completely dissipated and was seen as a weak small arc of 120 degrees length. CDR Machilipatnam gave hourly fixes of the "eye" from 0000 UTC of 8th till 1200 UTC of 9th May. No observation could be taken from this radar after 1200 UTC of 9th as water entered into the radar display room due to very heavy rain at the station in association with the cyclone. The cyclone detection radar at Visakhapatnam also tracked the cyclone from 2300 UTC of 8th till 1400 UTC of 9th May. As the cyclone lay more than 300 km away from the station, only "partial eye" was seen on this radar.

The CDRs at Madras and Machilipatnam observed "Double eye wall" of the cyclone in some of their hourly observations on 8th and 9th May. Madras reported "double eye" of the cyclone from 0600 to 1800 UTC on the 8th, while Machilipatnam reported it at some of the observations between 0900 UTC of 8th and 0700 UTC of 9th May. The average diameter of the "eye" considering all observations of Machilipatnam Radar was found to be about 29 km. The radar picture of the cyclone at 1100 UTC of 8th May showing the "double eye wall" is presented in Fig. 4. Interestingly, the cyclone centres given by the radars and the INSAT cloud imageries were in good agreement with each other.

2.4 Meteorological features

2.4.1 Pressure

In absence of actual observations from the cyclone field the lowest central pressure for the cyclone could be estimated with the help of the empirical relationship between satellite classification of the cyclone (T-Number), maximum wind speed and the pressure drop at the centre of the cyclone. As mentioned earlier, the peak intensity attained by the cyclone was T 6.5 on 8th

May, which corresponds to a pressure drop of 80 hPa. Taking the ambient surface pressure in the cyclone field as 1000 hPa, the central pressure of the cyclone on 8th May at the time of peak intensity was estimated to be 920 hPa. This pressure value however, differs slightly from the lowest surface pressure of 912 hPa recorded by the Ship 'Viswamohini' at 1200 UTC of 8th May when it seems the ship was located in the eye region of the cyclone. At this time the winds reported by the ship were around 3-4 on the Beaufort Scale (7-16 kts.) with slightly improved visibility as compared to outer fringe region of the storm as recorded by the ship. If the surface pressure value reported by the ship 'Viswamohini' is taken as correct, this may perhaps be the lowest pressure ever recorded in the Bay of Bengal region during the passage of a tropical cyclone. However it may be mentioned that the estimated lowest ever pressure in a Bay of Bengal cyclone was 911 hPa in the case of November 1977 Chirala (Andhra Pradesh 14-19 November) cyclone.

Over the land, the observatory at Machilipatnam, situated at a distance of 50 km. from the cyclone centre at 1330 UTC of 9 May, 1990 recorded the lowest pressure of 964.5 hPa. The barogram of Machilipatnam observatory for 9th May is shown in Fig. 5. Taking the central pressure of the storm as 920 hPa as estimated above, the pressure gradient between Machilipatanm and the landfall point works out to be about 0.9 hPa per km. Further inland, Bapatla observatory recorded the lowest surface pressure of 963.0 hPa at 1745 UTC when the cyclone lay at a distance of about 26 km. to the north of the station. From the nature of the damages seen around Bapatla the maximum sustained winds were estimated to be about 200 KMPH. Assuming the same pressure gradient of 0.9 hPa stil prevailing, the central pressure of the cyclone at this time works out to be about 940 hPa, thus suggesting that the intensity of the cyclone had slightly decreased after landfall. This was in agreement with the satellite and radar observations of 2300 hrs. of 9th May which also showed slight weakening of the system since 2030 hrs (1500 UTC) observation.

2.4.2 Winds

In absence of actual observations from the cyclone field, the maximum sustaind surface wind can only be estimated from the satellite cloud observation. The maximum intensity of the tropical cyclone as determined from the satellite pictures during the life cycle of this cyclone was T 6.5 in Dvorak's scale. Corresponding wind speed utilizing an empirical formula for the region works out to be 127 kt (235 KMPH). The estimation of wind speed from the damage report is another source of wind observation around the cyclone field in absence of actual observation. The wind observations around the cyclone field over land as estimated by the touring officer from the damage report is shown in Fig. 6.

Gale force winds were experienced in the coastal districts of Guntur and Krishna in Andhra Pradesh in association with the cyclone. As the cyclone approached the coast, surface winds at the coastal stations rose to an estimated speed of 150 km per hour. But immediately after the passage of the cyclone, winds of comparatively greater speed (estimated at 200 km per hour or more) were experienced in the above two districts. The damages due to gale winds were found to be much more severe in the rear of the storm, particularly in the left rear sector.

Hourly surface observations recorded at Machilipatnam Observatory indicated the commencement of gale winds of speed about 100 km per hour at the station from 1000 UTC of 9th May. At this time the cyclone was out in the sea centred at about 90 km away from the station. The wind speed at Machilipatnam rose to about 140 km per hour at 1200 UTC as the storm came closer to the coast and remained so till about 2100 UTC of 9th. The above observations also indicated that the winds in the rear of the cyclone were of higher speed than in the front.

2.4.3 Rainfall

In association with the cyclone widespread heavy to very heavy rainfall occurred in Coastal Andhra Pradesh and adjoining parts of Tamil Nadu during 8-12 May, 1990. The rainfall was particularly heavy in Guntur, Krishna, East Godavari, Visakhapatnam and Vizianagaram districts of Coastal Andhra Pradesh from where several stations reported 20 Cm or more of rain on both 10th and 11th May. An exceptionally heavy rainfall of 52.5 cm. was recorded at Yeleswaram in East Godavari district on May 11. A total of 110 cm, the highest amount in Andhra Pradesh, was recorded at this station during the period 8-12 May, 1990.

The isohyetal map of total rainfall for the storm period 8-12 May, 1990 over Coastal Andhra Pradesh is shown in Fig. 7.

2.4.4 Tidal wave / storm surge

The light house at Nagayalanka, which is situated on the mouth of the river Krishna, was close to the land fall point of the cyclone. The people who were present in the lighthouse at the time of landfall reported very high sea waves of the order of 5 metres. A rise in the level of sea water to about 12-15 feet above the normal tide level was also reported at Nagayalanka lighthouse during the passage of cyclone. At Edirumondi, situated in Krishna delta, the level of Krishna rose by 10-12 feet. On the basis of the above information it is assessed that the peak surge associated with the storm was of the order of 5 metres above the normal tide level at places near the landfall. At a distance of about 30 km. to the north of the crossing point, a surge of 2 to 3 metres was also reported along the coast near Machilipatnam.

Reports of sea water inundation of the coastal areas were also received. To the right of the storm track sea water entered over land upto a distance of about 20 km. Coastal stretch affected by the surge inundation was of the order of 100 km. Over the coastal areas to the left of the storm track there were no reports of sea water inundation over land.

2.5 <u>Damage</u>

The cyclone caused colossal damage to public and private properties in Andhra Pradesh. The loss of property was estimated at Rs.23,000 millions. A total of 5160 villages covering a population of 77.8 lakhs were affected by the cyclone. The loss of human lives in Andhra Pradesh due to the cyclone was reported as 928. Standing crops in 45,000 hectares of land were severely affected and more than 14 lakhs houses were either fully or partially damaged. Very heavy rainfall occurred in association with the cyclone and caused flash floods in coastal districts of Andhra Pradesh. This resulted in breaches of roads and rails and extensive damages to bridges, thus causing disruption in road and rail traffic in the above region for about a month.

The cyclone caused major havoc in Krishna and Guntur districts of Andhra Pradesh. Strong gales caused extensive damage to electric and telephone poles resulting in the breakdown of power supply and communication system in these districts for more than two weeks. Thousands of trees were uprooted. Banana plantations and mango Crops over vast stretches were damaged. Hundreds of thousands of poultry birds and thousands of live-stock also perished in the cyclone. The loss of human lives in Guntur and Krishna districts was reported as 561 (Guntur - 343 and Krishna -218). In Krishna district extensive areas of paddy fields wre inundated by sea/rain water.

According to the report of the survey team which visited the cyclone ravaged area immediately after the cyclone, coastal areas upto about 80 km. inland in Guntur and Krishna districts were affected by the gale winds speed reaching 200-220 km per hour. The Meteorological Observatory at Bapatla was considerably damaged. The roof of the Observatory building and the Stevenson Screen enclosures were blown off by strong gales. Some damage was also reported to the CDR Machilipatnam complex. Sea water gushed into the office compound and flooded the low lying areas through breaches in the compound wall. The anemometer cups of wind recorder at CDR Machilipatnam were also blown off by the gale force winds.

The cyclone caused only minor damages in Tamil Nadu. The worst affected area was the Chingleput district where one of the old shrines of Kasiviswanather Tample situated on the sea coast collapsed due to high waves which lashed the coast. Large number of huts on the coast were also washed away by the waves only six lives were reported lost in Tamil Nadu due to the cyclone.

2.6 Services provided by the India Meteorological Department

Cyclone warnings in India are provided in two stages of "Alert" and "Warning" 48 and 24 hours in advance of commencement of adverse weather and crossing coast respectively. Cyclone warnings are provided by the Cyclone Warning Centres located in the maritime states as well as from RSMC New Delhi. Detailed description of cyclone warning system in India is laid down in the Cyclone Operational Plan of the region (WMO TCP-21). In the case of May cyclone of 1990, adequate warnings were provided by the concerned Area Cyclone Warning Centres as well from RSMC New Delhi. Adequate co-ordinations were made by the IMD with the concerned State and Central Government authorities. As a result, the Government responded quickly and massive evacuation of people from vulnerable area was completed in time in Andhra Pradesh and Tamilnadu. In fact, a total of 6,50,000 people were evacuated to safer areas. This minimised the loss of human lives. It may be mentioned that a cyclone of similar intensity struck the same area in 1977 which took a toll of about 10,000 human lives.

2.7 Response from the Govt. and the User Organizations

The accuracy and timeliness of the cyclone warnings and advisories provided by the India Meteorolgoical Department (IMD) in connection with the Machilipatnam cyclone of May, 1990 were highly acclaimed by the Government officials, user organisations and the press. Prof. M.G.K. Menon, the then Minister of State for Science & Technology, Government of India and a noted scientist communicted his appreciation in writing to the Director General of Meteorology (DGM) on the good work done by the IMD in the area of cyclone detection, tracking and warning. The cyclone warning work of India Meteorological Department has been appreciated in the Parliament of the country. Copies of some of these appreciations are attached as Annex.I to the report.

2.8 Other scientific aspects of the May cyclone 1990

2.8.1 Structure

The tropical cyclone of May 1990 was a storm with moderate size having average diameter of the circulation field of about 1000 km towards its later part of life. The cyclone developed a double walled eye and the situation continued for more than 48 hours till its landfall on May 9, 1990. The system was tracked both by the Cyclone Detection Radars (CDRs) at Madras and Machilipatnam. These radars reported the diameter of the eye, Radius of Maximum Reflectivity (RMR) [which may be considered approximately as the diameter of the ring of the maximum wind] and the width of the eye wall. From the satellite observations the eye temperature information was also obtained for a limited period. Such information obtained from the CDR Madras is shown in Fig. 8(a) to 8(c) and from CDR Machilipatnam in Fig. 9(a) to 9(c). The eye temperature information from INSAT cloud imageries is shown in Fig. 10. From CDR Madras observation it may be seen that the eye diameter was varying from 40 km to about 20 km. On May 8, the average diameter was about 20 km when it was in its most intense stage. Eye wall width varied from about 5 km to 25 km. Similar variations were observed in the case of observations recorded by the CDR at Machilipatnam. These observations suggest that the cyclone was in its most intense stage on May 8.

2.8.2 Vertical wind shear

Vertical shear of the zonal winds between 200 and 850 hPa over the North Indian Ocean and adjoining land areas were computed in the case of cyclones and depressions. These values were calculated by utilizing the winds at 850 and 200 hPa from the land stations and 5 deg. latitude/longitude grid point winds available from the European Centre For Medium Range Forecasting (ECMWF), U.K. for the oceanic areas. The vertical wind shear values between 200 and 850 hPa in respect of the cyclone for 1200 UTC of 6 and 7 May are shown in Fig. 11(a) and 11(b).

One distinct feature in the case of May cyclone was that very strong anticyclonic vertical shear existed on 6th May north of the cyclone centre when the system was in the pre-hurricane stage. The vertical wind shear was almost nil over the storm centre and comparatively smaller cyclonic shear to its south. On May 7, vertical shear pattern was similar to that of 6 May with an east-west line of zero vertical wind shear passing through the centre of cyclone, accompanied by strong westerly shear to the north and easterly shear to the south of the cyclone indicating large horizontal gradient of vertical wind shear. Picture is typical of a tropical cyclone in its formative stage. The above features also suggest considerable horizontal temperature gradient to the north of the cyclone centre. The large anticyclonic shear over this region is attributed to the occurrence of stronger westerly winds at 200 hPa.

2.8.3 Distribution of other dynamical parameters in the cyclone field

Objective analysis

Objective analysis is carried out by three dimensional multivariate optimum interpolation (OI) method. The OI analysis produces fields of five basic parameters - geopotential height, u & v components of wind, temperature and relative humidity. From the u & v analysis various derived parameters, viz. vorticity, divergence, vertical motion and integrated horizontal flux of water vapour divergence etc. are obtained. The analysis is carried out on $1^{o} \times 1^{o}$ lat./long. grid in the horizontal and 12 levels in the vertical upto 50 hPa.

In view of the sparseness of data over the oceanic areas, there exists the problem of misrespresentation of the the cyclone vortex in the objectively analysed fields. The vortex may either be misplaced or completely missing in the final product. In order to handle the problem of misplaced vortex it is essential to carry out 'bogusing' by feeding synthetic data into the system at the pre-analysis stage or by introducing an artificial vortex after the analysis. In the present case bogusing is done by feeding synthetic data which were generated by empirical means. In the scheme adopted here the surface pressure distribution is first obtained via an empirical relationship proposed by Holland (1980) which has the form:

$$Pr = Pc + (Pe - Pc) \exp(-a/r^{b})$$

where Pr is the surface pressure at radius r, Pe is the environmental pressure, Pc is the central pressure, and a and B are empirical constants. The constants a and b are related to the radius of maximum wind (RMW) by the following equation:

$$RMW = (a)^{1/b}$$

The parameters Pc and RMW are obtained from the satellite and radar information, Pe is determined from a preliminary analysis of surface chart. The value of constant b is taken as 1.5 in the present case.

Once the surface pressure distribution has been determined, the surface wind distribution is obtained via the gradient wind relationship taking the storm motion into account. The upper air geopotential profile is computed hydrostatically from the surface pressure and first guess or analysed environmental temperature. The upper winds are obtained from the surface winds with a composite vertical wind shear factor. Data are generated upto 10 times the RMW in the horizontal and upto 300 hPa in the vertical.

The distribution of dynamical parameters as a result of objective analysis are discussed below.

2.8.3.1 Vergence field

The vergence field associated with the tropical cyclone and its neighbouring areas for 12 UTC at 850, 500 and 200 hPa of 7 and 8 May, 1990 are shown in Fig. 12(a) to 12(c) and 13(a) to 13(c) respectively. Low level convergence and high level divergence pattern around the cyclone centre is evident. There is also a slight increase in low level convergence on 8th compared to 7th showing the intensification of the system on 8th. Overall convergence - divergence fields around the storm centre were however, weaker than normal for such a strong tropical cyclone.

2.8.3.2 Vorticity field

The relative vorticity in respect of May 1990 cyclone at different radii for different levels and different dates were computed. The value of relative vorticity at different levels at 4 deg. radius around the storm centre from 00 UTC of 7 May to 12 UTC of 8 May at 12 hour interval have been shown in Fig. 14. Figures show level to level increase of relative vorticity from 7th to 8th indicating the on-going intensification of the system. The change in vorticity from cyclonic to anticyclonic took place between 300 and 100 hPa during this period.

2.8.3.3 Vertical velocity

The computations of vertical velocity around the cyclone field for 12 UTC of 7 and 8 May for 850, 500 and 200 hPa are shown in Fig. 15(a) to 15(c) and 16(a) to 16(c) respectively. The patterns are similar to the normal pattern of vertical velocity field observed in the case of mature tropical cyclone. The vertical velocity field is upward around the cyclone field. Strong downward motion away from the cyclone centre in the forward and rear sector normally seen in the case of mature tropical cyclone is evident from the diagramme.

2.8.4 Movement

During the initial stages of development of the storm it was located on the southern periphery of the sub-tropical high pressure cell over the Bay of Bengal. The ridge line at 200 hPa high pressure cell lay along latitude 14.0 deg. North till the evening of 7 May (Fig. 17). The storm came under the influence of south-easterly /southerly winds on the western periphery of the high pressure cell from 6th morning and thus changed its course from west to north-west. At the same time the winds at 200 hPa of coastal stations, Karaikal (43346), Madras (43279), Machilipatnam (43185) considerably strengthened from 15kts to 35 kts and the sub-tropical high pressure also showed northward shift by 2-3 deg. latitude. On the morning of 7th the 200 hPa ridge line lay along lat. 17.0 deg. North over the Bay of Bengal and remained at the same position till 10th evening (Fig. 18).

3. MONSOON SEASON (JUNE - SEPTEMBER) CYCLONIC DISTURBANCES

3.1 Deep Depression (13-15 June)

A depression formed over the northwest Bay of Bengal near lat. 21.0^{o}N, long. 89.0^{o}E at 1200 UTC of 13 June, 1990 during the onset phase of the southwest monsoon. Moving in a west-north-westerly direction, it crossed Orissa coast in India near Balasore (42895) on the morning of 14th June. The system intensified into a deep depression over the land on 14th evening and was centred near Jamshedpur (42798). Moving further west-north-west it weakened and dissipated over the eastern parts of Madhya Pradesh on 15th evening.

The maximum sustained wind speed associated with the system was 33 kts. at 1200 UTC of 14 June. The satellite cloud imagery of 0600 UTC of 14 June is shown in Fig. 19. Under the influence of this system the monsoon advanced further into Bihar and eastern parts of Madhya Pradesh.

3.2 Depression (14-17 August)

The depression developed on 14th August near Lat. 19.0°N, Long 87.5°E from a pre-existing disturbance in thé lower tropospheric levels embedded in the monsoon trough region over northwest Bay of Bengal. Moving in a west-north-westerly direction, it crossed north Andhra Pradesh - south Orissa coast on 15th morning. Continuing to move west-north-westwards as a land depression, it lay centred near lat. 22.0°N, Long 79.0°E on the evening of 16th August. The system dissipated over north-western parts of Madhya Pradesh on 17th August.

This depression increased the southwest monsoon activity over the Indian peninsula during the above period. The maximum sustained wind associated with this system was of the order of 27 kts. The INSAT cloud imagery of 0600 UTC of 15 August, 1990 is shown in Fig. 20.

3.3 Depression (20-24 August)

This depression formed over the north Bay of Bengal near lat. 20.0^{o}N, long. 89.0^{o}E at 0300 UTC of 20th August. The system moved west-northwest and crossed north Orissa coast near Paradip (42976) on 21st morning. It continued to move west-north-westwards over the land as a depression till 24th evening and dissipated over western parts of Rajasthan on 25th August.

The southwest monsoon activity over the northern and central parts of India was enhanced under the influence of this depression. The long west-north-westward track of the depression was due to the system being embedded in a deep easterly flow of an anticyclone in upper troposphere with ridge lines running along 30-32^{o}N latitude far to the north of the depression centre. The satellite cloud imagery of the depression at 0600 UTC of 20 August, 1990 is shown in Fig.21.

3.4 Depression (3-4 September)

The system developed from the remnant of Typhoon 'Becky' which crossed Bangladesh coast as a low pressure area on 1st September. The low pressure area moved westwards and intensified into a depression over the Gangetic West Bengal on 3rd September near lat. 22.5°N, long. 88.0°E. The depression was short-lived and rapidly dissipated over Bihar Plateau by the morning of 5th September.

4. POST MONSOON SEASON (OCTOBER - DECEMBER)

4.1 Depression (7-8 October)

A depression developed on 7th morning over north Bay of Bengal neat Lat. 20.0 Deg. North Long. 87.5 Deg. East from a pre-existing disturbance in the lower tropospheric levels during the withdrawal phase of southwest monsoon. The system initially moved in a northwesterly direction and crossed north Orissa - West Bengal coast on the morning of 7th October. Later, it came under the influence of a westerly trough in the middle and upper troposphere moving across north India on 8th October and recurved towards northeast. The depression dissipated over northern parts of Gangetic West Bengal by 9th morning.

4.2 Deep Depression (31 Oct. - 4 Nov.)

A low pressure area formed over the south Bay of Bengal on the morning of 31 October and intensified into a depresion on the same afternoon near Lat. 10.5 Deg. North, Long. 87.5 Deg. East. Moving north-north-west-wards it intensified into a deep depres- sion and was centred neat Lat. 16.0 Deg. North, Long 85.5 Deg. East on 2nd morning. The deep depression crossed south Orissa coast near Gopalpur (43049) on the evening of 3rd November. It rapidly dissipated over land by 4th evening.

The system attained the peak intensity of T 2.0 at 1800 UTC of 1st November as indicated by the INSAT cloud imageries and maintained the same intensity till 0600 UTC of 3rd November. The INSAT cloud imagery of 0600 UTC of 1 November 1990 is shown in Fig. 22. This system caused heavy rainfall over the coastal areas of south Orissa where it remained almost stationary for 3 days. This has caused high and flash floods locally resulting heavy damages to the properties and standing crops in south coastal Orissa.

4.3 Depression (14 - 15 November)

This depression formed on 14th morning near Lat. 14.0 Deg. North, Long 82.0 Deg. East from a pre-existing disturbance in the lower tropospheric level over Southwest Bay of Bengal off Tamilnadu coast (Fig. 23). Moving westwards, it crossed North Tamilnadu - South Andhra Pradesh coast on the evening of 14th Nov. and rapidly weakened into a low pressure area over the land. This system caused heavy rainfall at a few places in south Andhra Pradesh coast.

4.4 Depression (16-18 November)

This system formed from the remnant of the Bay of Bengal depression of 14-15 November which moved across the Indian Peninsula as a low pressure area and emerged into the east Arabian Sea on 16th Nov. It intensified into a depression near Lat. 14.5 Deg. North, Long 73.5 Deg. East on the same evening. Moving initially in a westerly direction and then slowly recurving towards north-east, the depression was centred near Lat. 15.5 Deg. North, Long 72.5 Deg. East on 18th morning. The system dissipated over the sea by the same evening.

The maximum intensity of the system was T 2.0 at 0530 UTC of 17th as indicated by the INSAT Satellite cloud imagery (Fig. 24). The maximum sustained surface winds associated with the system were of the order of 30 kts. on that day. The system did not cause any significant weather over the west coast of India.

4.5 Severe Cyclonic Storm (14-18 December)

The system developed as a depression in the ITCZ region over the South Bay of Bengal on 14th December near Lat. 8.0 Deg. North, Long 88.0 Deg. East. The depression moved initially in a northwesterly direction and intensified into a cyclonic storm and was centred near Lat. 12.0 Deg. North, Long 85.0 Deg. East on 16th morning. Moving slowly further northwards and then recurving towards the northeast, it intensified into a severe cyclonic storm and was centred on 17th morning near Lat. 16.5 Deg. North, Long 86.5 Deg. East, about 800 kms southsouthwest of Calcutta (42809). After 17th morning the cyclone came under the influence of south-westerly winds prevailing on the western periphery of the sub-tropical high pressure cell at 200 hPa with ridge line running along Lat. 13°N. The system attained the peak intensity of T 3.5 as indicated by the INSAT cloud imagery of 0600 UTC of 17th December (Fig.25) and maintained the same upto 2200 UTC of same day. The system weakened into a cyclonic storm in the morning of 18th and into a depression in the evening of 18th before crossing coast near Cox'Bazar in Bangladesh in the night of 18-19 December, 1990. The storm was kept under surveillance by the INSAT-1D satellite, Coastal CDRs at Visakhapatnam, Paradip and Calcutta in India and similar radars in Bangladesh. Full scientific and operational picture of this system will emerge after detailed observational data near the track and landfall point are available after it drifted away from the Indian coast.

5. TRACK PREDICTION BY MODELLING

The RSMC, New Delhi is running as a routine a few track forecasting models to obtain advisories regarding future positions of cyclonic disturbances. Forecasts are verified with respect to the best tracks. In this section, verification of forecast by different techniques for all the cyclonic disturbances formed in the Bay of Bengal and the Arabian Sea have been documented. Generally, climatology, persistence, analogue and statistical models are run as a routine. The analogue technique is run only for the tropical cyclones but other techniques are used for all the cyclonic disturbances. The statistical technique is at present not run in operational mode.

The analogue technique is run for obtaining the advisories for 12, 24 and 36 hours for tropical cyclones. The forecast errors by analogue method for different time projections for all the tropical cyclones formed during 1990 are shown in Table-11. Results indicate that the forecast for May tropical cyclone for all the hours by the analogue technique exhibited reasonable forecast skill. However, forecast errors for the recurving December cyclone are quite large. This indicates the inherent difficulty in dealing with recurving storms by such models.

6. ENVIRONMENTAL FLOW AND CLOUDINESS

In this section the atmospheric setting in terms of broad scale circulation features and mean fractional cloudiness over the region between 40^{o}E to 110^{o}E and 10^{o}S to 40^{o}N are discussed. For this purpose, information on Outgoing Longwave Radiation (OLR) has been used to determine the mean fractional cloudiness over 2.5 deg grid with threshold temperature values of 265^{o}K. The monthly cloudiness anomaly chart and mean monthly wind charts for 850 and 200 hPa for the region may be seen in Figs. 26 to 33. From the distribution of mean cloudiness over the region, it is seen that during the summer months of April and May the maximum convective area over the Bay of Bengal usually extends from the equator to 10^{o}N East of 85^{o}E. In June with the northward shift of the ITCZ over the North Indian Ocean the maximum convective area lies over the bay of bengal between 10^{o} and 20^{o}N over the Arabian Sea. In the month of July, August and September, the band of maximum cloudiness shifts to the north of 20° N. During October and November, the convective activity becomes more pronounced over the Bay of Bengal between the equator and 10° N, east of 86° E.

During the month of May 1990, the area of maximum cloudiness over the Bay of Bengal existed between the equator and 16° N, east of 88° E and over the Arabian Sea between 10° N and 14° N, east of 71° E. The maximum cloudiness shifted northward and covered whole of the north Bay of Bengal in the month of July. The mean maximum cloud band shifted southward in the month of August and lay between Lat. 10° N and 18° N, while in the mean pattern the maximum cloudiness was observed to the north of 20° N over the Bay of Bengal. This feature was reflected well in the synoptic weather conditions during this month. The monsoon depressions formed over the Bay of Bengal a little to the south of the normal position during this month.

The band of maximum cloudiness during the months of September to December did not show any significant change from the normal position.

The sub-tropical ridge line at 200 hPa in May 1990 lay between 12° N and 15° N over the North Indian Ocean. It showed a northward shift to 30° N in the month of August and thereafter it shifted southward. It lay along 18° N in October and further moved southward to 8 N in December, 1990. The ridge line in all the above months lay nearly along about the normal positions.

7. DISSEMINATION OF WARNINGS

The cyclone warnings were disseminated in India through various conventional modes like high priority telegrams, T/P, Telex, telephone and through electronic and print media. In the past it has been observed that Radio broadcast and telecast of cyclone warnings was most effective. For the past few years a satellite based communication system known as Disaster Warning System (DWS) is being utilised for thedissemination of cyclone warnings directly from the meteorological services to the cluster of population likely to be affected by cyclone. This is a unique system being used in this part of the world for communicating cyclone warnings with a view to ensuring their fail-proof receptions. This system functioned well during the 1990 cyclone season.

8. CO-OPERATION AMONG PANEL COUNTRIES

One of the prerequisites for improving cyclone warning services among the Panel countries of the WMO/ESCAP Panel on Tropical Cyclones is the increased co-operation among the Panel countries. The Regional Specialised Meteorological Centre (RSMC), New Delhi is issuing Tropical Weather Outlook daily since September, 1990. Tropical Cyclone Advisories are regularly being issued to the Member countries of the Panel from RSMC, New Delhi, whenever there is a cyclone in the North Indian Ocean.

During the 1990 cyclone season, RSMC - New Delhi regularly issued Cyclone Advisories along with observations to the countries concerned. During the December 1990 cyclone, New Delhi received CDR observations from Bangladesh which were very helpful in tracking the system.

9. CONCLUSION

In 1990, there were in all 10 cyclonic disturbances of which there were only two tropical cyclones and both of them originated in the Bay of Bengal. The cyclone, which developed in the month of May, crossed the Indian coast in Andhra Pradesh about 30-40 km southwest of Machilipatnam in the evening of May 9, 1990. This has caused considerable damage to properties and loss of lives. However, due to timely and adequate warnings and effective action taken by the State Governments to evacuate a very large population from the coastal areas, the loss of human lives was restricted to below one thousand inspite of the severity of the cyclone and the area being highly surge prone. The cyclone warning services in connection with the May cyclone, provided by the India Meteorological Department have been appreciated by the Government, User organizations and the public in general. An interesting fact about the cyclone is that it had developed a double walled eye. A ship from the eye region reported central pressure of 912 hPa, which is probably the lowest pressure ever recorded by any ship over this region.

The other tropical cyclone which formed over the Bay of Bengal in December, 1990, was also severe one but it weakened over the ocean before crossing the Bangladesh coast near Cox's Bazar in the evening of 18-19 December. Media reports indicated that there was some loss of properties and lives in Bangladesh in association with this cyclone also.

The depressions brought welcome rains to the Panel area. One of these depressions caused significant damages in India due to heavy rainfall.

/d:\kkp\pcl/

TABLE-1: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF SEVERE CYCLONIC STORM WITH A CORE OF HURRICANE WINDS, 4 - 10 MAY 1990 (Bay of Bengal)

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	T. NO.	MIN. SURFACE PRESSURE (hPa)	MAX.* WIND (kt)	OUTER MOST CLOSED ISOBAR	ΔP (hPa)	SIZE OF THE STORM OUTERMOST ISOBAR (Deg.Lat.)
MAY									
04	00	8.5	87.0	1.0	1006	16	1006	2	7
	06	8.5	87.0	1.5	1002	27	1006	4	10
	12	9.5	87.0	1.5	1000	27	1004	4	5
	18	9.5	86.0	1.5	1002	33	1006	4	6
05	00	10.0	85.5	2.0	998	33	1004	6	6
	06	10.0	85.0	2.5	999	35	1006	7	5
	12	10.1	84.7	3.0	994	45	1004	10	7
	18	10.3	83.9	3.5	991	55	1006	15	8
06	00	10.3	83.3	3.5	991	55	1006	15	8
	06	10.0	83.2	4.5	976	77	1006	29.4	8
	12	10.2	82.9	4.5	976	77	1004	29.4	8
	18	10.3	82.5	4.5	976	77	1006	29.4	10
07	00	11.3	82.3	5.0	964	90	1004	40.2	8
	06	11.3	81.8	6.0	940	115	1006	65.6	9
	12	11.4	81.7	6.0	938	115	1004	65.6	8
	18	14.5	80.8	5.5	950	102	1002	51.6	8
08	00	13.3	81.8	6.5	924	127	1004	80.0	9
	06	13.6	81.4	6.5	924	127	1004	80.0	8
	12	13.9	81.1	6.5	920	127	1000	80.0	8
	18	14.5	80.8	5.5	950	102	1002	51.6	8
09	00	15.1	81.0	5.0	960	90	1000	40.2	7
	06	15.4	80.9	5.0	960	90	1000	40.2	7
	12	15.9	81.0	5.0	956	90	996	40.2	9
	18	16.0	80.5			65	1000		9
10	00	16.5	80.0			40	1000		8
	06	16.5	79.5			27	1000		10
	12	17.0	79.0			16	996		10

DEPRESSION FORMATION AT 0600 UTC OF 04 MAY.
CYCLONIC STORM FORMATION AT 0600 UTC OF 05 MAY.
SEVERE CYCLONIC STORM FORMATION AT 1800 UTC OF 05 MAY.
SEVERE CYCLONIC STORM WITH A CORE OF HURRICANE WINDS FORMATION AT 0600 UTC OF 06 MAY.
SEVERE CYCLONIC STORM WITH A CORE OF HURRICANE WINDS WEAKENED INTO A CYCLONIC STORM AT 2100 UTC OF 09 MAY.
DISSIPATION OF CYCLONIC STORM AT 1200 UTC OF 10 MAY.

* Estimated wind speed corresponding to T-Number

TABLE-2: BEST TRACK POSITIONS ALONGWITH OTHER PARAMETERS OF DEPRESSION (BAY OF BENGAL) 13 - 15 JUNE, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC* WIND (KT)
JUNE					
13	06	21.0	89.0	992	16
	12	21.0	89.0	991	27
	18	21.5	88.5	994	27
14	00	21.5	88.0	992	27
	06	22.0	87.0	991	27
	12	22.0	87.0	990	33 DD
	18	22.0	86.0	995	27
15	00	22.0	85.0	995	27
	06	22.0	84.0	997	27
	12	22.0	82.5	995	16

DEPRESSION FORMATION AT 1200 UTC OF 13 JUNE

DEPRESSION DISSIPATION AT 1200 UTC OF 15 JUNE

* Estimated wind speed corresponding to T-Number

TABLE-3: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (BAY OF BENGAL) 14 - 17 AUGUST, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC* WIND (KT)
AUGUST					
14	06	19.0	88.0	996	16
	12	19.0	87.5	994	27
	18	19.0	86.5	994	27
15	00	19.0	86.0	993	27
	06	19.5	85.0	995	27
	12	20.5	83.5	995	27
	18	21.5	82.5	995	27
16	00	21.5	81.5	995	27
	06	22.0	80.5	996	27
	12	22.0	79.0	995	27
	18	22.5	77.5	997	27
17	00	23.0	77.5	997	27
	06	23.0	77.0	998	16

DEPRESSION FORMATION AT 1200 UTC OF 14 AUGUST

DEPRESSION DISSIPATION AT 0600 UTC OF 17 AUGUST

* Estimated wind speed corresponding to T-Number

TABLE-4: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (BAY OF BENGAL) 20 - 24 AUGUST, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC* WIND (KT)
AUGUST					
20	00	22.0	89.0	997	16
	06	20.0	88.5	996	27
	12	20.5	88.5	995	27
	18	20.5	87.5	995	27
21	00	20.5	86.0	991	27
	06	20.5	86.0	986	27
	12	20.5	84.0	991	27
	18	20.5	83.0	996	27
22	00	21.0	82.0	994	27
	06	21.5	81.0	996	27
	12	21.5	80.5	994	27
	18	22.0	79.0	995	27
23	00	22.5	77.5	995	27
	06	23.0	77.5	996	27
	12	23.5	77.0	994	27
	18	24.0	75.0	996	27
24	00	24.0	73.5	997	27
	06	25.0	72.5	997	27
	12	25.5	72.5	994	27
	18	26.5	72.0	995	16

DEPRESSION FORMATION AT 0300 UTC OF 20 AUGUST
DEPRESSION DISSIPATION AT 1800 UTC OF 24 AUGUST

* Estimated wind speed corresponding to T-Number

TABLE-5: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (REMANANT OF BECKY TYPHOON) 3 - 4 SEPTEMBER, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC* WIND (KT)
SEPTEMBER					
03	00	22.5	88.5	996	16
	06	22.5	88.2	995	27
	12	22.5	87.0	995	27
	18	22.5	86.0	996	27
04	00	22.5	85.0	995	27
	06	22.5	84.5	996	27
	12	22.5	84.0	995	27
	18	23.0	83.0	997	27
05	00	23.5	82.0	997	16

DEPRESSION FORMATION AT 0300 UTC OF 03 SEPTEMBER

DEPRESSION DISSIPATION AT 0000 UTC OF 05 SEPTEMBER

* Estimated wind speed corresponding to T-Number

TABLE-6: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (BAY OF BENGAL) 6 - 8 OCTOBER, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC.* WIND (KT)
OCTOBER					
06	12	18.0	91.0	1002	16
	18	18.0	90.0	1002	27
07	00	20.0	88.5	1000	33
	06	20.5	88.0	1000	33
	12	21.0	87.5	998	27
	18	21.0	87.0	999	27
08	00	21.5	87.5	999	27
	06	22.0	87.5	1000	27
	12	22.5	87.5	999	27
	18	23.5	88.0	1001	16

DEPRESSION FORMATION AT 1800 UTC OF 6 OCTOBER

DEPRESSION DISSIPATION AT 1800 UTC OF 8 OCTOBER

* Estimated wind speed corresponding to T-Number

TABLE-7: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (BAY OF BENGAL) 31 OCTOBER - 4 NOVEMBER, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC* WIND (KT)
OCTOBER					
31	06	10.5	87.5	1007	16
	12	10.5	87.5	1004	27
	18	10.5	87.0	1004	27
NOVEMBER					
01	00	12.0	86.5	1003	27
	06	13.5	86.0	1003	27
	12	14.0	86.5	1002	27
	18	16.0	85.5	1001	33
02	00	16.0	85.0	1001	33
	06	17.0	84.5	1001	33
	12	17.0	84.5	1002	33
	18	17.5	84.0	1003	33
03	00	18.0	84.5	1001	33
	06	17.5	84.5	1001	33
	12	18.5	84.5	1001	27
	18	18.5	85.0	1001	27
04	00	19.0	84.5	1001	27
	06	19.0	84.5	1003	27
	12	20.0	84.0	1002	16

DEPRESSION FORMATION AT 1200 UTC OF 31 OCTOBER
DEPRESSION DISSIPATION AT 1200 UTC OF 4 NOVEMBER

* Estimated wind speed corresponding to T-Number

TABLE-8: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (BAY OF BENGAL) 14 - 15 NOVEMBER, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC.* WIND (KT)
NOVEMBER					
14	00	14.0	82.0	1010	27
	06	14.0	81.0	1010	27
	12	14.0	80.5	1008	27
	18	14.5	80.0	1009	27
15	00	14.5	77.5	1009	16

DEPRESSION FORMATION AT 0000 UTC OF 14 NOVEMBER
DEPRESSION DISSIPATION AT 0000 UTC OF 15 NOVEMBER

* Estimated wind speed corresponding to T-Number

TABLE-9: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF DEPRESSION (ARABIAN SEA) 16 - 18 NOVEMBER, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	MIN. SFC. PRESSURE (hPa)	MAX. SFC* WIND (KT)
NOVEMBER					
16	00	14.5	75.5	1011	16
	06	14.5	73.5	1009	27
	12	14.5	73.5	1008	27
	18	14.5	73.5	1009	27
17	00	14.5	73.0	1008	27
	06	14.0	72.0	1008	27
	12	14.8	72.0	1007	33
	18	15.0	72.0	1008	33
18	00	15.5	72.5	1009	27
	06	15.5	72.5	1010	16

DEPRESSION FORMATION AT 0600 UTC OF 16 NOVEMBER

DEPRESSION DISSIPATION AT 0600 UTC OF 18 NOVEMBER

* Estimated wind speed corresponding to T-Number

TABLE-10: BEST TRACK POSITIONS ALONG WITH OTHER PARAMETERS OF SEVERE CYCLONIC STORM (BAY OF BENGAL) 14 - 18 DECEMBER, 1990

TIME (UTC)		CENTRE POSITION LAT. (°N)	LONG. (°E)	T. NO.	MAX. SFC* WIND (KT)	
DECEMBER						
14	00	7.0	88.5	1.0	16	
	06	7.5	88.0	1.0	16	
	12	8.0	88.0	1.5	27	D
	18	8.5	87.5	1.5	27	
15	00	9.0	87.0	2.0	33	
	06	9.8	86.5	2.0	33	DD
	12	10.5	86.0	2.0	33	
	18	11.0	85.5	2.5	35	
16	00	12.0	85.0	2.5	35	
	06	13.0	85.5	2.5	35	
	12	14.0	85.5	3.0	45	
	18	14.5	86.0	3.0	45	CS
17.	00	15.5	86.0	3.0	45	
	06	17.0	86.5	3.5	55	
	12	18.0	87.0	3.5	55	SCS
	18	19.5	89.0	3.5	55	
18	00	20.5	90.5	1.5	27	D
	06	21.0	91.0	1.5	27	
	12	20.0	92.0	1.0	16	

DEPRESSION FORMATION AT 1200 UTC OF 14 DECEMBER
CYCLONIC STORM FORMATION AT 0300 UTC OF 16 DECEMBER
SEVERE CYCLONIC STORM FORMATION AT 0300 UTC OF 17 DECEMBER
SEVERE CYCLONIC STORM DISSIPAION AT 0000 UTC OF 18 DECEMBER

* Estimated wind speed corresponding to T-Number

TABLE-11: 12, 24 and 36 hour forecast position errors for individual tropical cyclones over the Bay of Bengal based on Analog Forecast Model.

Tropical Cyclones	Forecast errors (km)		
	12 hour	24 hour	36 hour
5 - 9 May, 1990	73	121	103
14 - 18 Dec., 1990	180	347	760
Average	127	234	432

TABLE-12: 12, 24, 36 and 48-hour forecast position errors for Tropical Cyclones and Depressions in the Bay of Bengal and the Arabian Sea in 1990 based on Climatology, Persistence and CLIPER Models.

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Tropical Depression	FORECAST ERRORS (KM)											
	12-hour			24-hour			36-hour			48-hour		
	A	B	C	A	B	C	A	B	C	A	B	C
1. 5 - 9 May	97	112	94	187	168	144	276	265	194	412	392	294
2. 13 - 15 June	162	59	91	347	210	267	600	296	279	-	-	-
3. 14 - 17 August	116	119	97	221	183	159	399	352	296	677	525	572
4. 20 - 24 August	141	184	164	186	226	161	259	361	271	326	420	332
5. 3 - 4 September	128	107	94	233	78	71	377	123	183	531	-	-
6. 6 - 8 October	114	89	53	211	227	102	-	-	-	-	-	-
7. 31 Oct.- 4 November	120	171	130	99	285	165	124	455	222	101	696	355
8. 13 - 15 November	276	174	180	-	-	-	-	-	-	-	-	-
9. 16 - 18 November	78	133	97	140	200	122	211	561	329	247	-	-
10. 14 - 18 December	169	162	153	345	255	298	520	386	463	726	570	649
Average	140	131	115	219	203	165	346	350	280	431	521	440

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

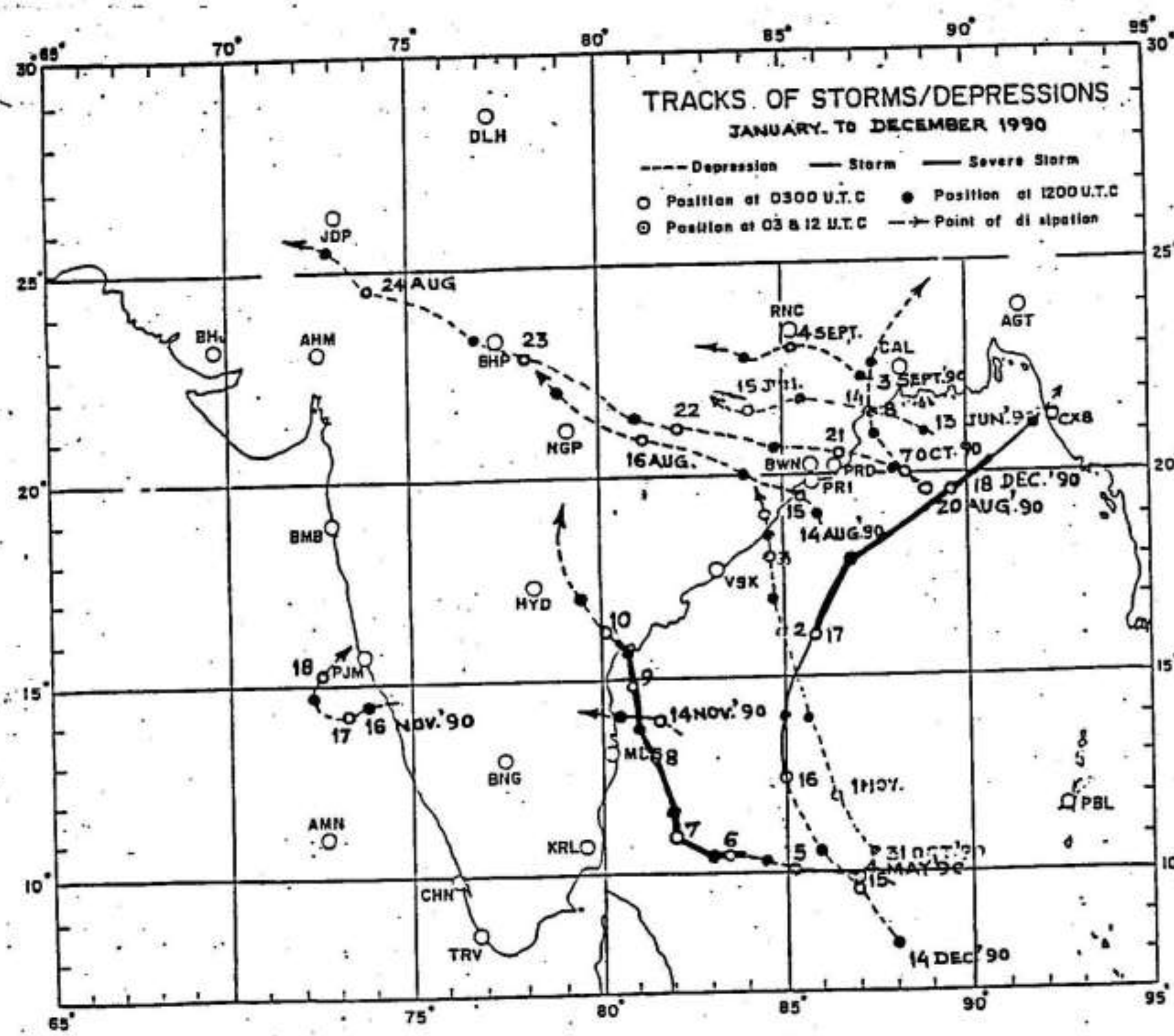

FIG. 1 - TRACKS OF CYCLONES AND DEPRESSIONS OF 1990.

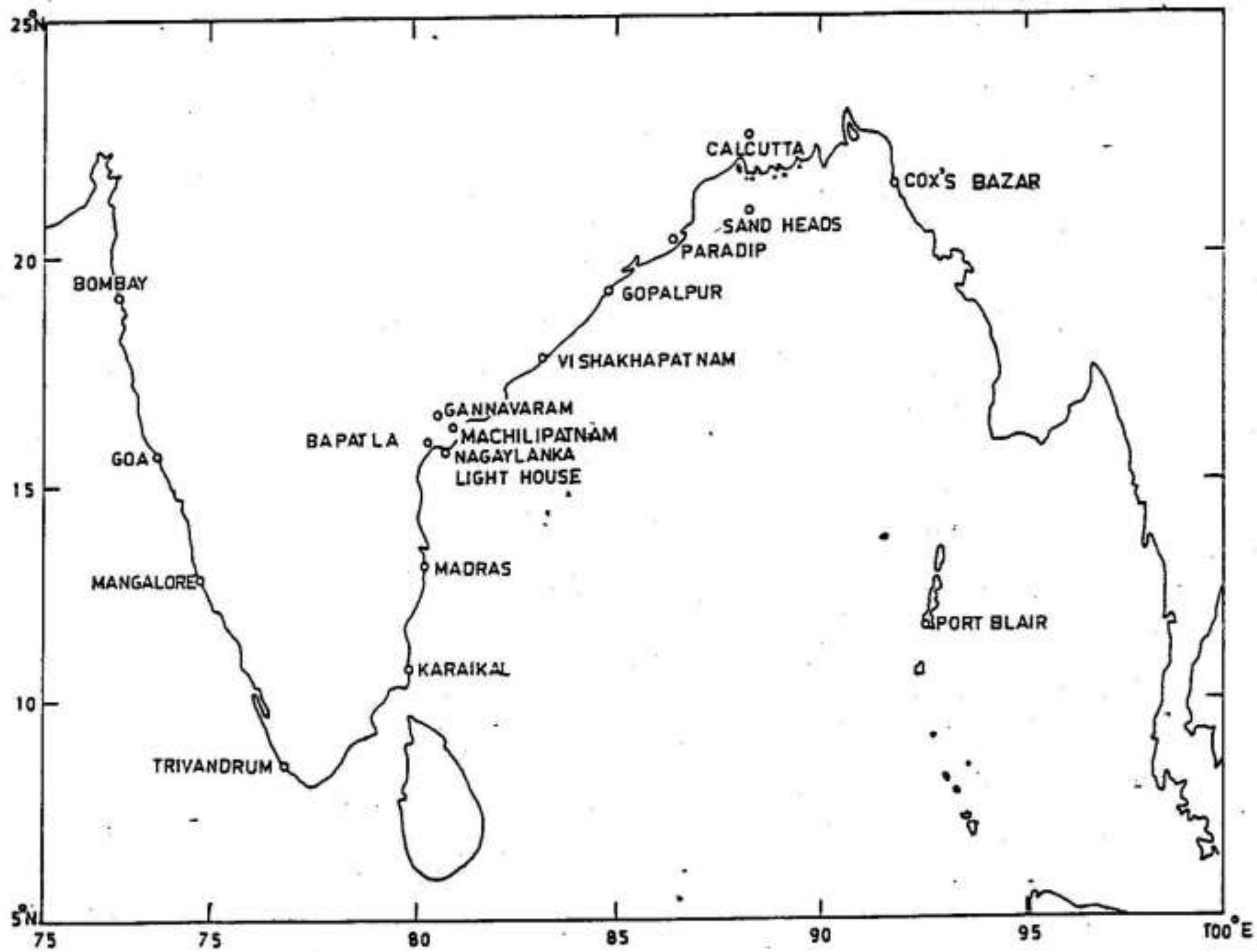

FIG. 2 - LOCATION OF COASTAL STATIONS.

FIG. 3 - INSAT-1B SATELLITE IMAGERY - 0900 UTC OF 8 MAY, 1990.

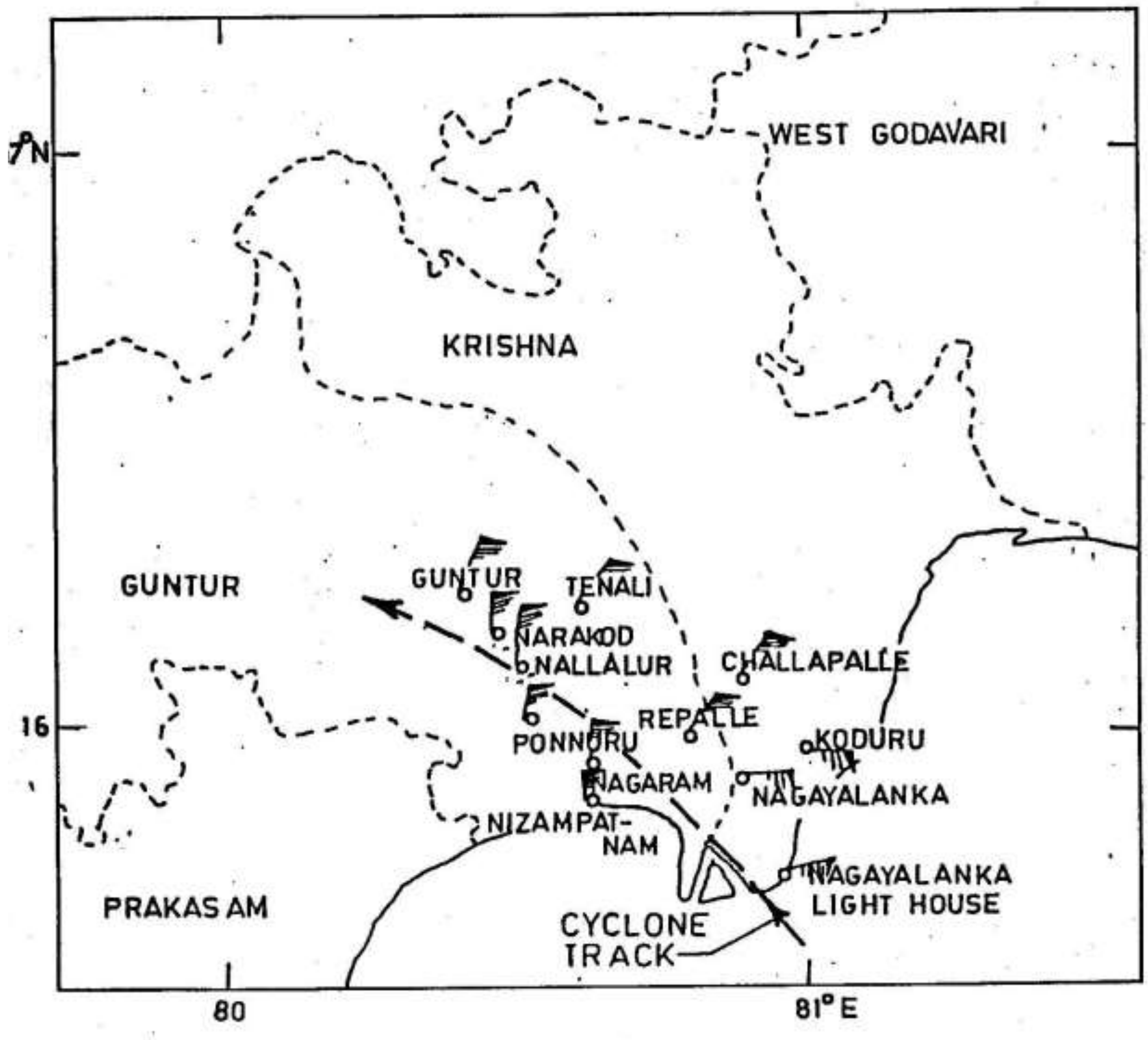

FIG. 6 (a) ESTIMATED SURFACE WINDS (Kt.) IN ASSOCIATION WITH THE CYCLONE BEFORE LANDFALL.

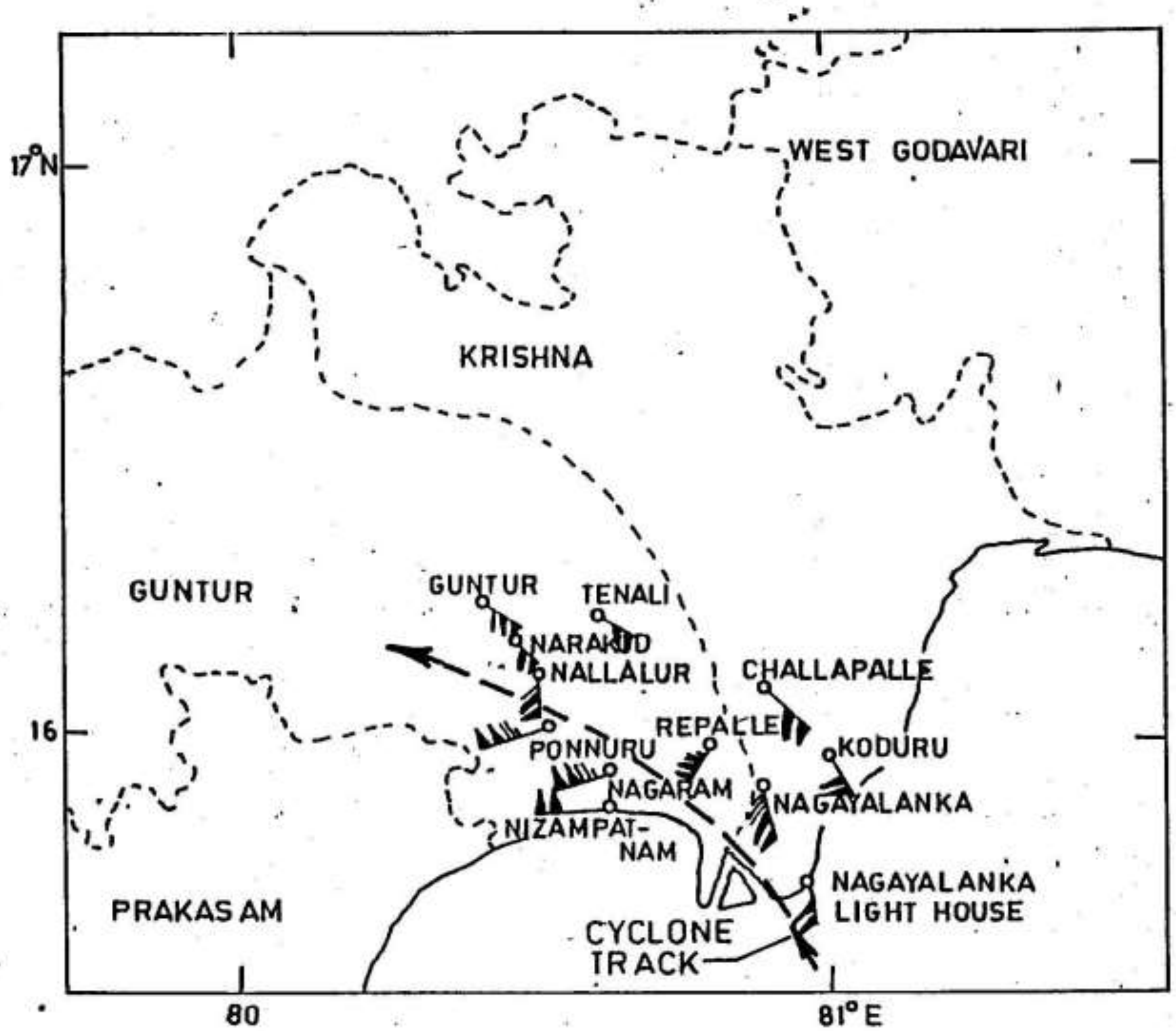

FIG. 6 (b) ESTIMATED SURFACE WINDS (Kt.) IN ASSOCIATION WITH THE CYCLONE AFTER LANDFALL.

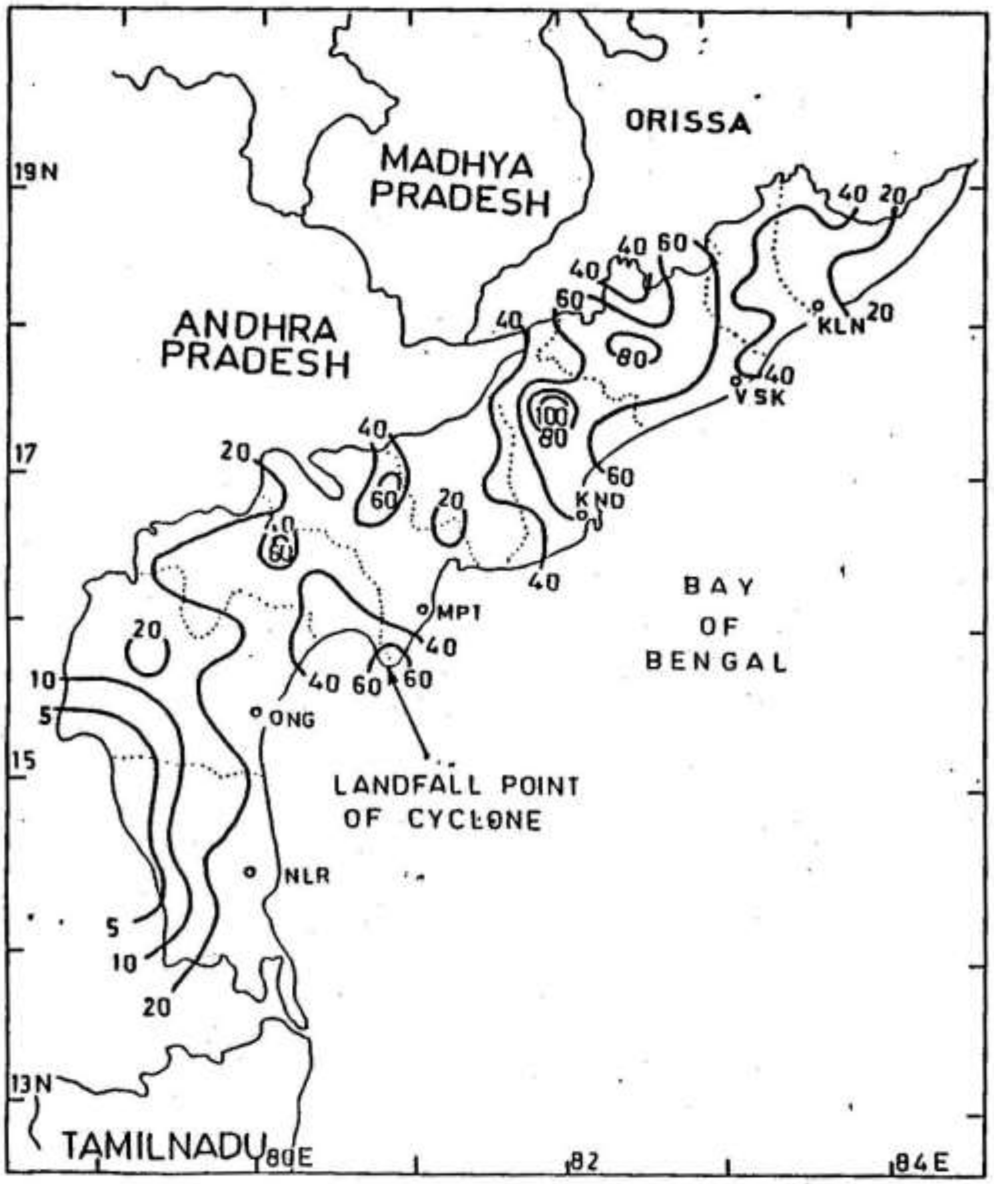

FIG. 7. ISOHYETAL MAP OF TOTAL RAINFALL (cm) OVER COASTAL ANDHRA PRADESH FOR THE PERIOD 8 - 12 MAY, 1990.

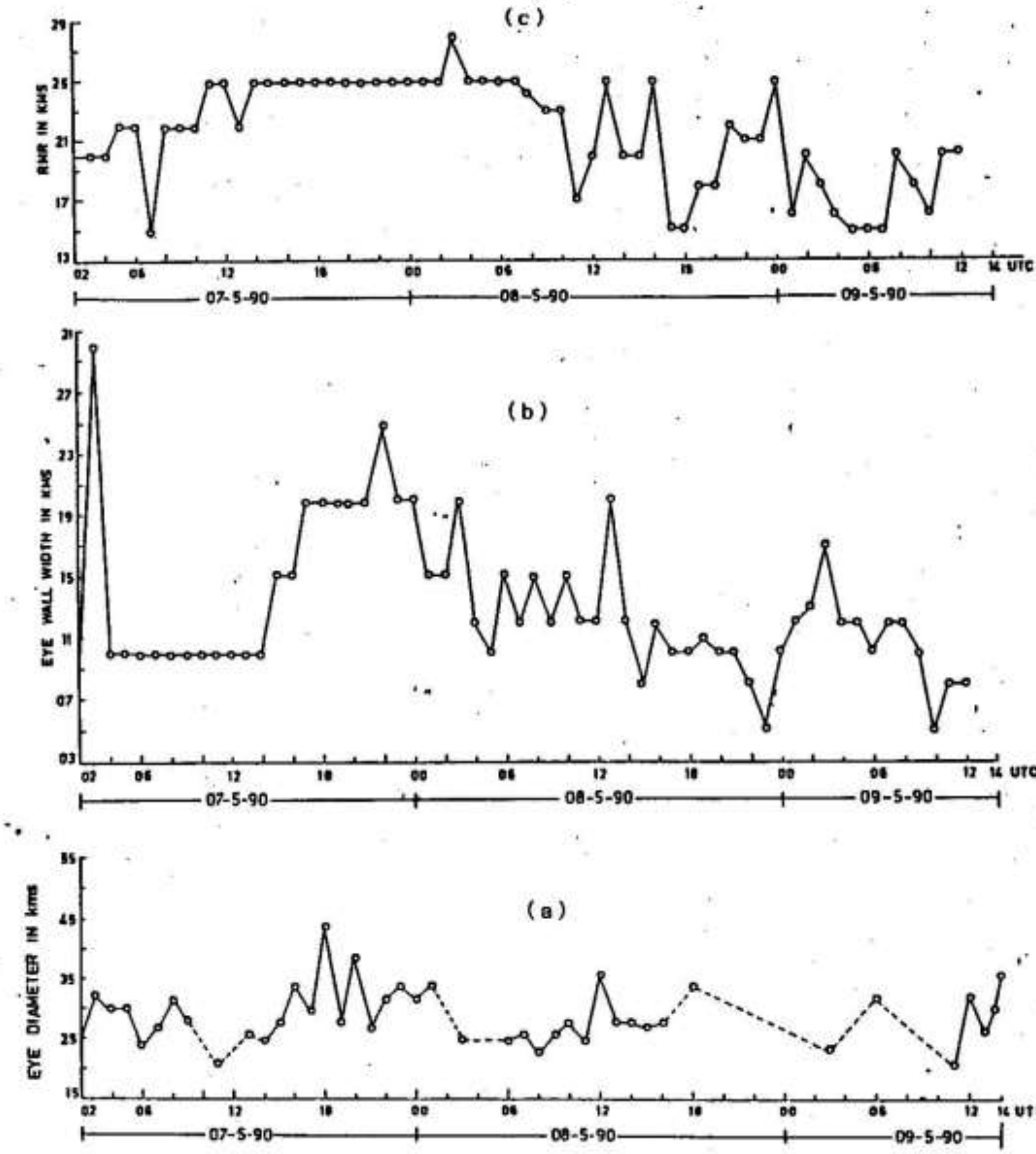

FIG. 8 - OBSERVATIONS OF (a) EYE DIAMETER (b) EYE WALL WIDTH AND (c) RADIUS OF MAXIMUM REFLECTIVITY (RMR) FROM CDR MADRAS.

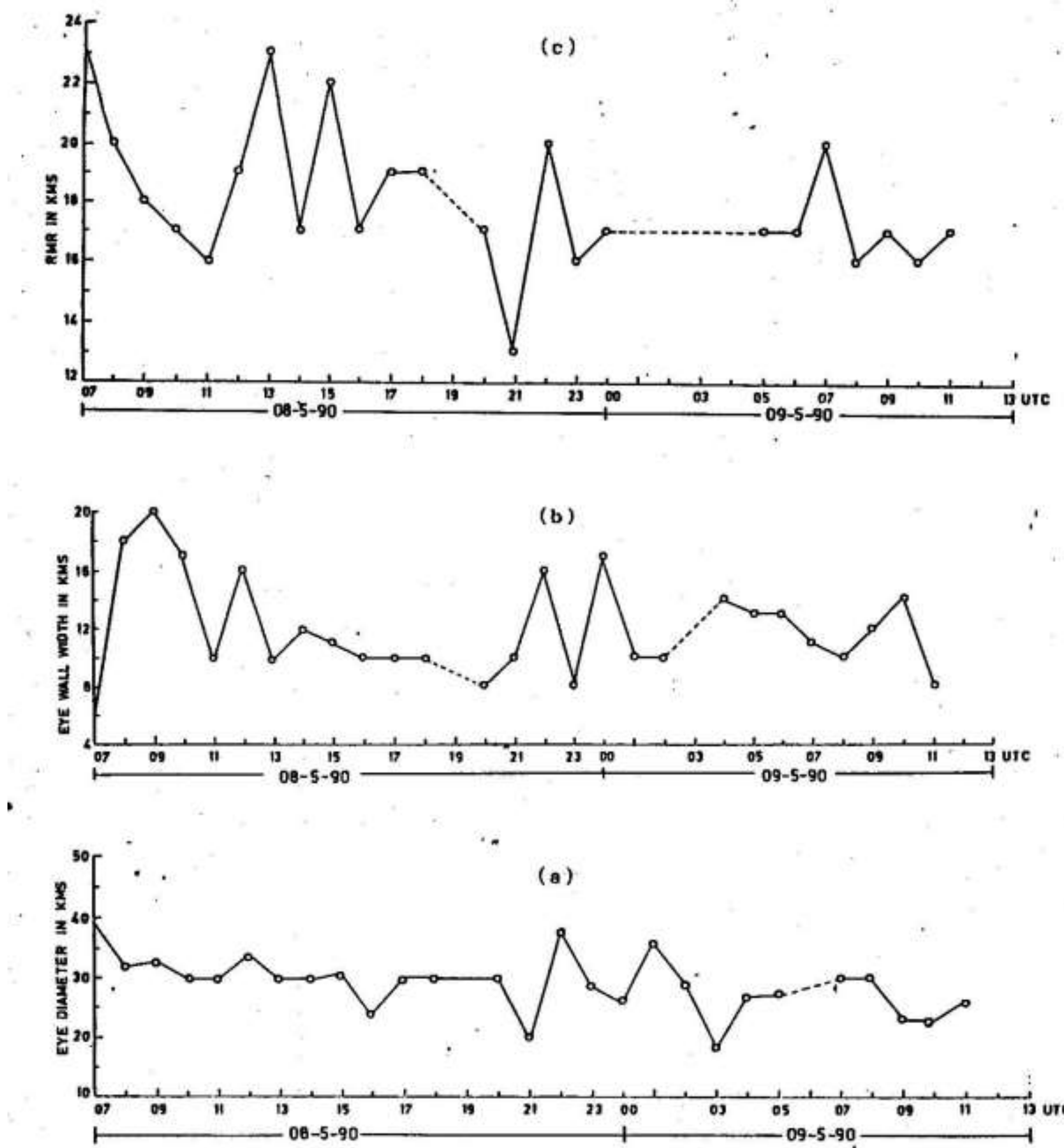

FIG. 9 - OBSERVATIONS OF (a) EYE DIAMETER (b) EYE WALL WIDTH AND (c) RADIUS OF MAXIMUM REFLECTIVITY (RMR) FROM CDR MACHILIPATNAM.

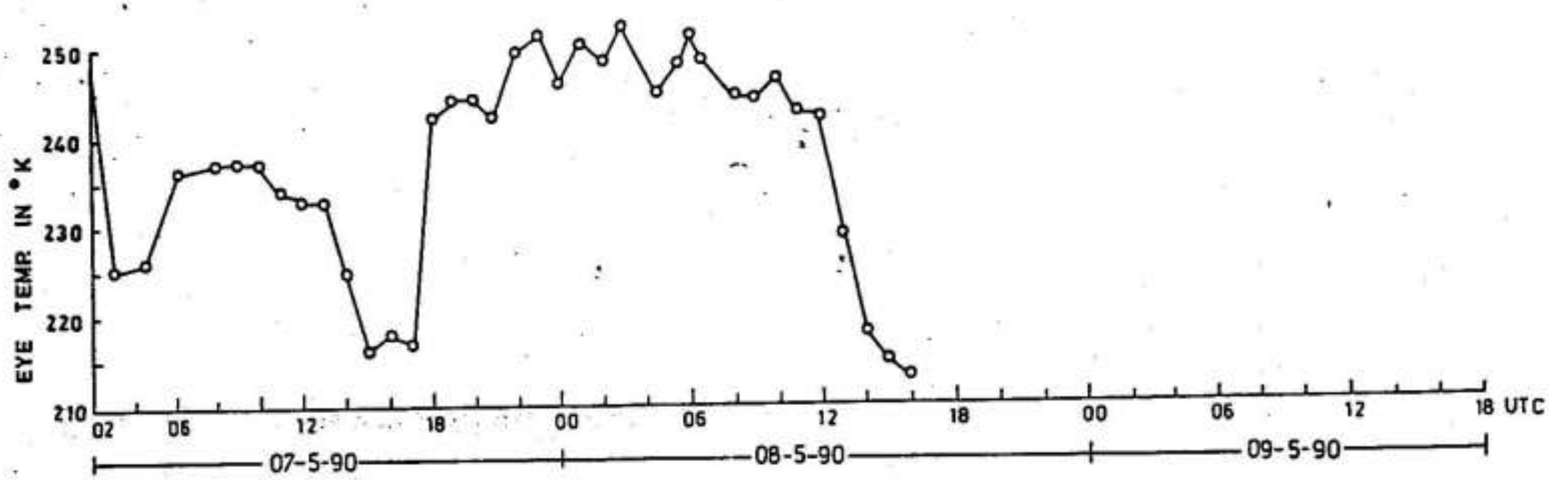

FIG. 10 - EYE TEMPERATURES OF MAY CYCLONE AS DERIVED FROM INSAT-1B SATELLITE.

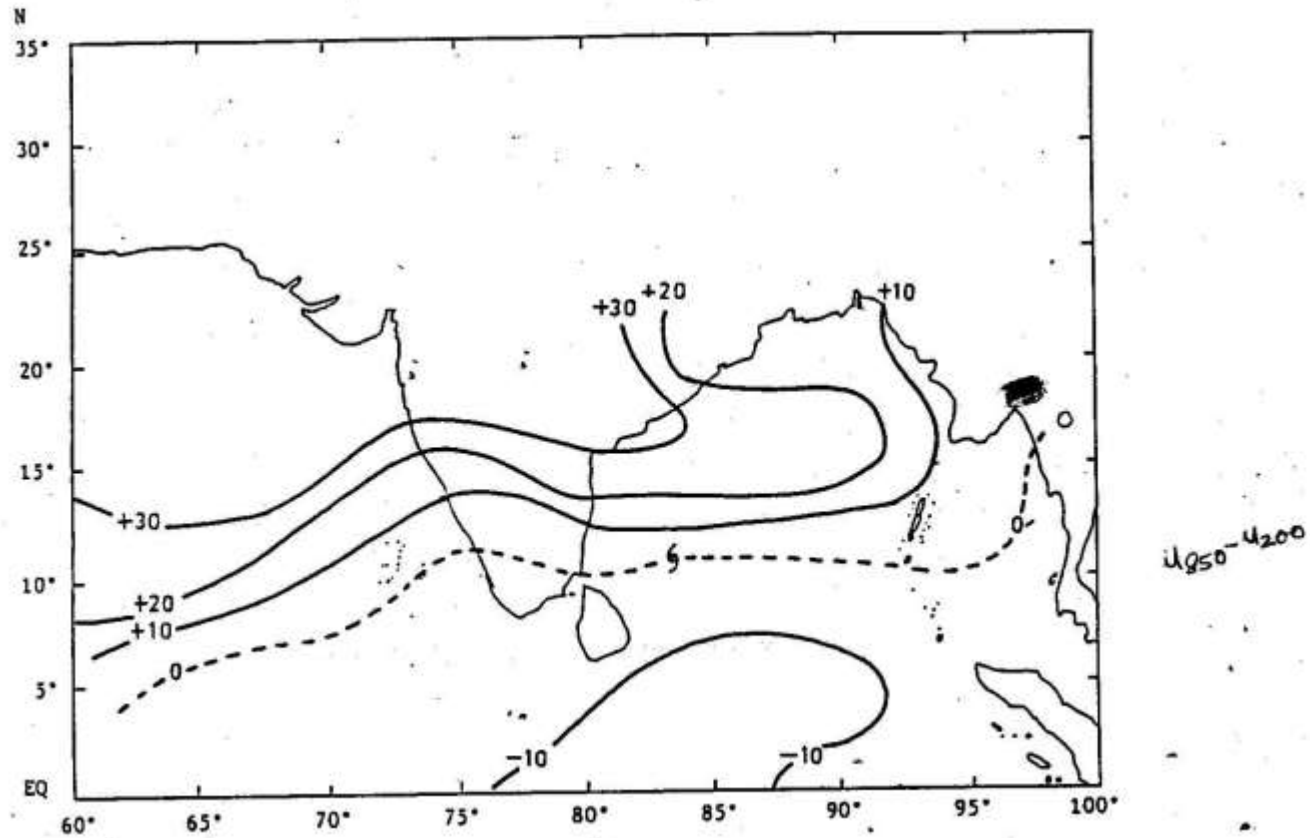

FIG. 11(a) - VERTICAL SHEAR OF ZONAL WIND BETWEEN 850 AND 200 hPa AT 1200 UTC OF 6 MAY 1990.
(UNIT: cm Sec.$^{-1}$ 650 hPa^{-1})

§ - POSITION OF CYCLONE

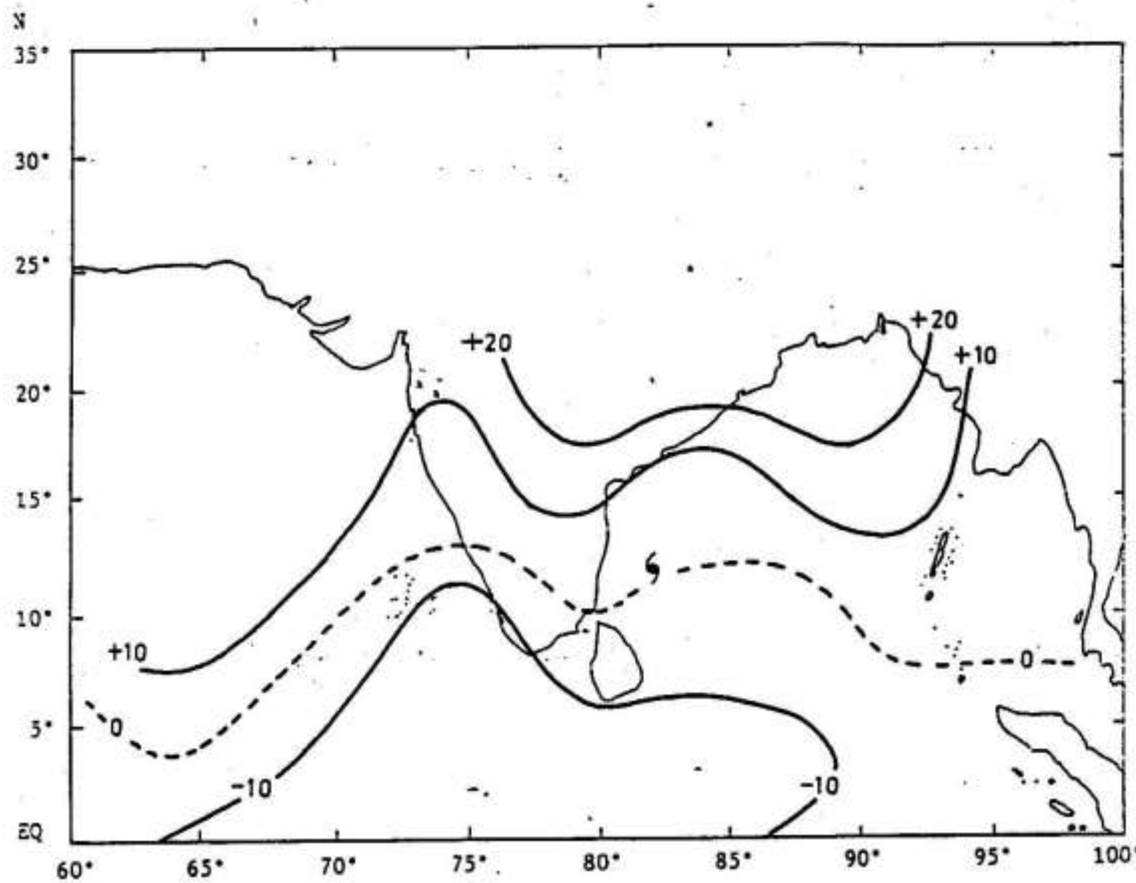

FIG. 11(b) - VERTICAL SHEAR OF ZONAL WIND BETWEEN 850 AND 200 hPa AT 1200 UTC OF 7 MAY 1990.

(UNIT: cm $Sec.^{-1}$ 650 hPa^{-1})

ʕ - POSITION OF CYCLONE

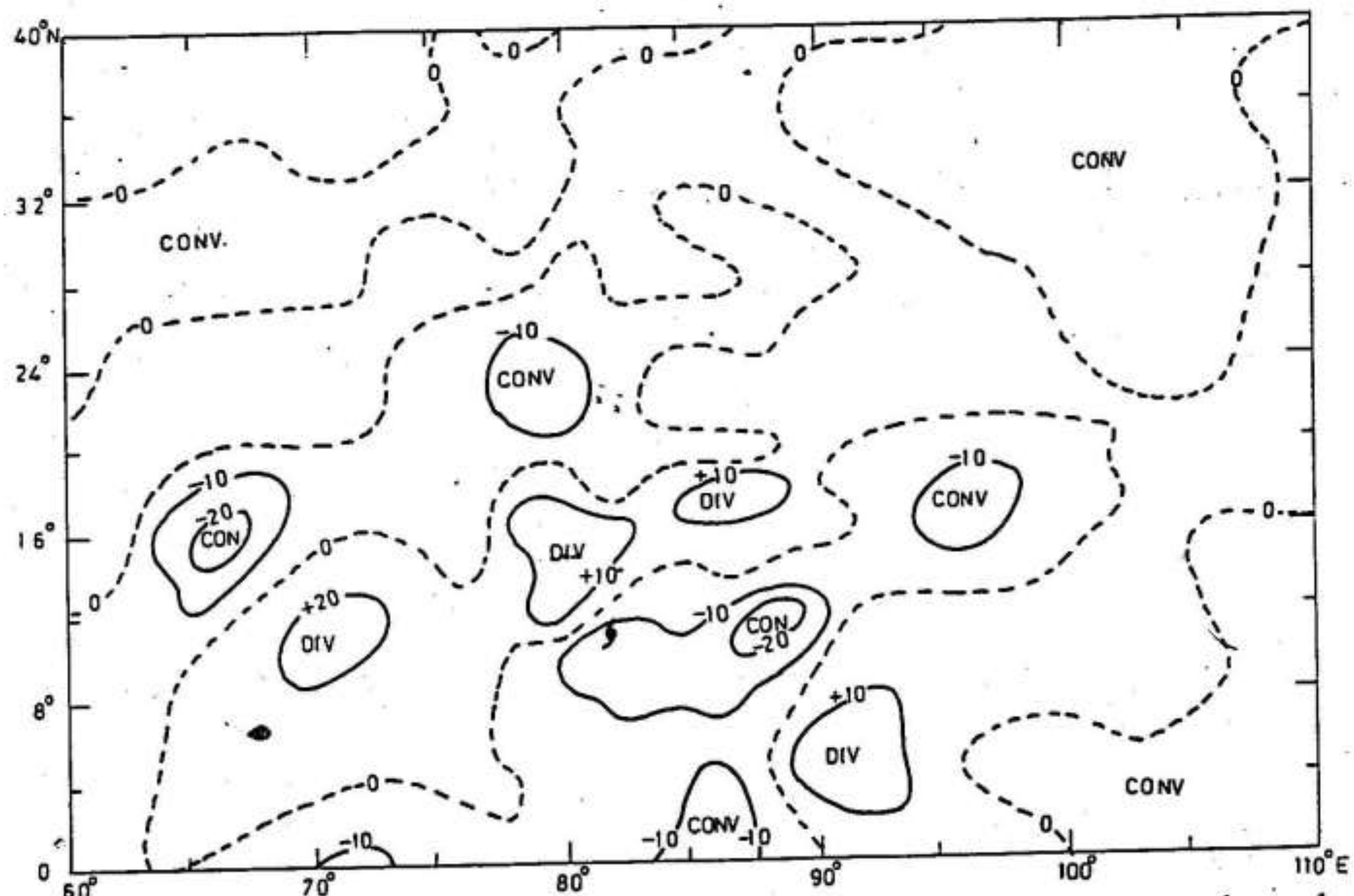

FIG. 12(a) - VERGENCE AT 850 hPa - 1200 UTC OF 7 MAY, 1990 (UNIT: 10^{-6} Sec.$^{-1}$)

- POSITION OF CYCLONE

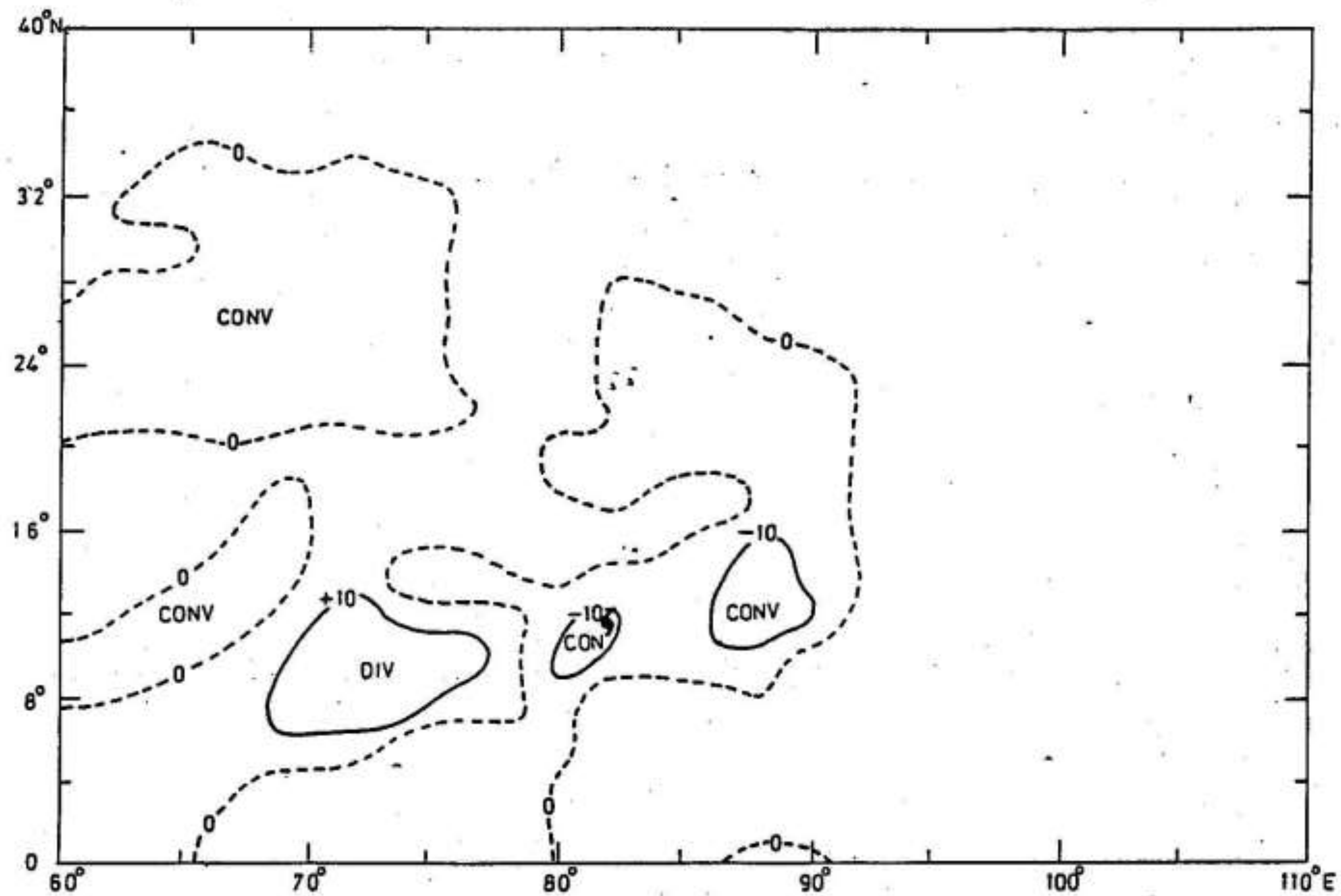

FIG. 12(b) - VERGENCE AT 500 hPa - 1200 UTC OF 7 MAY, 1990 (UNIT: 10^{-6} Sec.$^{-1}$)

- POSITION OF CYCLONE

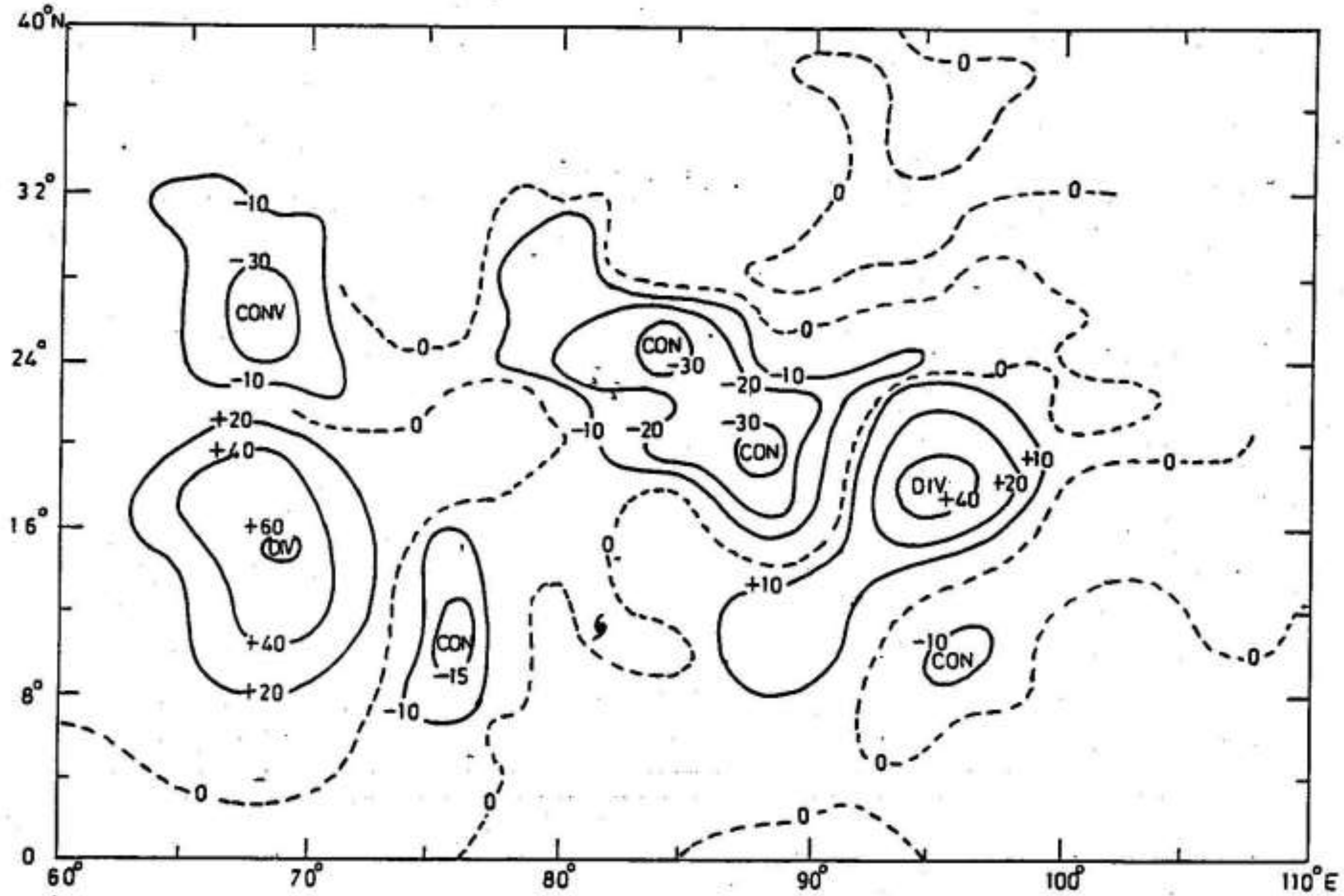

FIG. 12(c) - VERGENCE AT 200 hPa - 1200 UTC OF 7 MAY, 1990 (UNIT: 10^{-6} Sec.$^{-1}$)

ʂ - POSITION OF CYCLONE

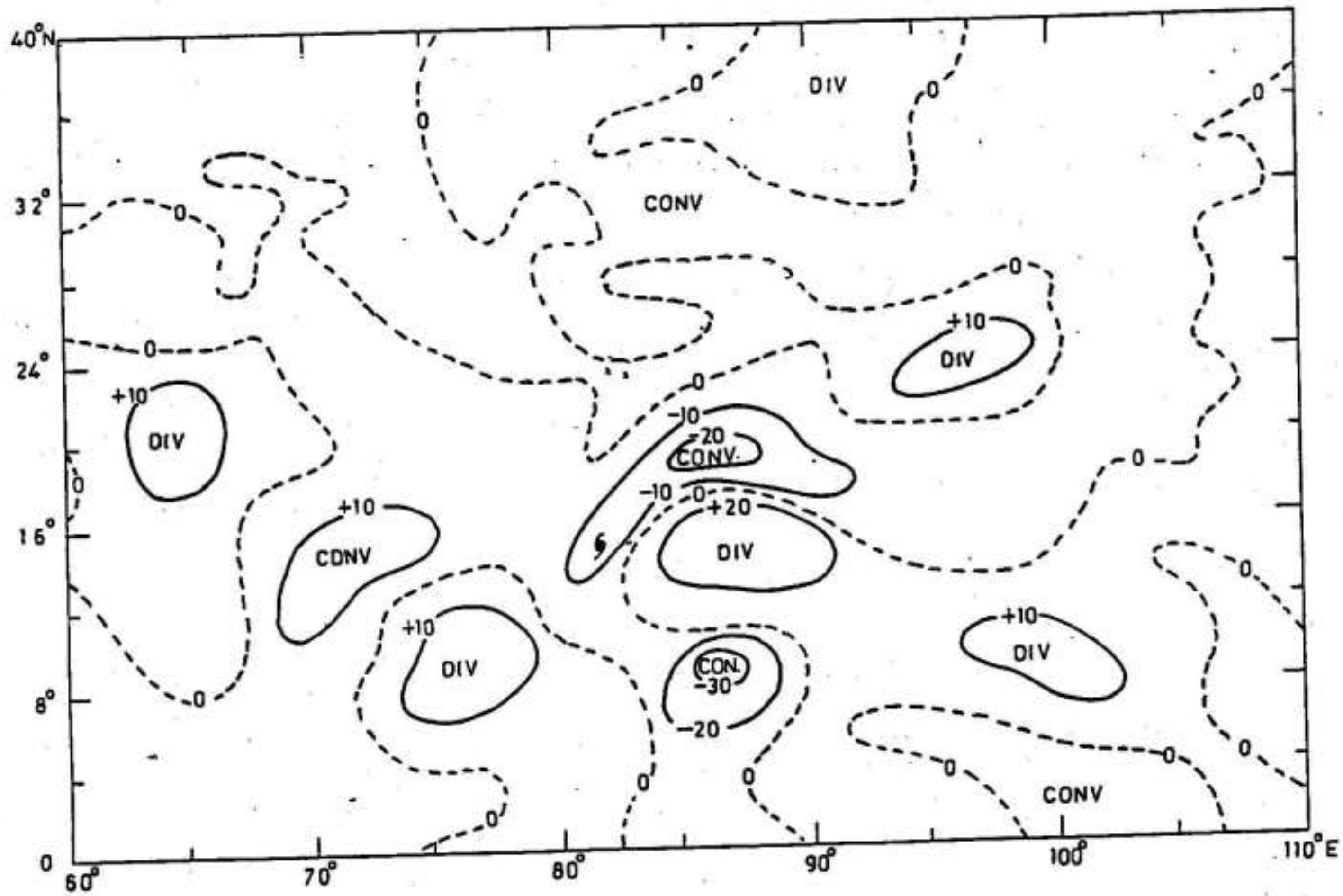

FIG. 13(a) - VERGENCE AT 850 hPa - 1200 UTC OF 8 MAY, 1990.
(UNIT: 10^{-6} $Sec.^{-1}$)
§ - POSITION OF CYCLONE.

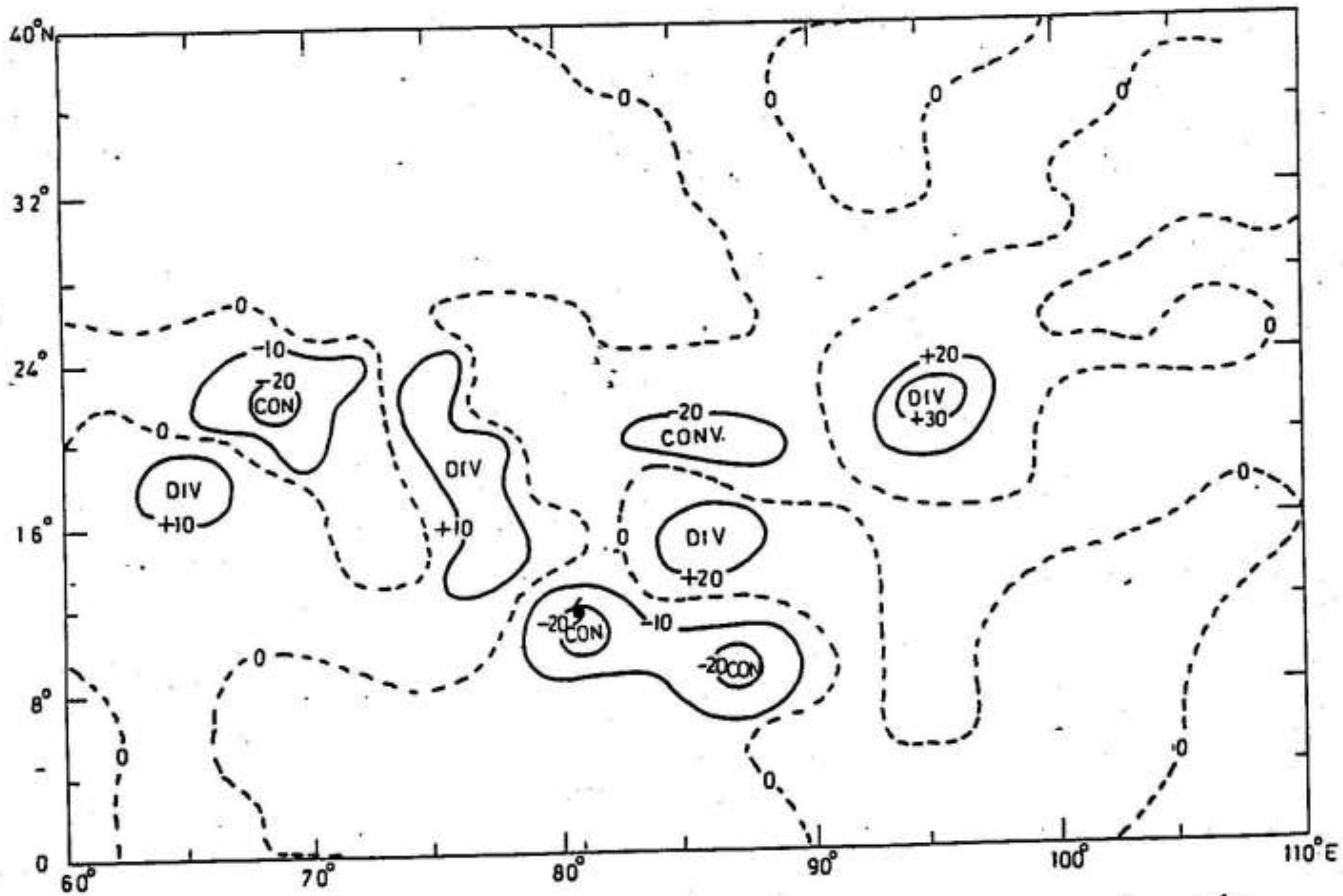

FIG. 13(b) - VERGENCE AT 500 hPa - 1200 UTC OF 8 MAY (UNIT: 10^{-6} Sec.$^{-1}$)

§ - POSITION OF CYCLONE

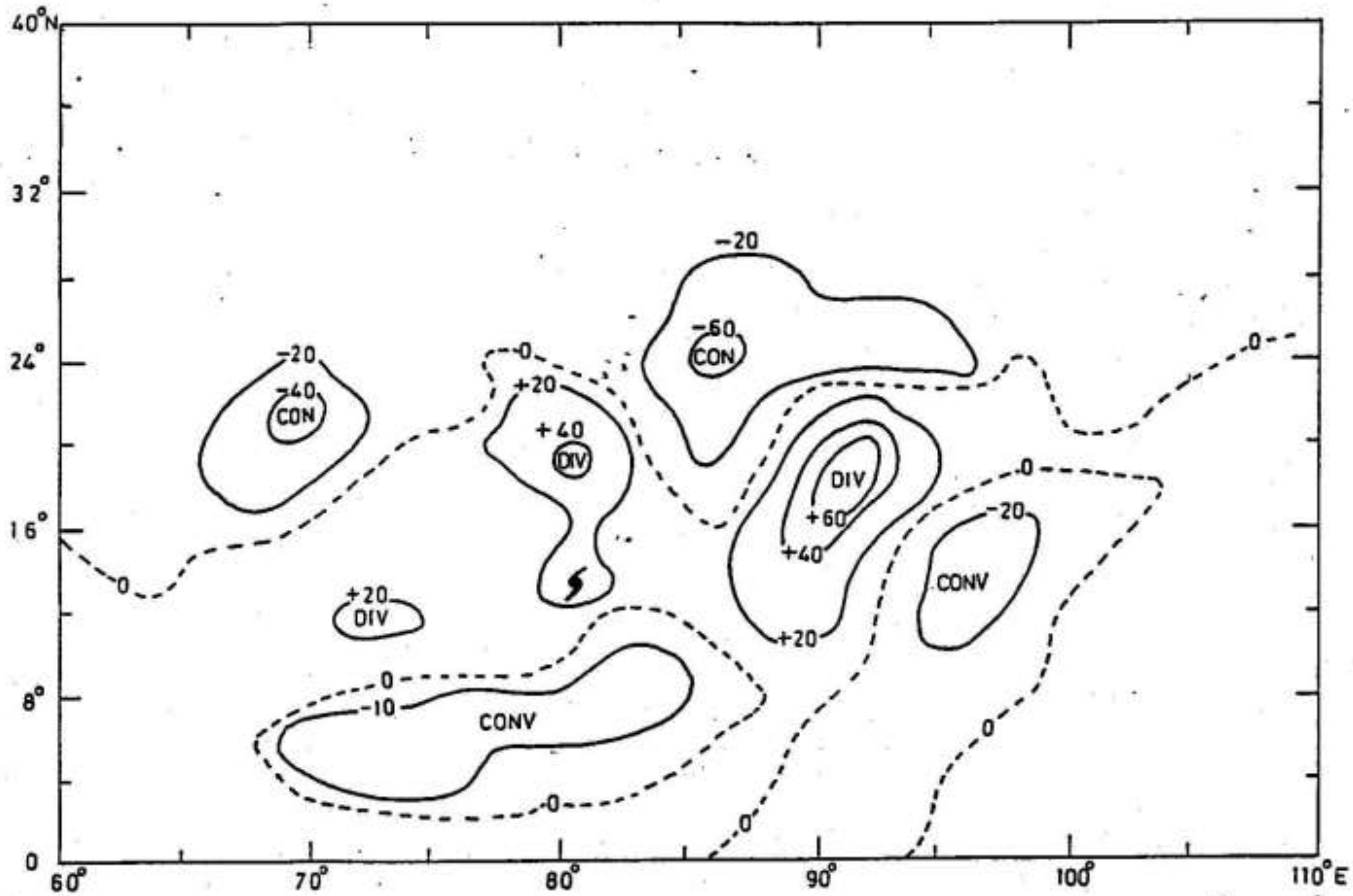

FIG. 13(c) - VERGENCE AT 200 hPa - 1200 UTC OF 8 MAY, 1990 (UNIT: 10^{-6} Sec.$^{-1}$)

(cyclone symbol) - POSITION OF CYCLONE

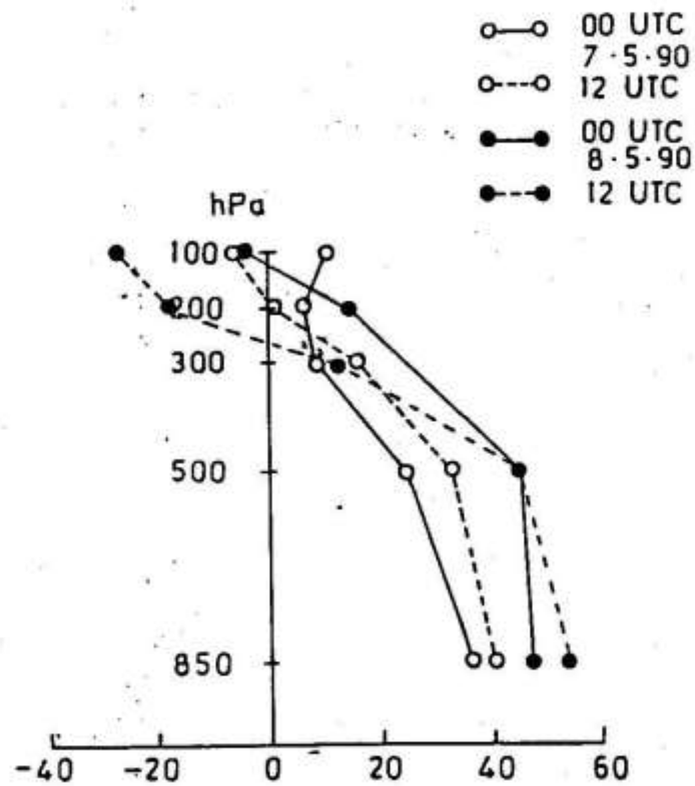

FIG. 14 - RELATIVE VORTICITY PROFILES AVERAGED WITHIN 4° RADIUS OF CYCLONE CENTRE FOR 7 AND 8 MAY, 1990.
(UNIT: 10^{-5} Sec.$^{-1}$)

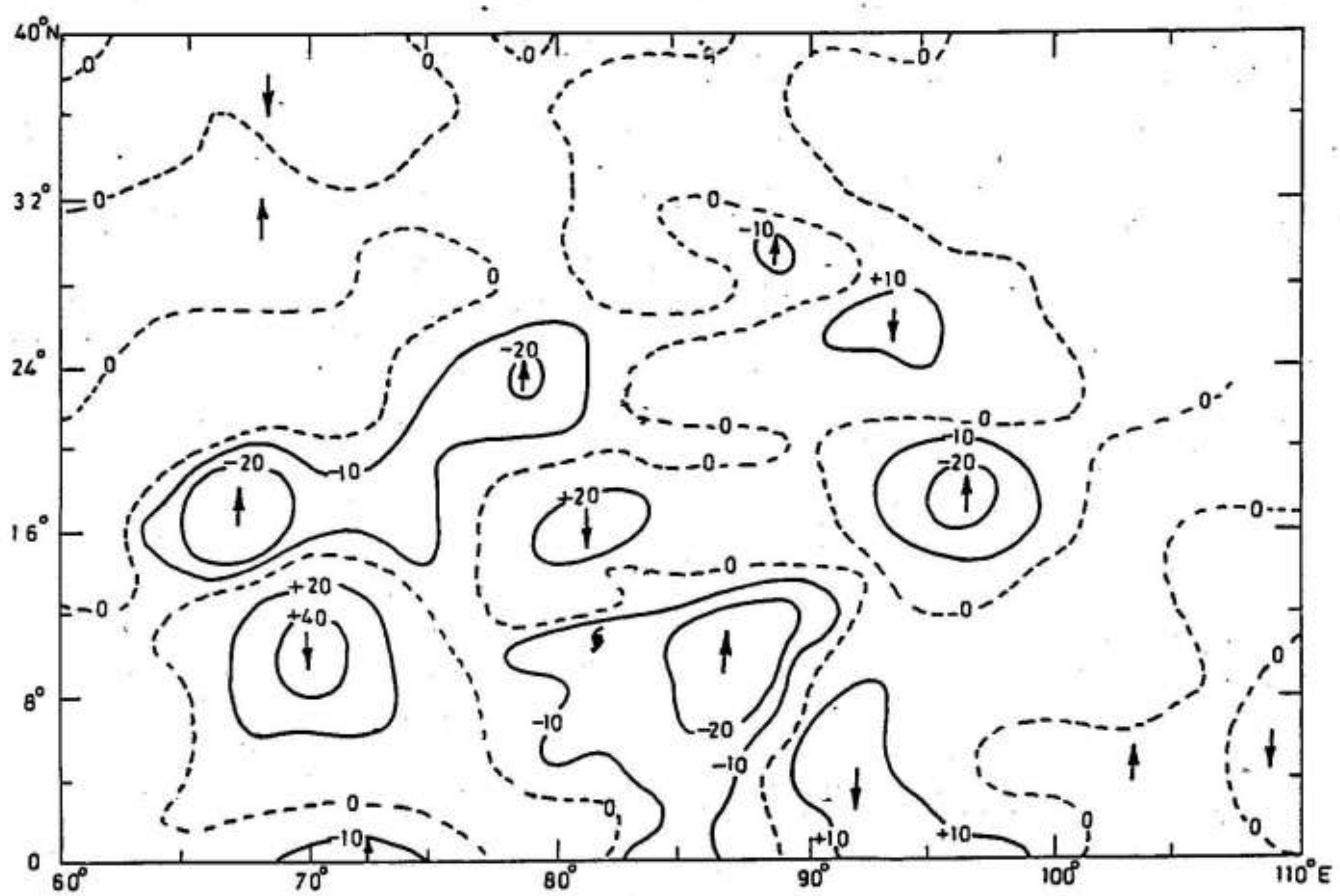

FIG. 15(a) - VERTICAL VELOCITY FIELD AT 850 hPa - 1200 UTC OF 7 MAY, 1990
(UNIT: 10^{-6} hPa $Sec.^{-1}$)
§ - POSITION OF CYCLONE

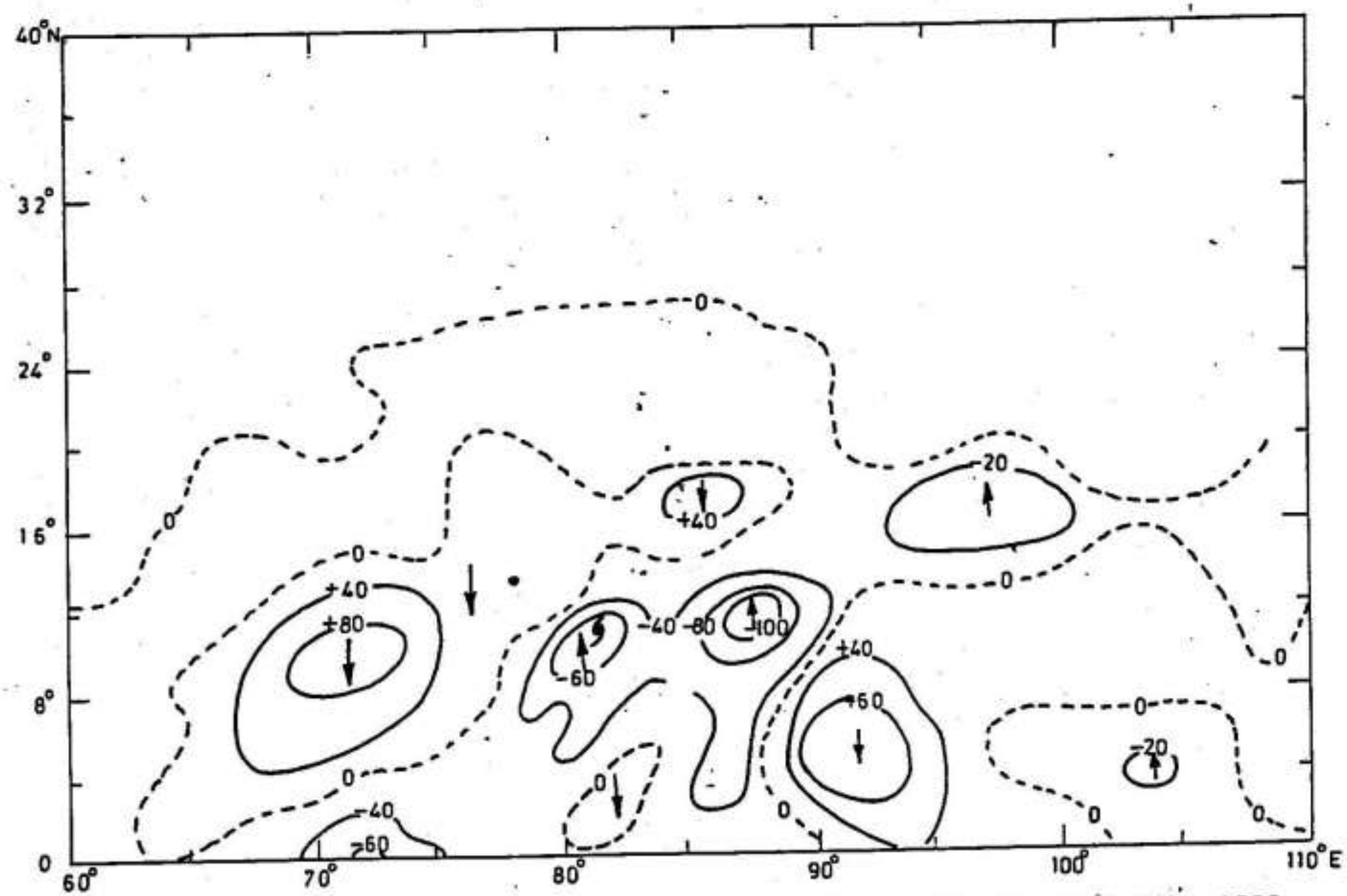

FIG. 15(b) - VERTICAL VELOCITY FIELD AT 500 hPa - 1200 UTC OF 7 MAY, 1990
(UNIT: 10^{-6} hPa $Sec.^{-1}$)
§ - POSITION OF CYCLONE

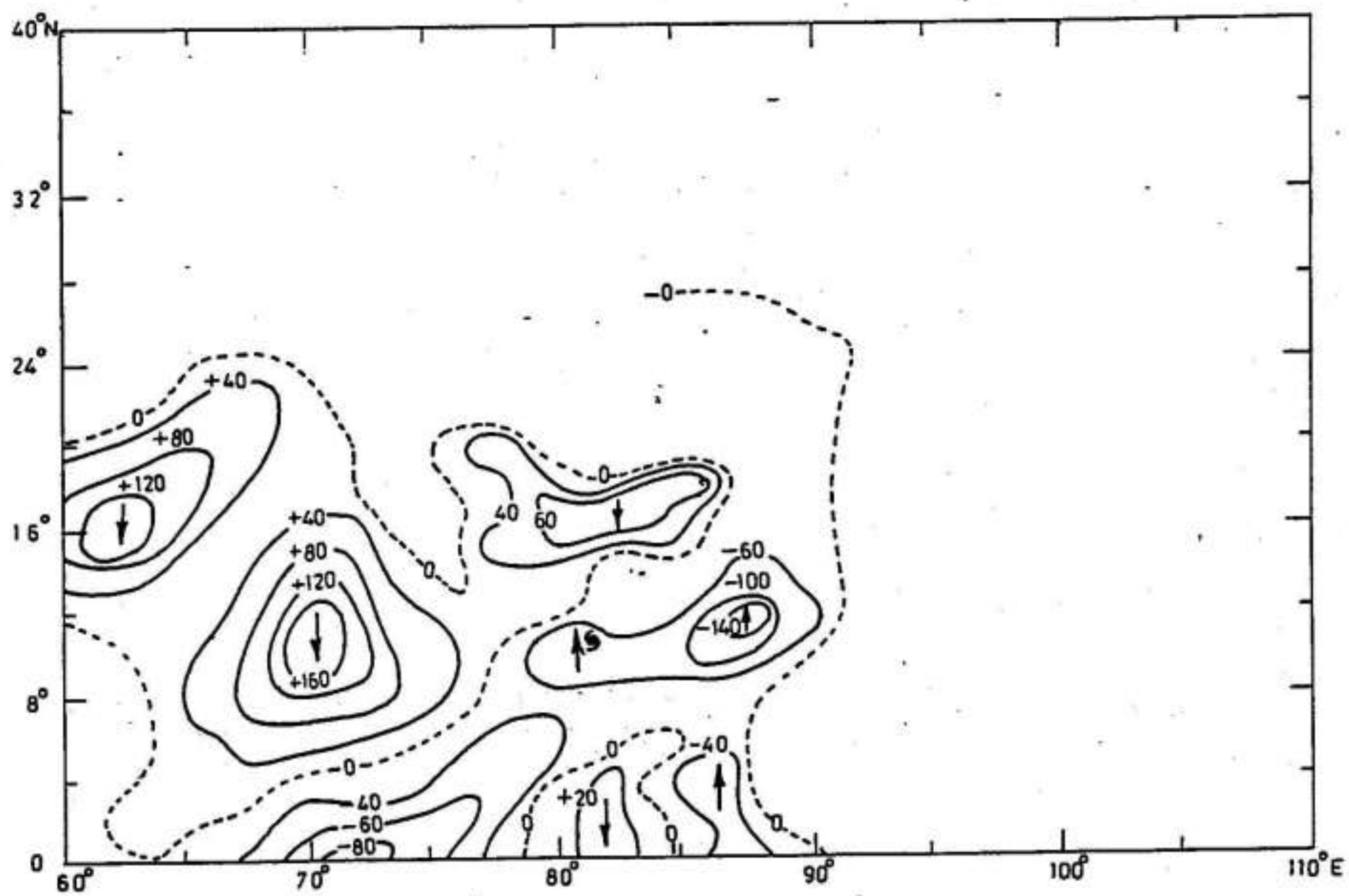

FIG. 15(c) - VERTICAL VELOCITY FIELD AT 200 hPa - 1200 UTC OF 7 MAY, 1990
(UNIT: 10^{-6} hPa Sec.$^{-1}$)
- POSITION OF CYCLONE

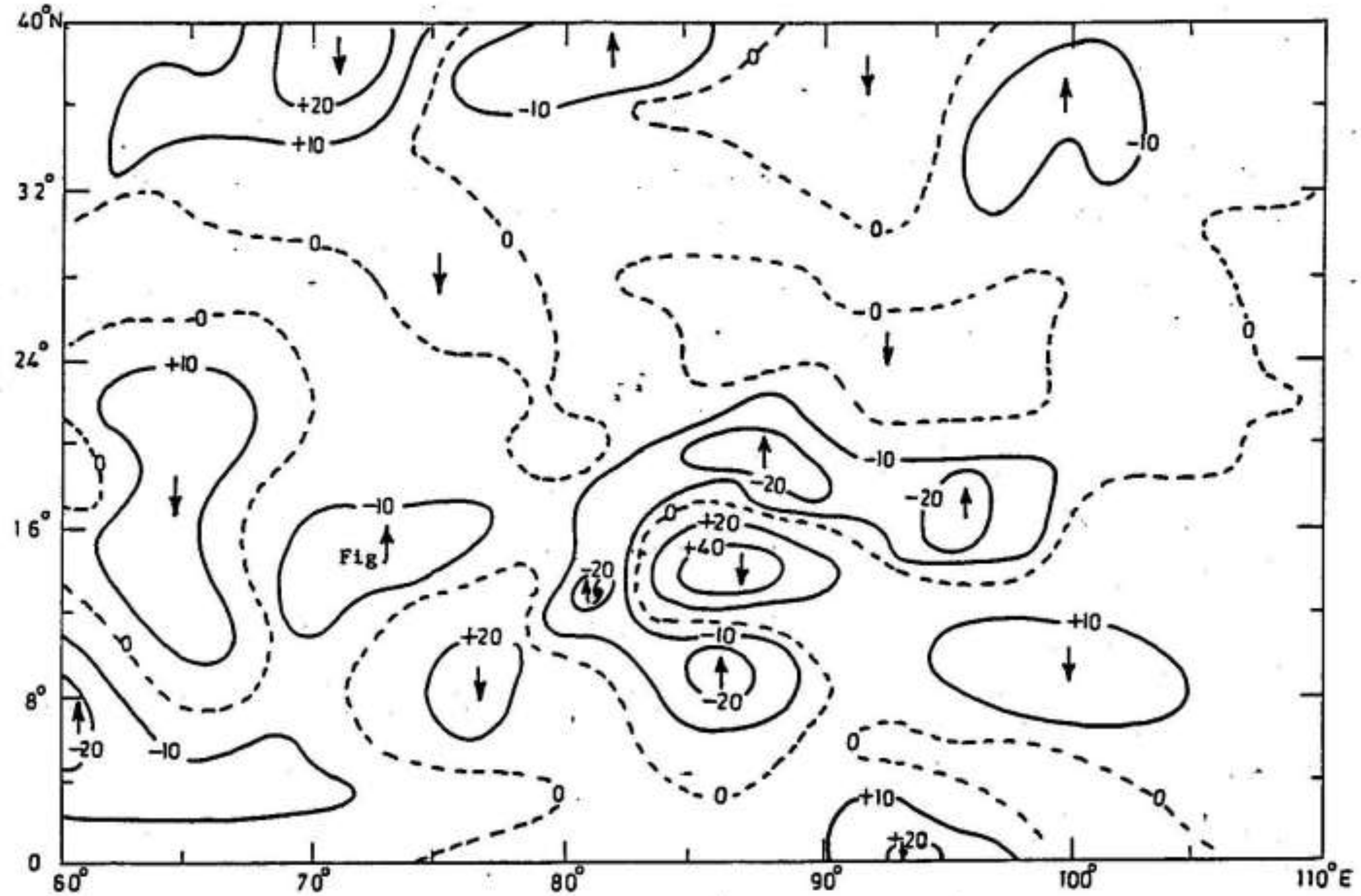

FIG. 16(a) - VERTICAL VELOCITY FIELD AT 850 hPa - 1200 UTC OF 8 MAY, 1990
(UNIT: 10^{-6} hPa $Sec.^{-1}$)
§ - POSITION OF CYCLONE

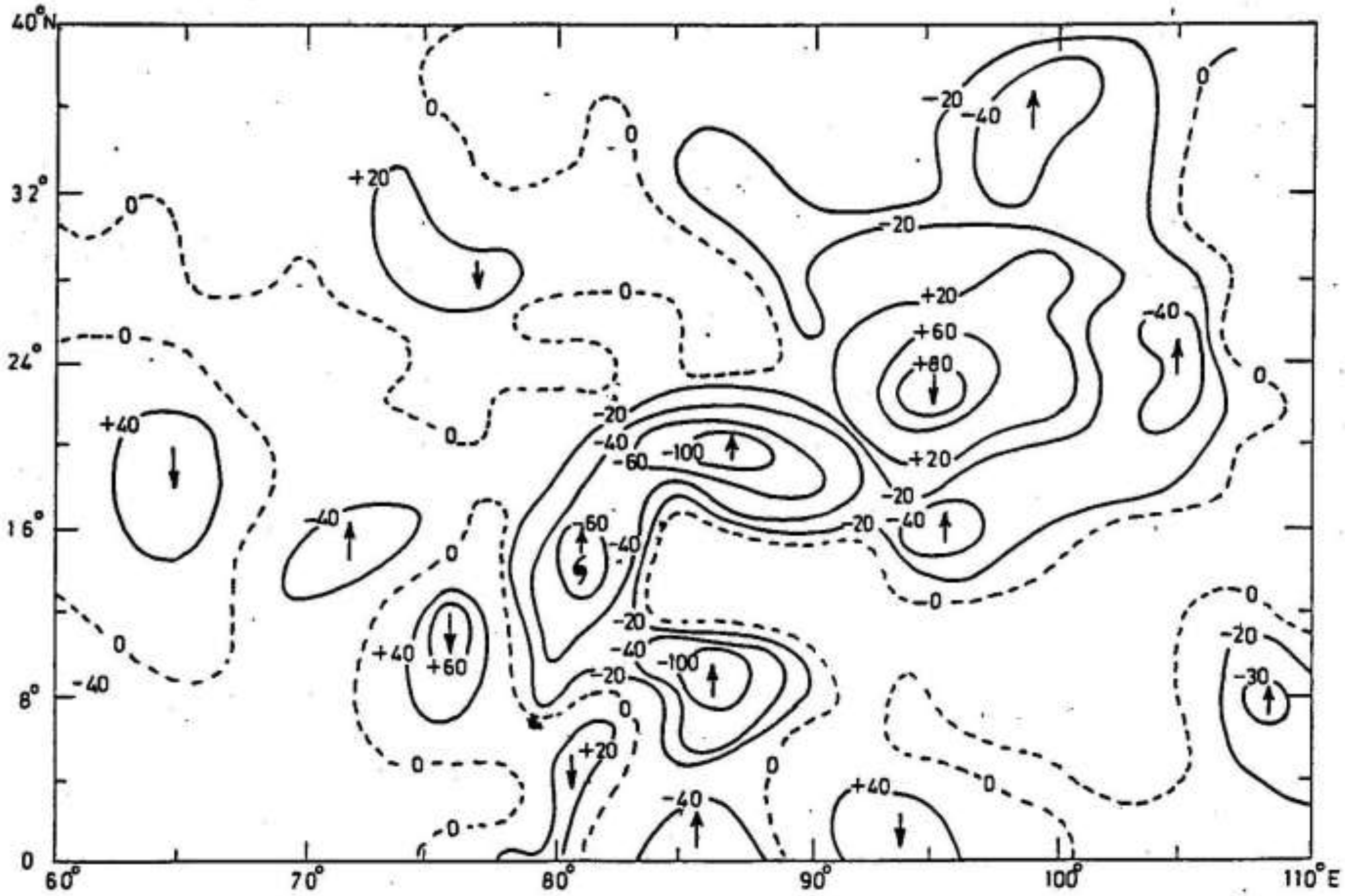

FIG. 16(b) - VERTICAL VELOCITY FIELD AT 500 hPa - 1200 UTC OF 8 MAY, 1990 (UNIT: 10^{-6} hPa Sec.$^{-1}$)

§ - POSITION OF CYCLONE

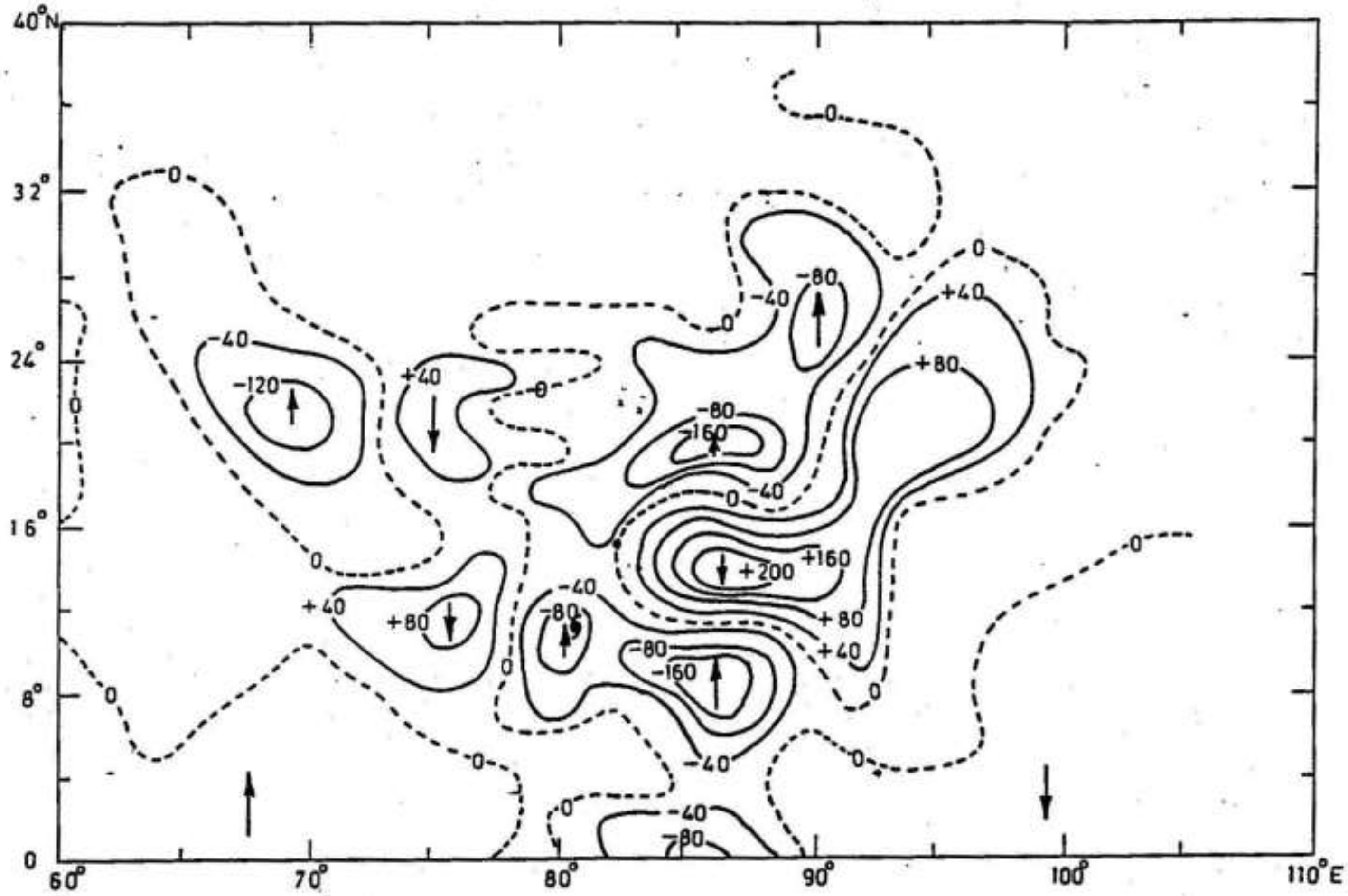

FIG. 16(c) - VERTICAL VELOCITY FIELD AT 200 hPa - 1200 UTC OF 8 MAY, 1990
(UNIT: 10^{-6} hPa $Sec.^{-1}$)
- POSITION OF CYCLONE

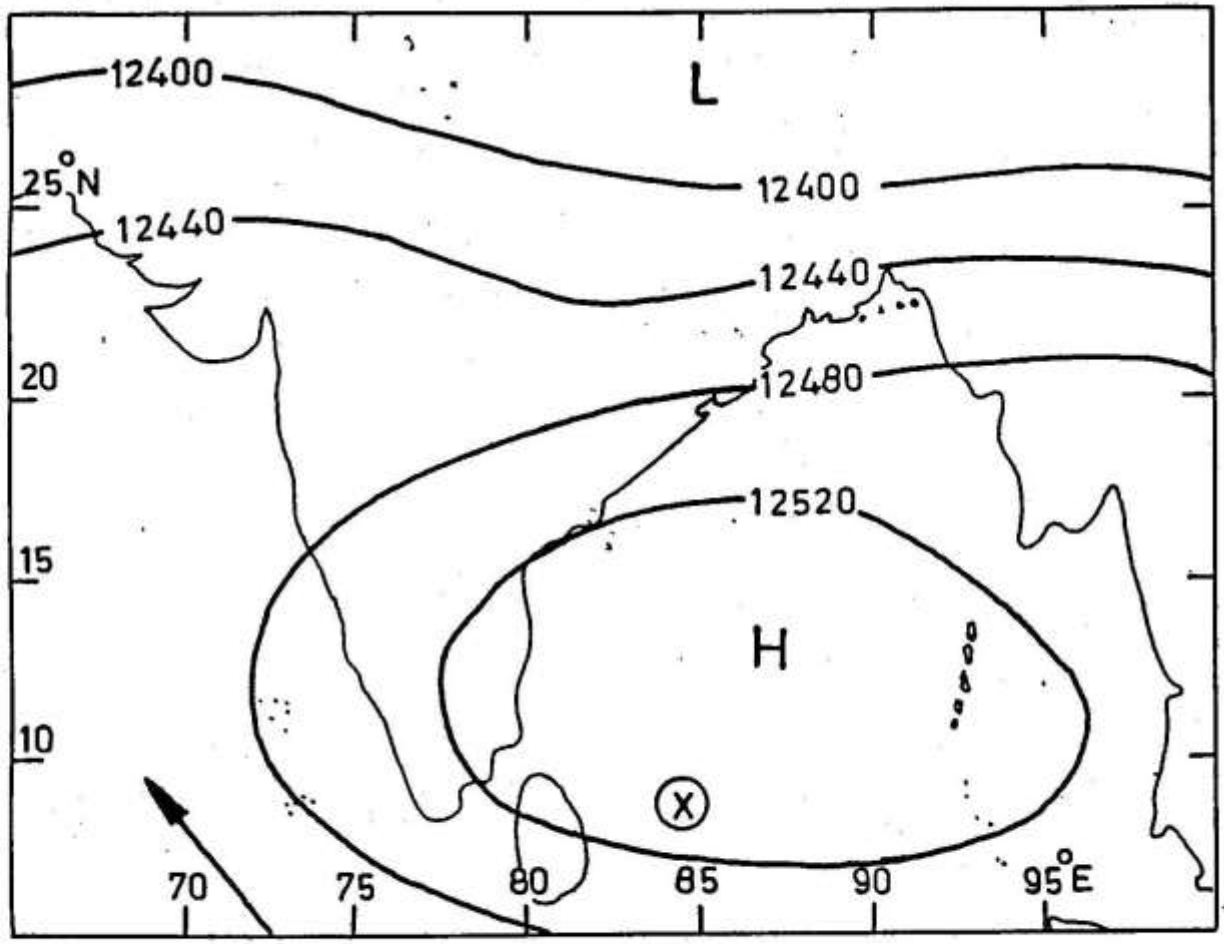

FIG.17. 200 hPa ANALYSIS–12 UTC OF 5 MAY 1990
(Ⓧ-IS THE SEA LEVEL POSITION OF THE STORM)

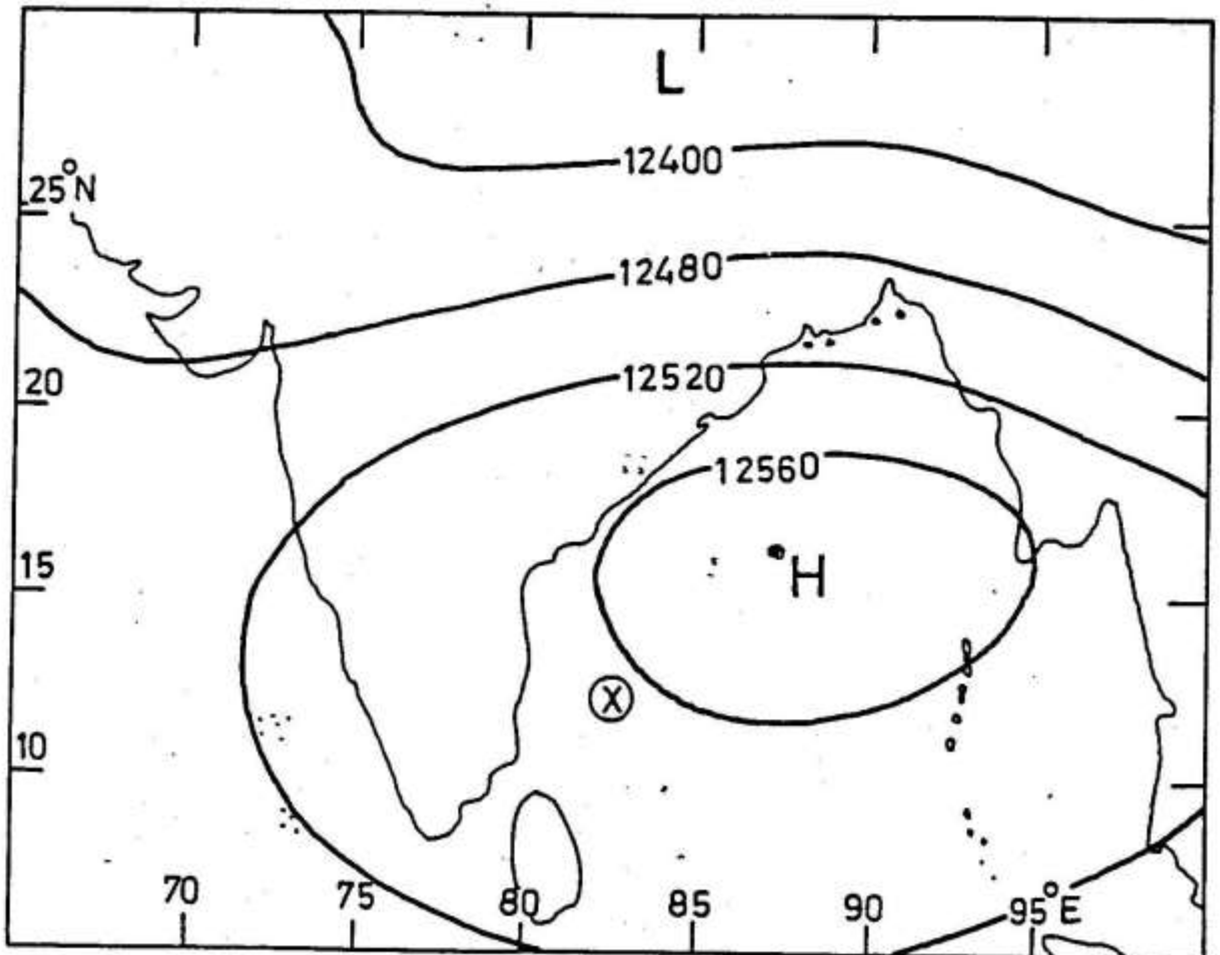

FIG 18 200hPa ANALYSIS-12 UTC OF 7 MAY 1990
(Ⓧ - IS THE SEA LEVEL POSITION OF THE STORM)

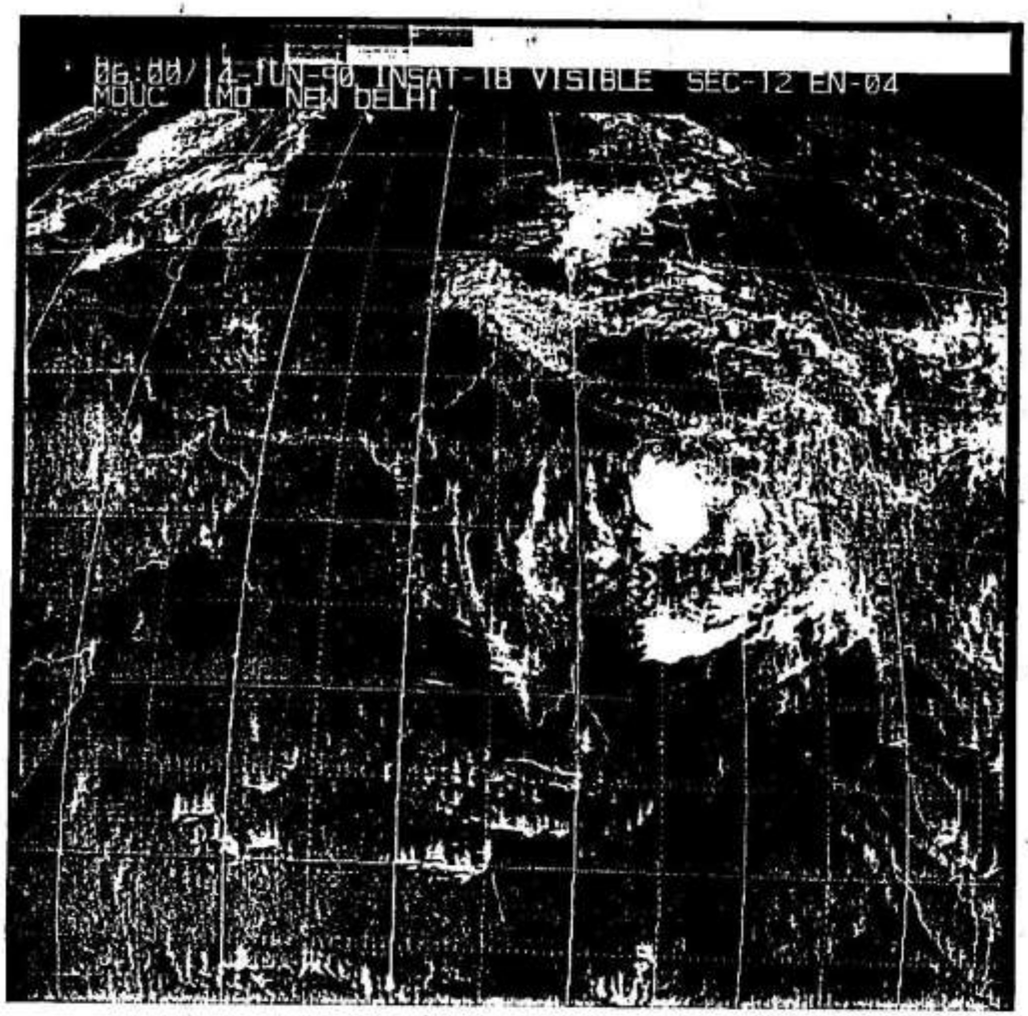

FIG. 19 - INSAT-1B SATELLITE IMAGERY-0600 UTC OF 14 JANUARY, 199

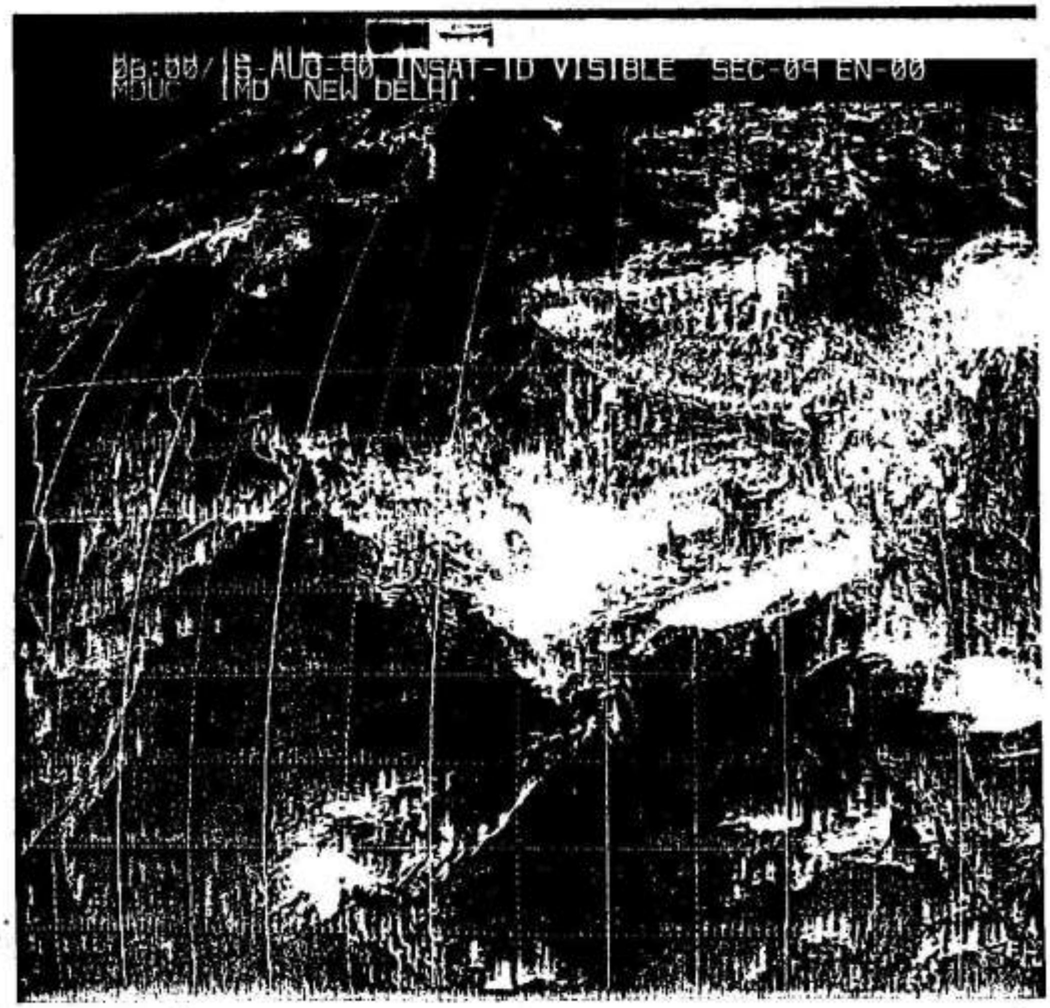

FIG. 20 - INSAT-1B SATELLITE IMAGERY-0600 UTC OF 15 AUGUST, 1990.

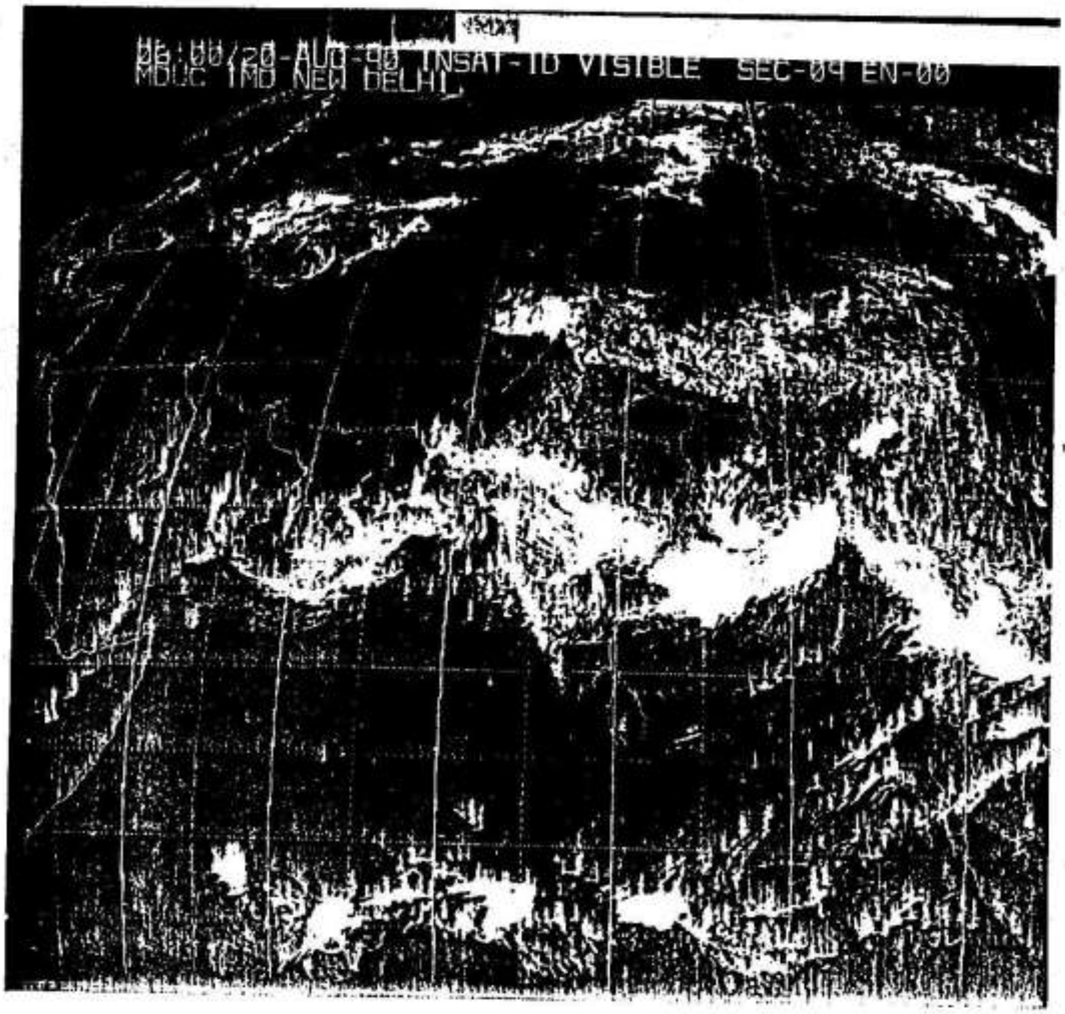

FIG. 21 - INSAT-1B SATELLITE IMAGERY-0600 UTC OF 20 AUGUST, 1990.

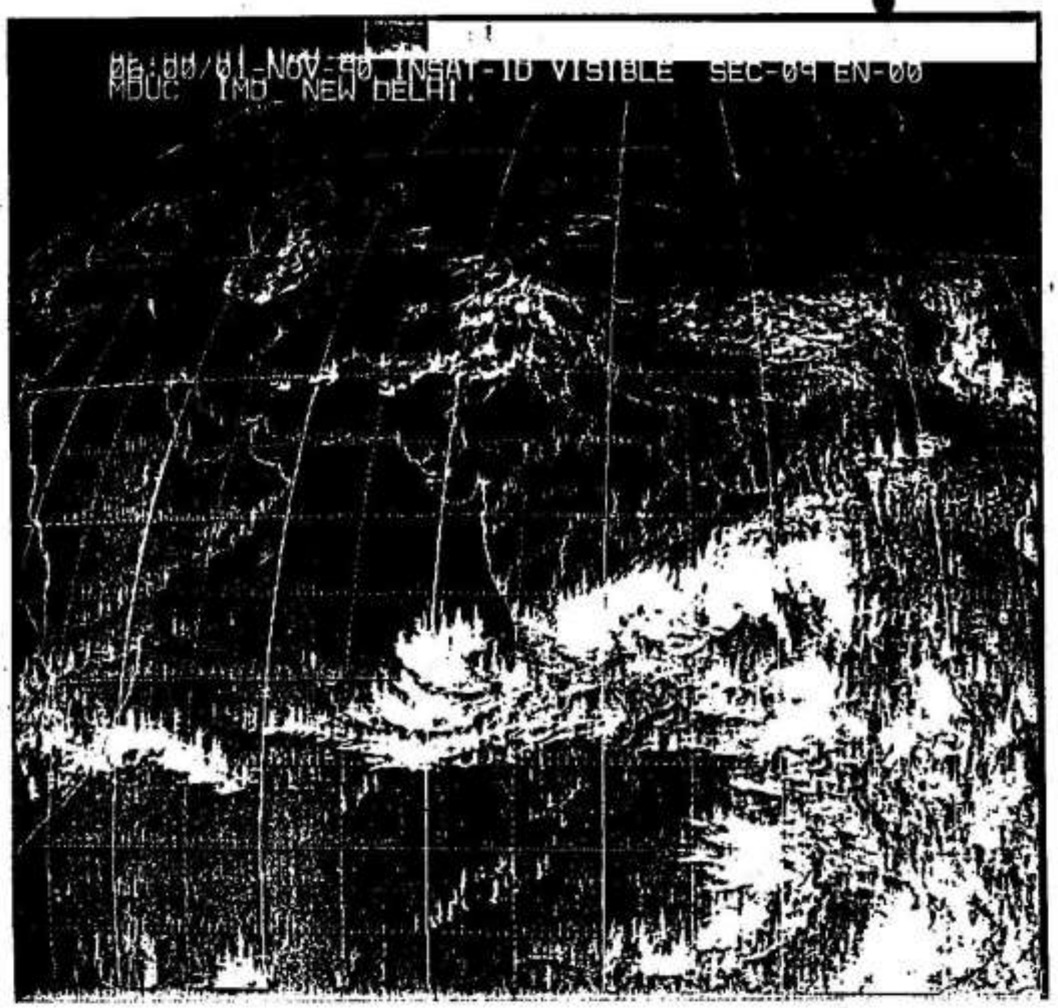

FIG. 22 – INSAT-1D SATELLITE IMAGERY 0600 UTC OF 1 NOVEMBER, 1990.

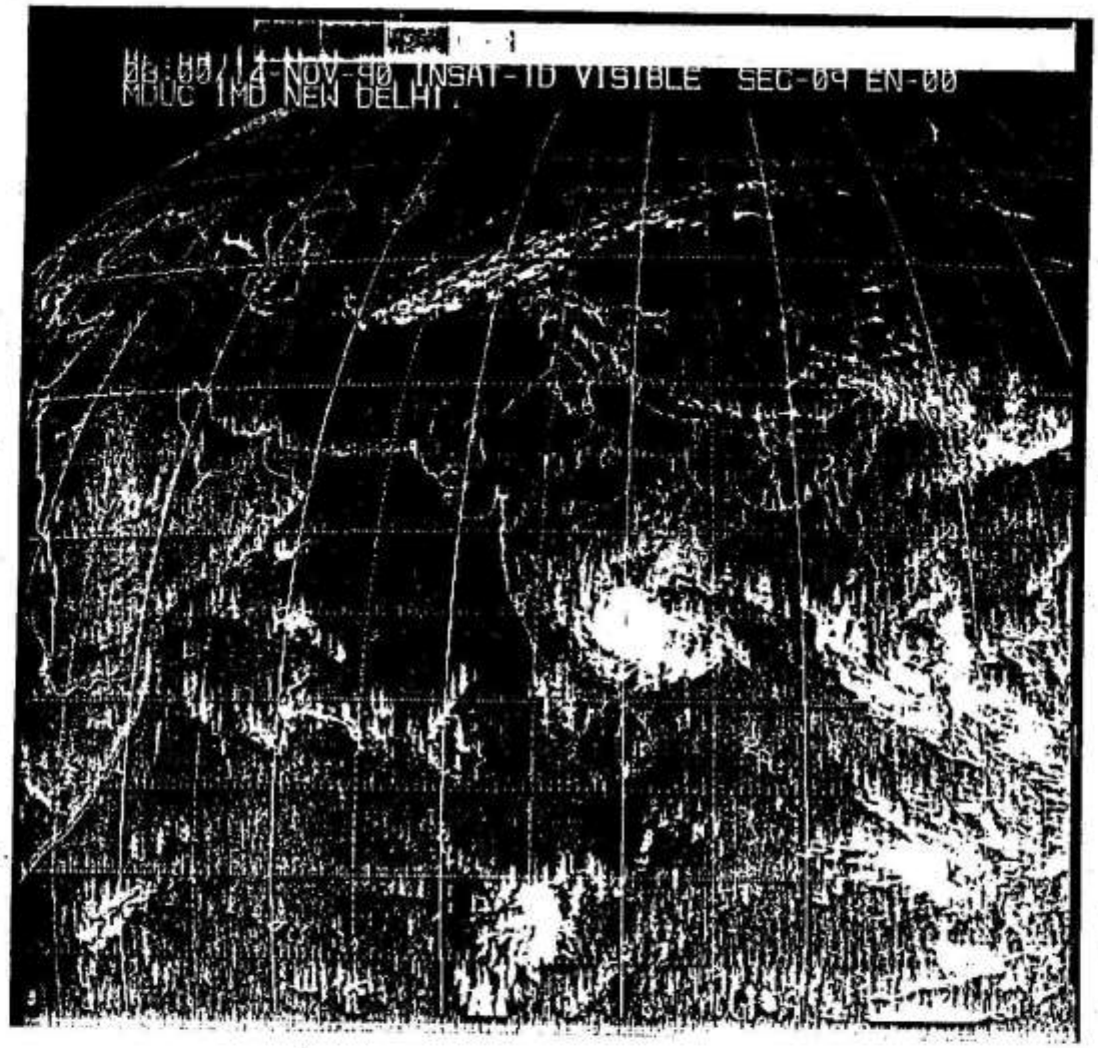

FIG. 23 - INSAT-1B SATELLITE IMAGERY-0600 UTC OF 14 NOVEMBER, 1990

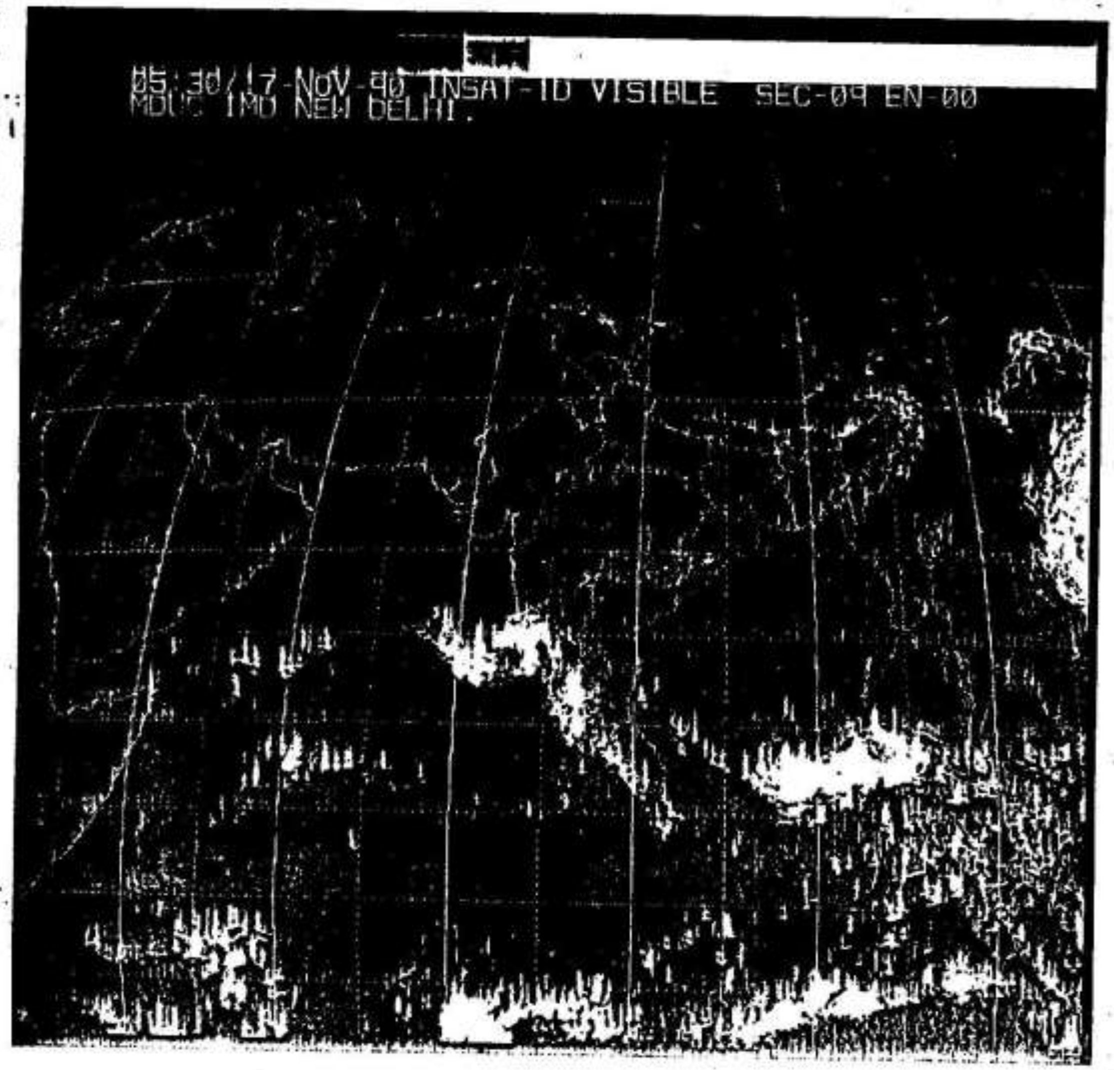

FIG.24 – INSAT-1B SATELLITE IMAGERY-0530 UTC OF 17 NOVEMBER, 1990.

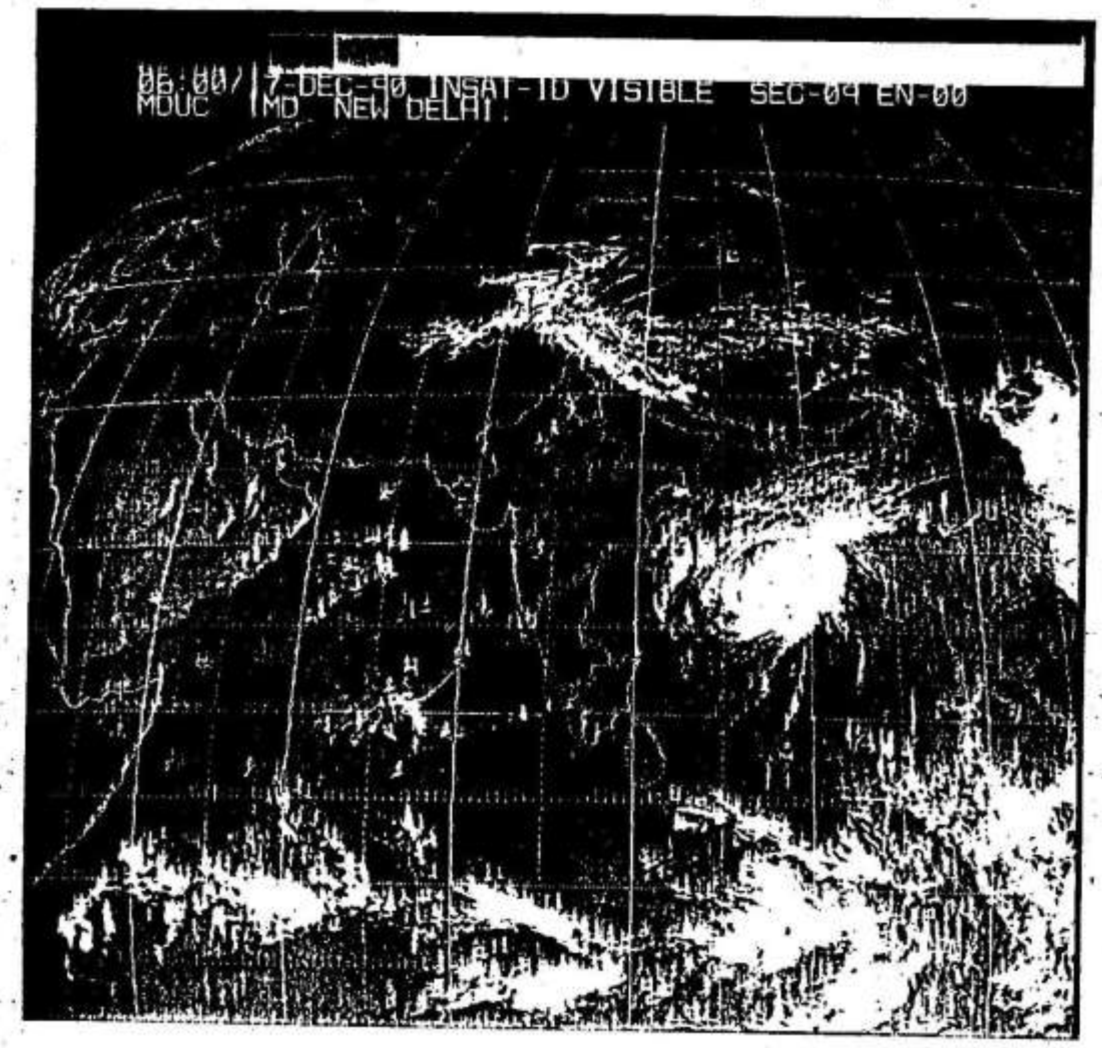

FIG.25 - INSAT-1B SATELLITE IMAGERY - 0600 UTC OF 17 DECEMBER, 1990.

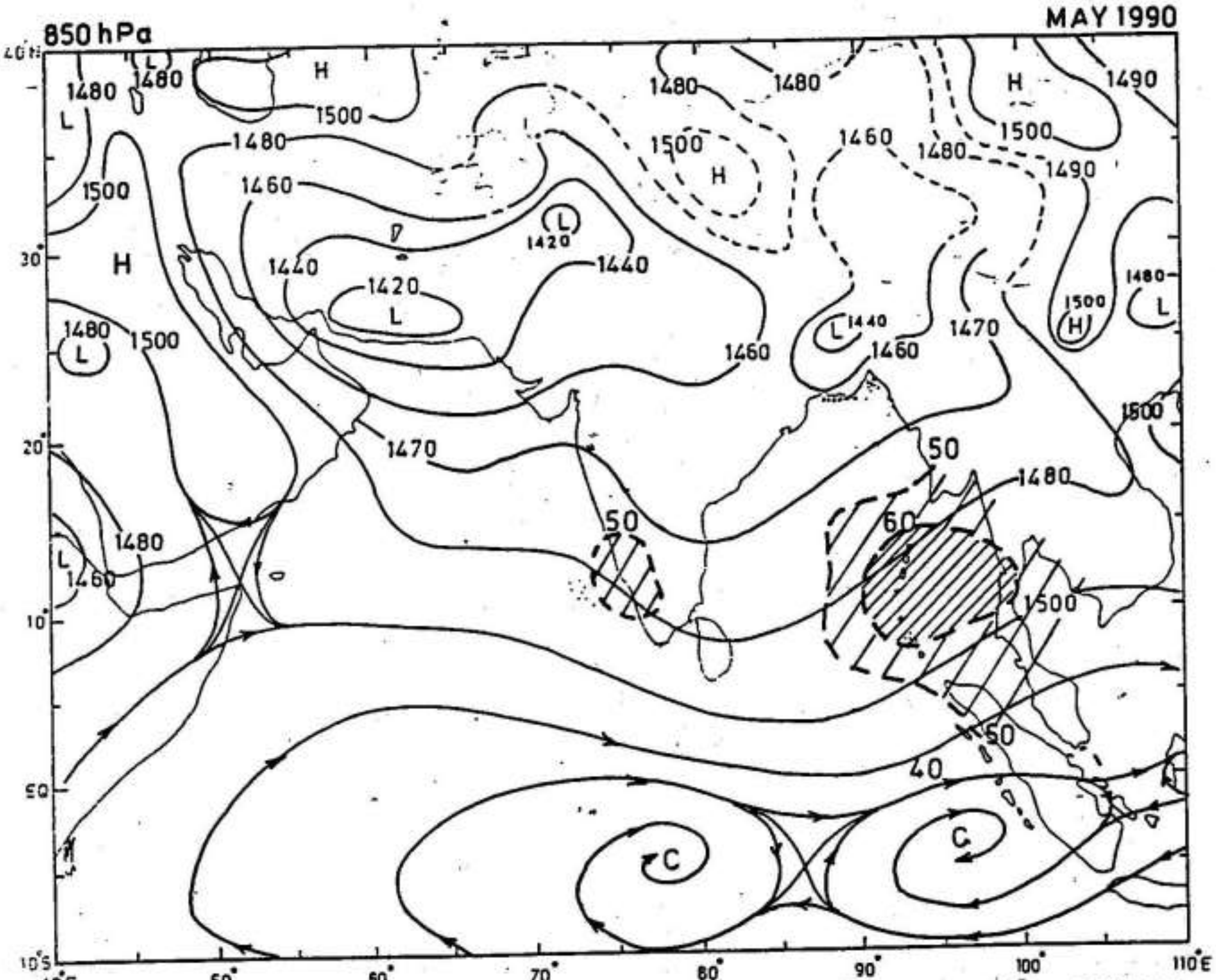

FIG. 26(a) - MONTHLY MEAN 850 hPa CONTOUR ANALYSIS OF MAY 1990. AVERAGE FRACTIONAL CLOUDINESS EXCEEDING 50 PER CENT WITH THRESHOLD TEMPERATURE 265°K SHOWN BY HATCHED AREA.

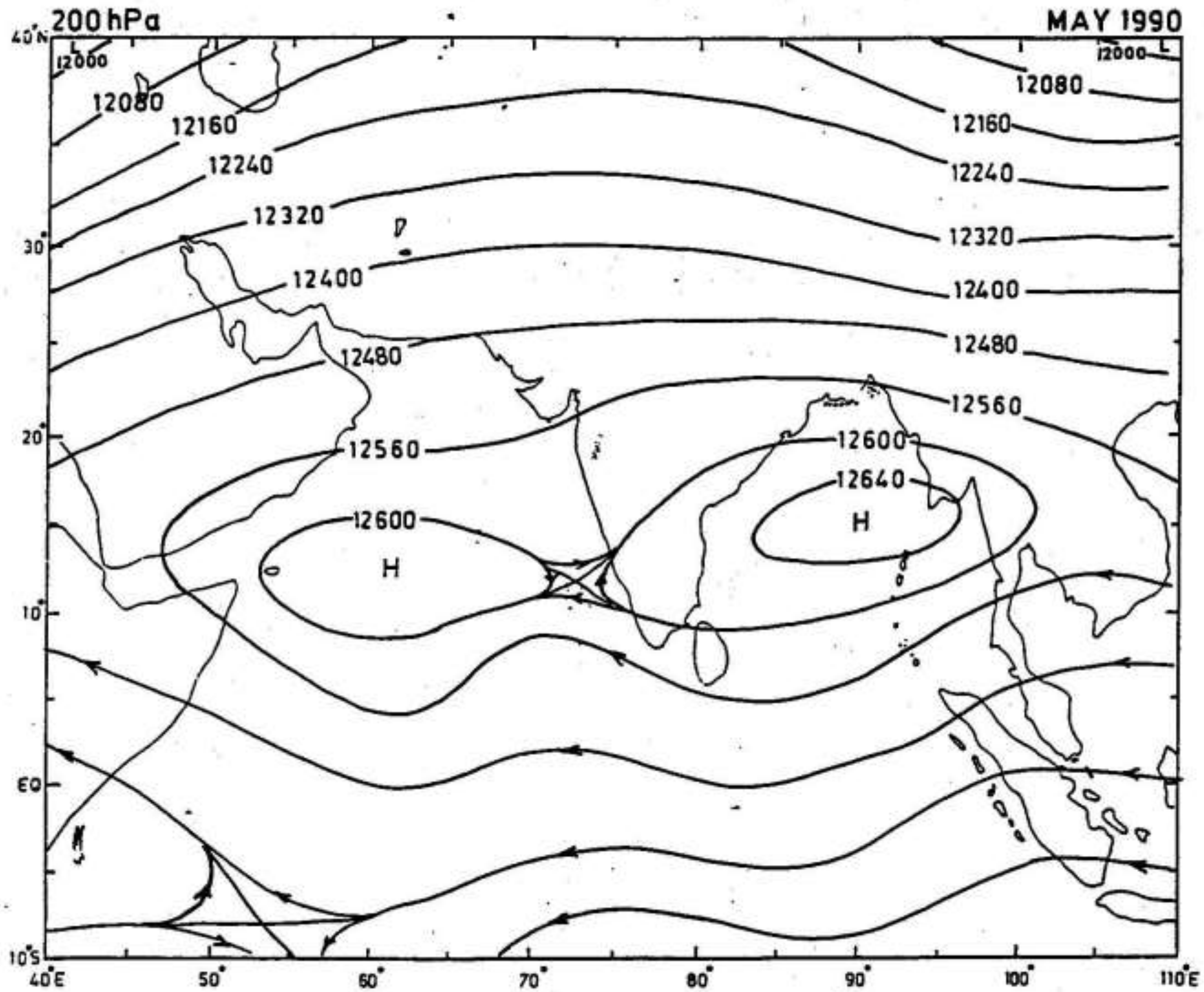

FIG. 26(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF MAY, 1990.

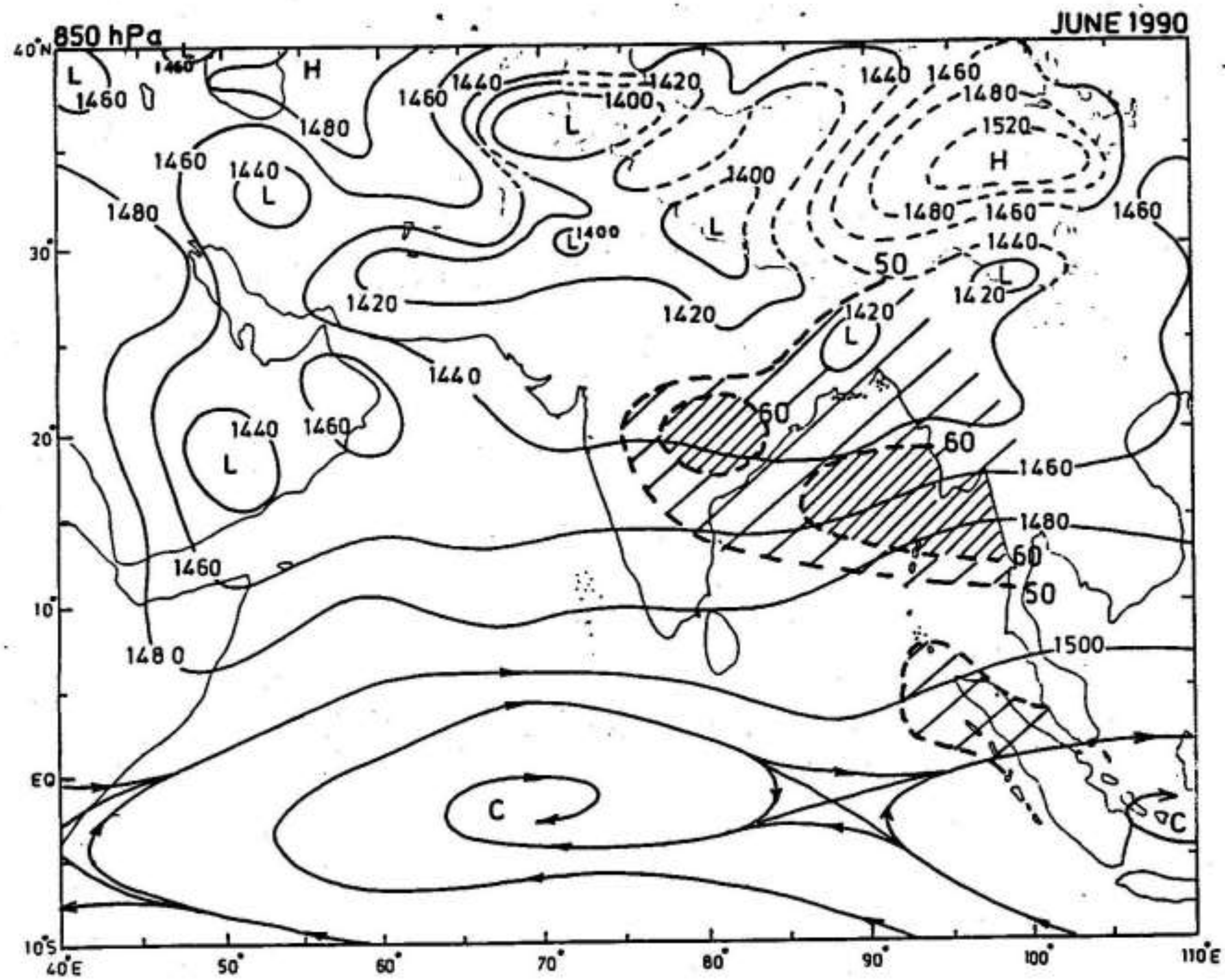

FIG. 27(a) - SAME AS IN FIG. 26(a) BUT FOR JUNE 1990.

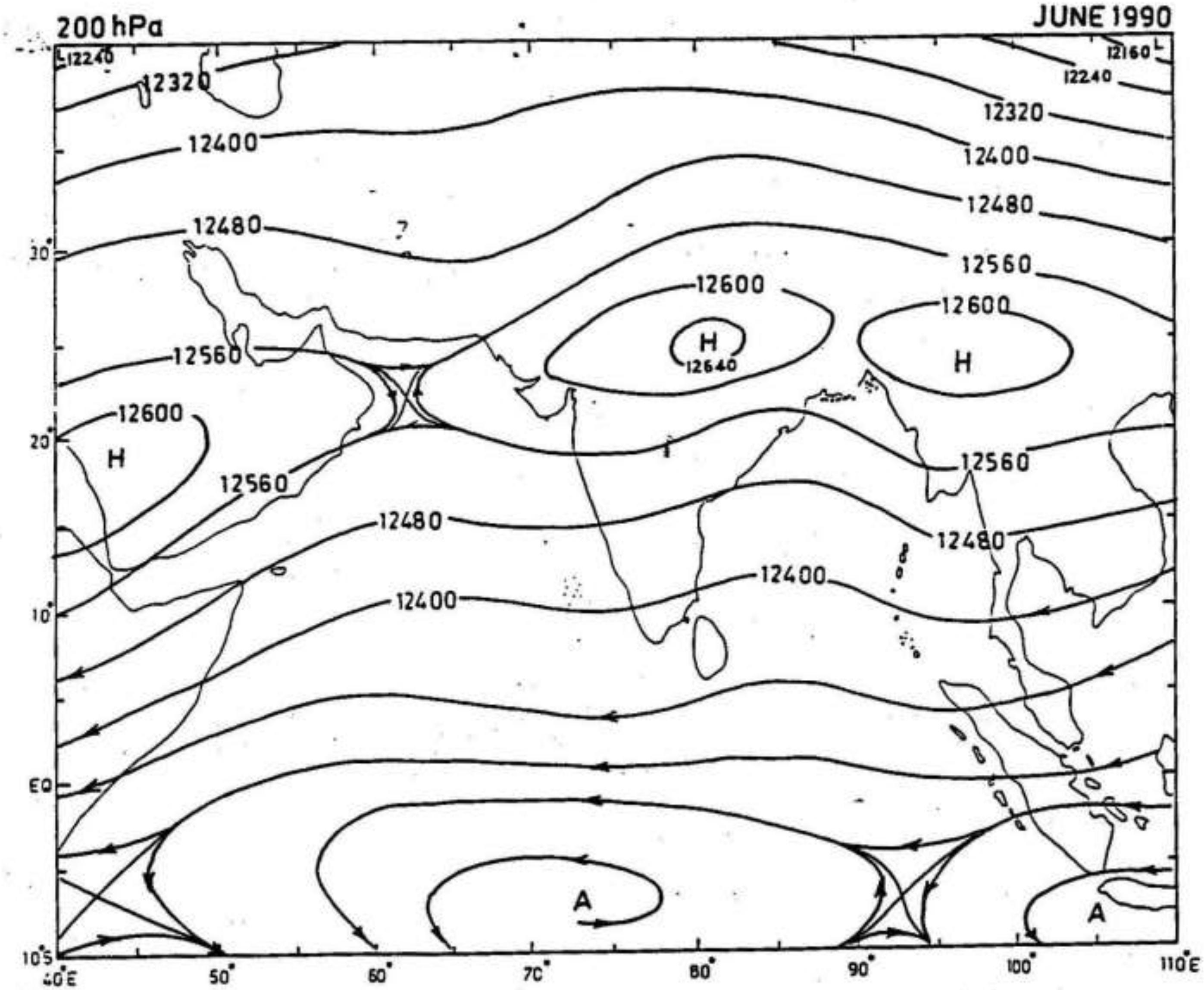

FIG. 27(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF JUNE, 1990.

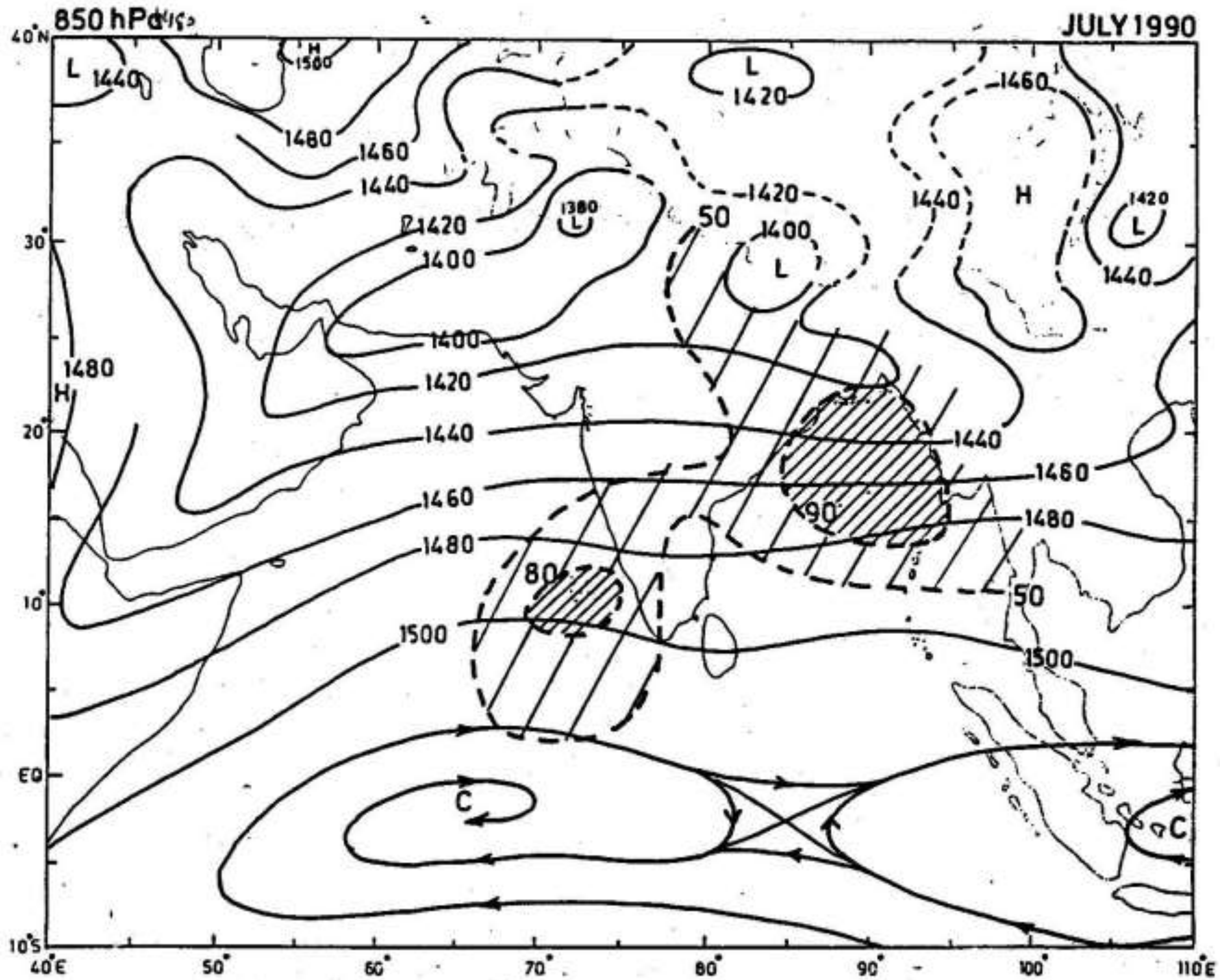

FIG. 28(a) - SAME AS IN FIG. 26(a) BUT FOR JULY 1990.

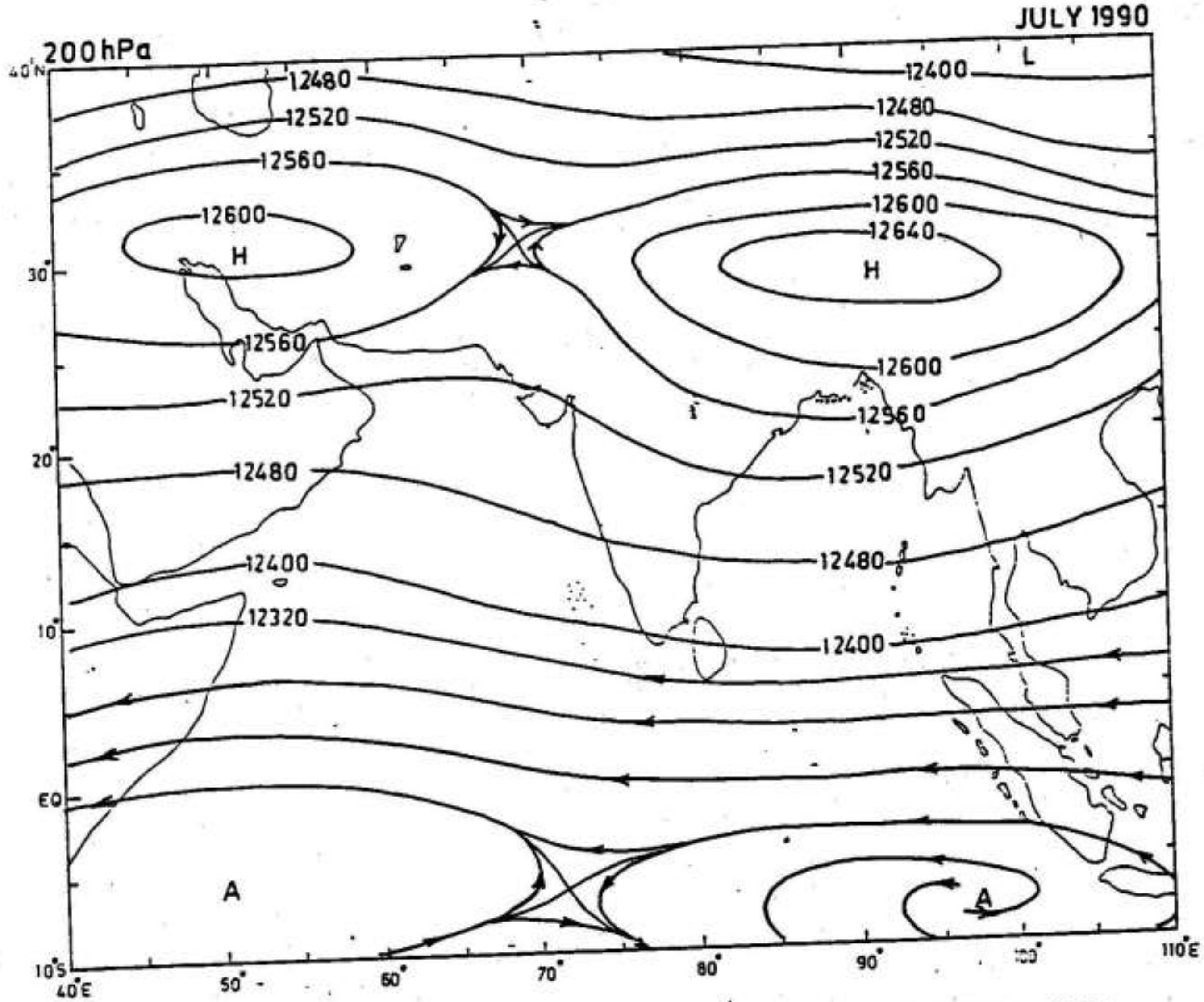

FIG. 28(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF JULY, 1990.

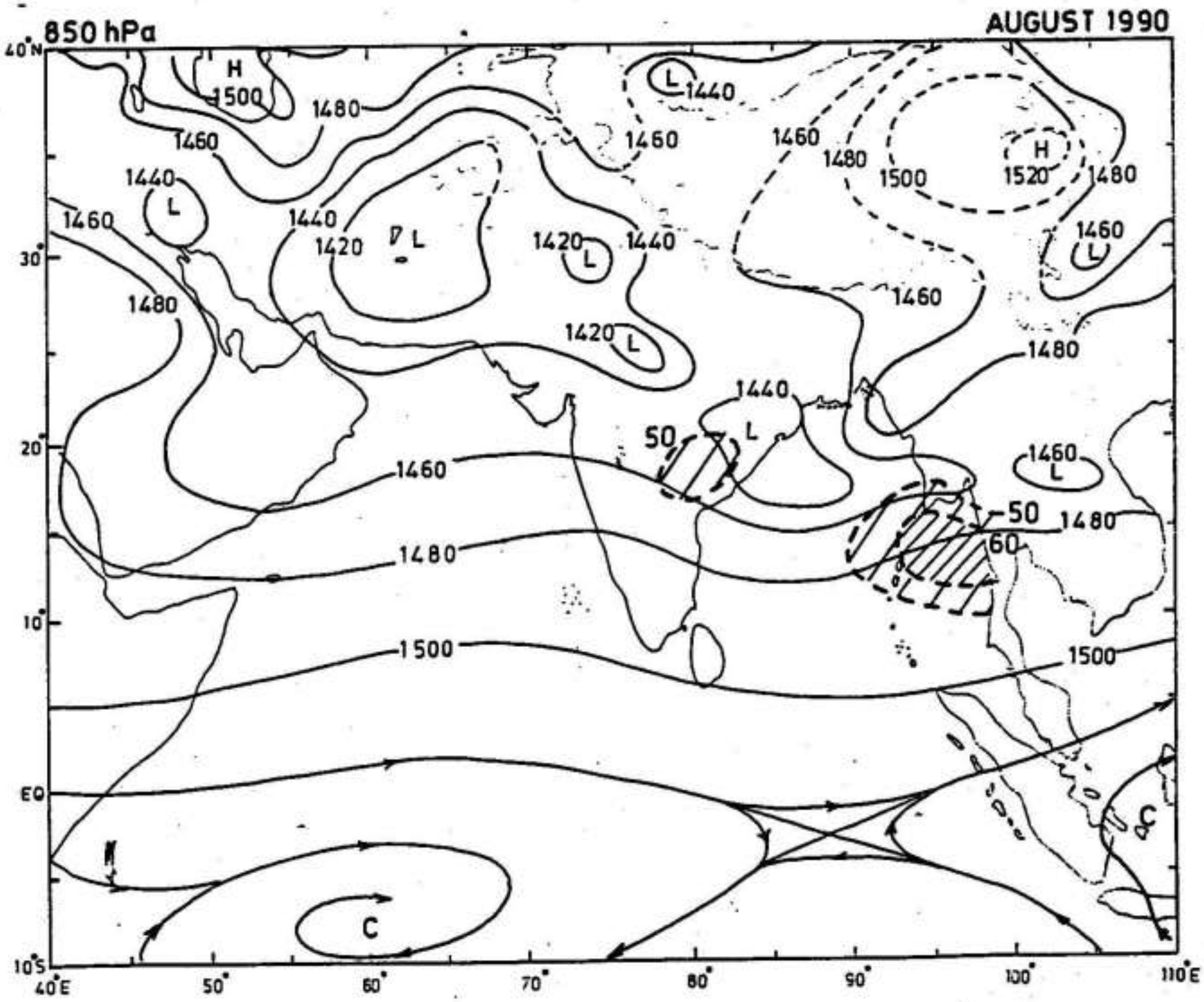

FIG. 29(a) - SAME AS IN FIG. 26(a) BUT FOR AUGUST 1990.

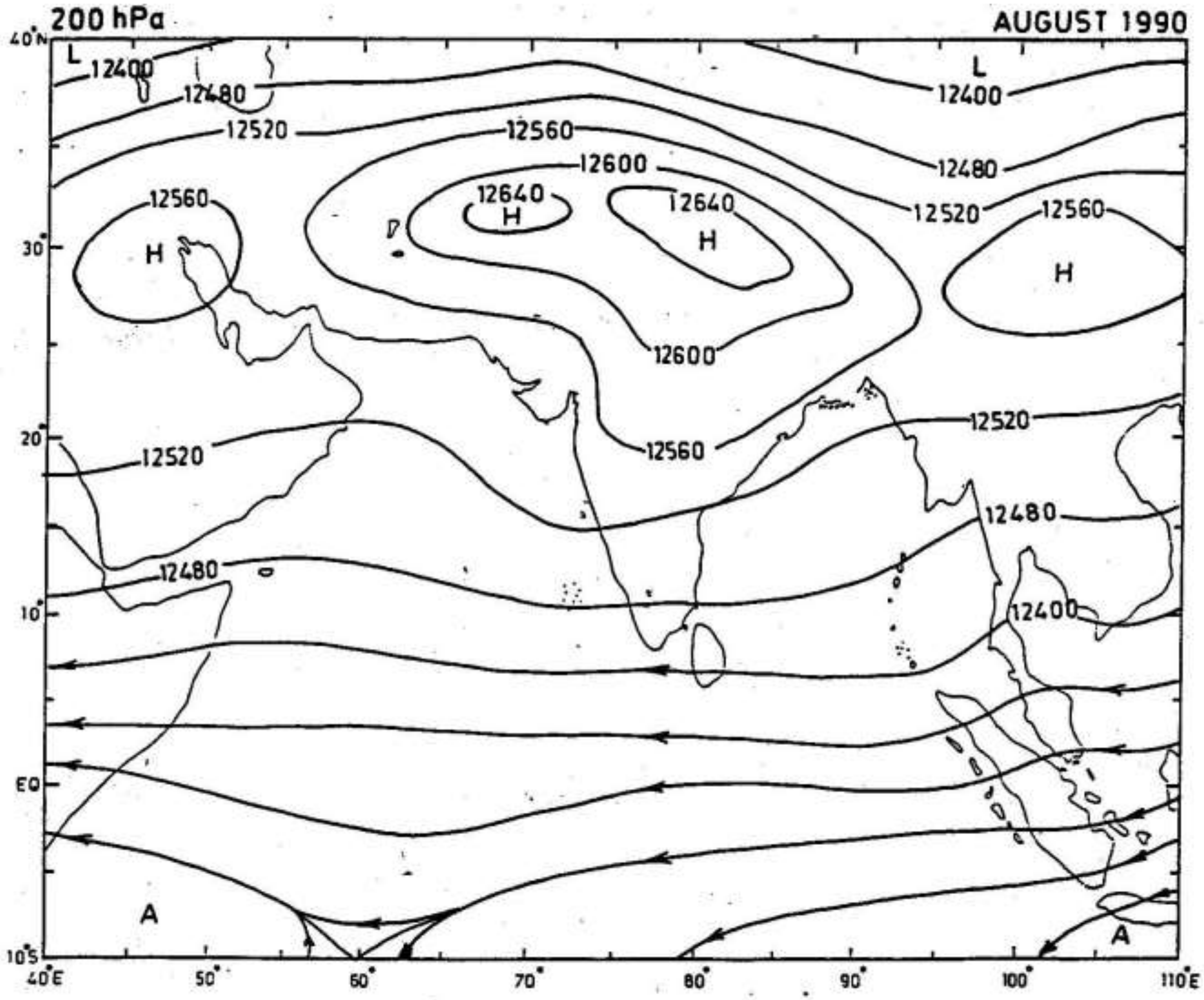

FIG. 29(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF AUGUST, 1990.

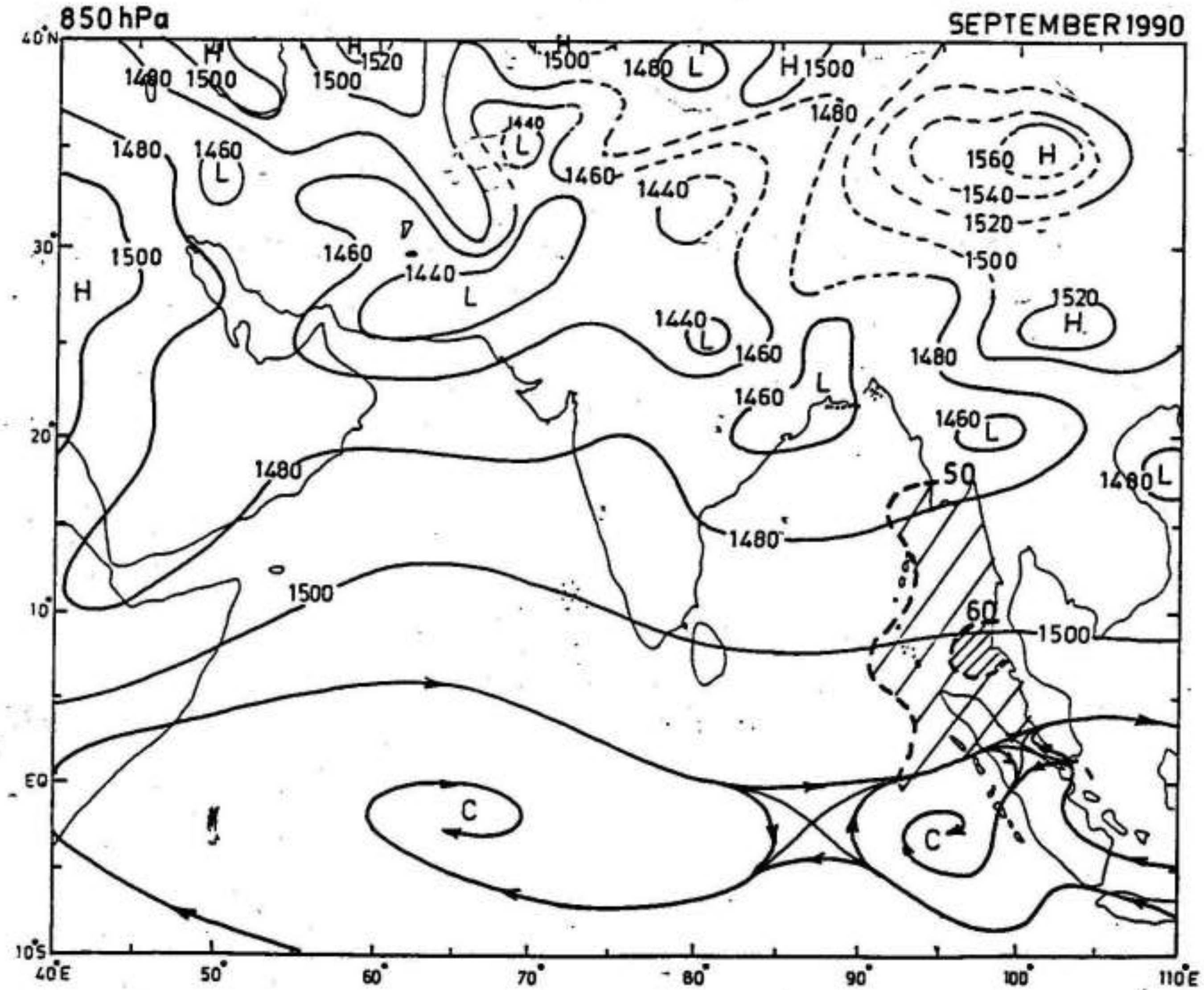

FIG. 30(a) - SAME AS IN FIG. 26(a) BUT FOR SEPTEMBER, 1990.

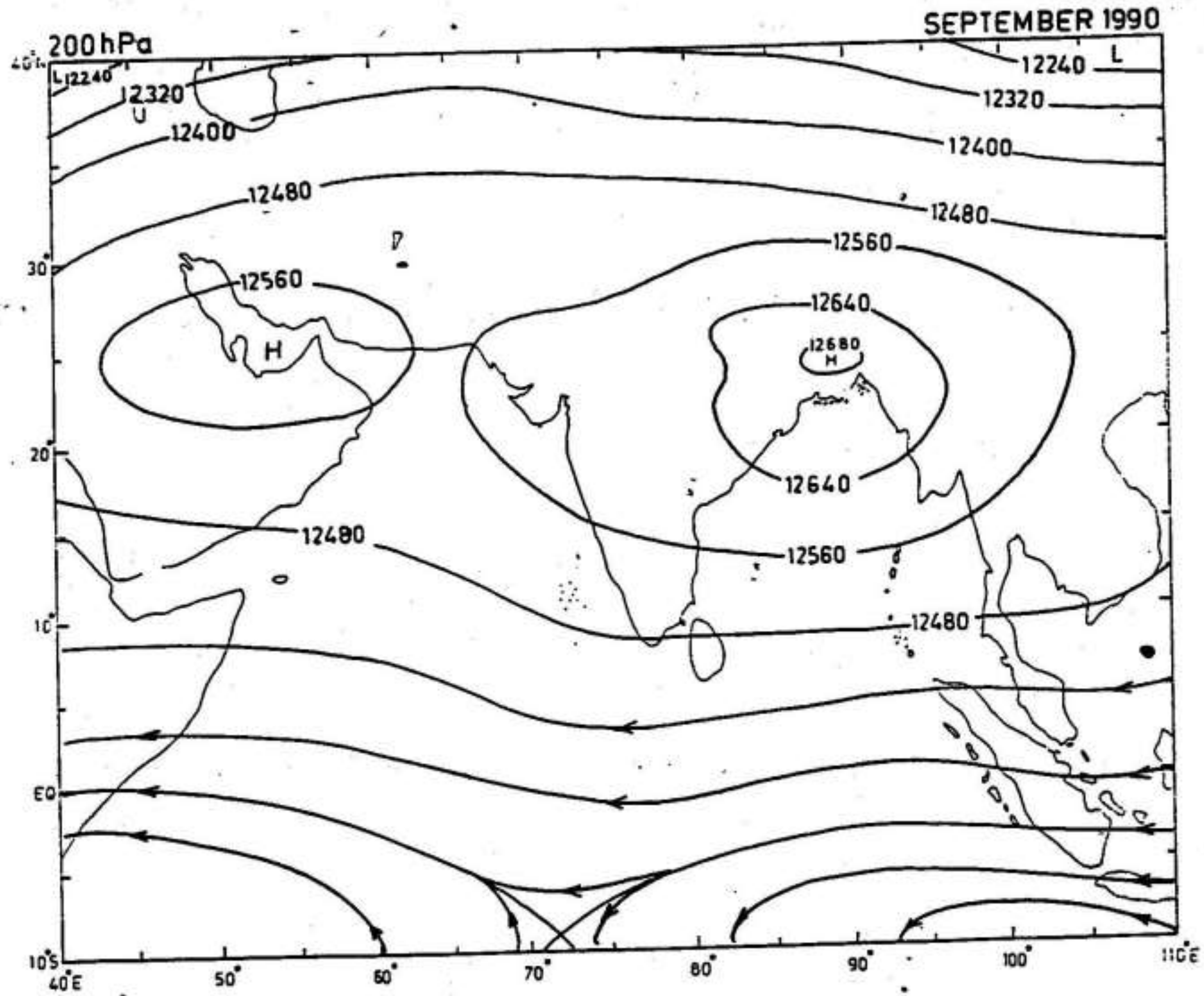

FIG. 30(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF SEPTEMBER, 1990.

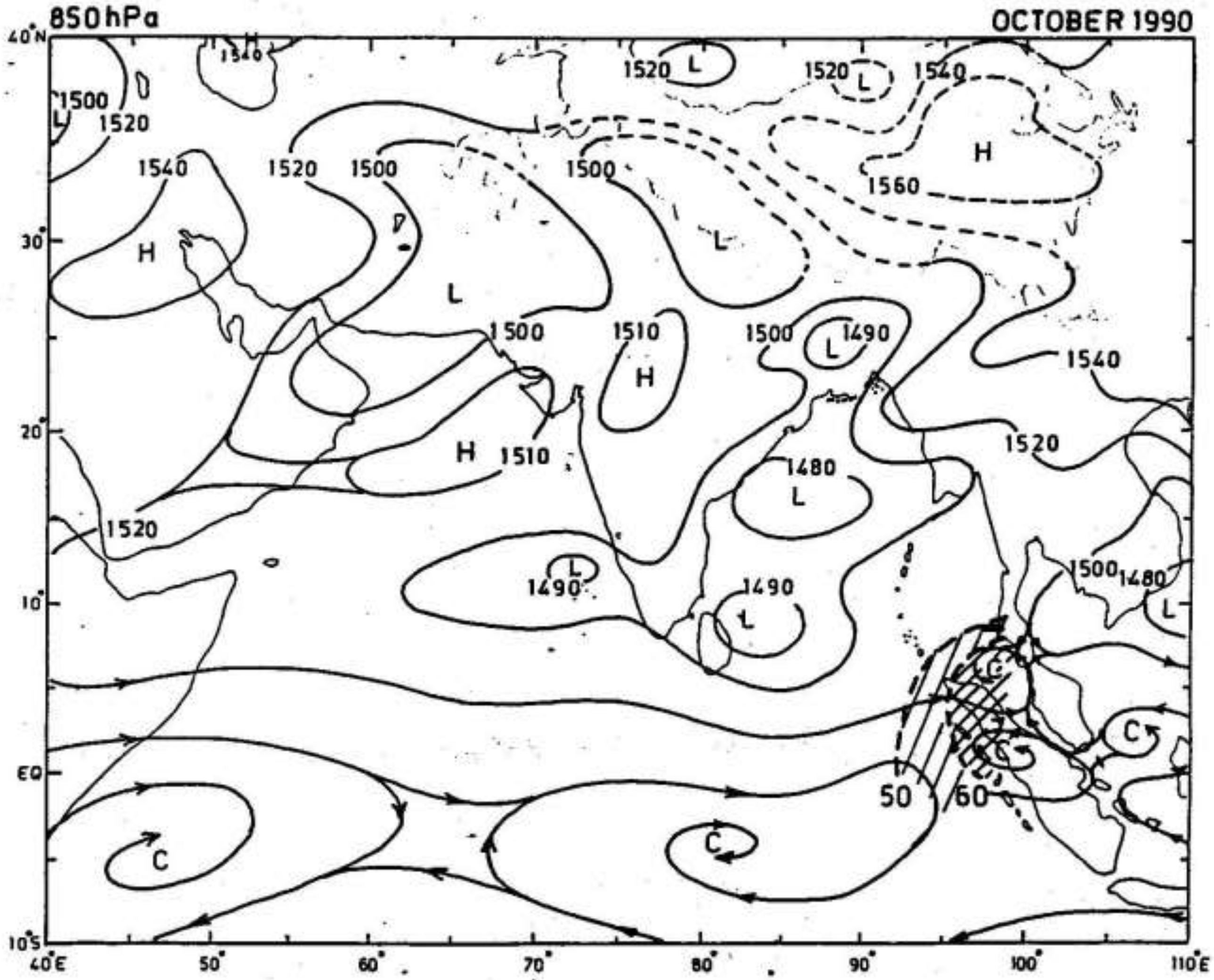

FIG. 31(a) - SAME AS IN FIG. 26(a) BUT FOR OCTOBER, 1990.

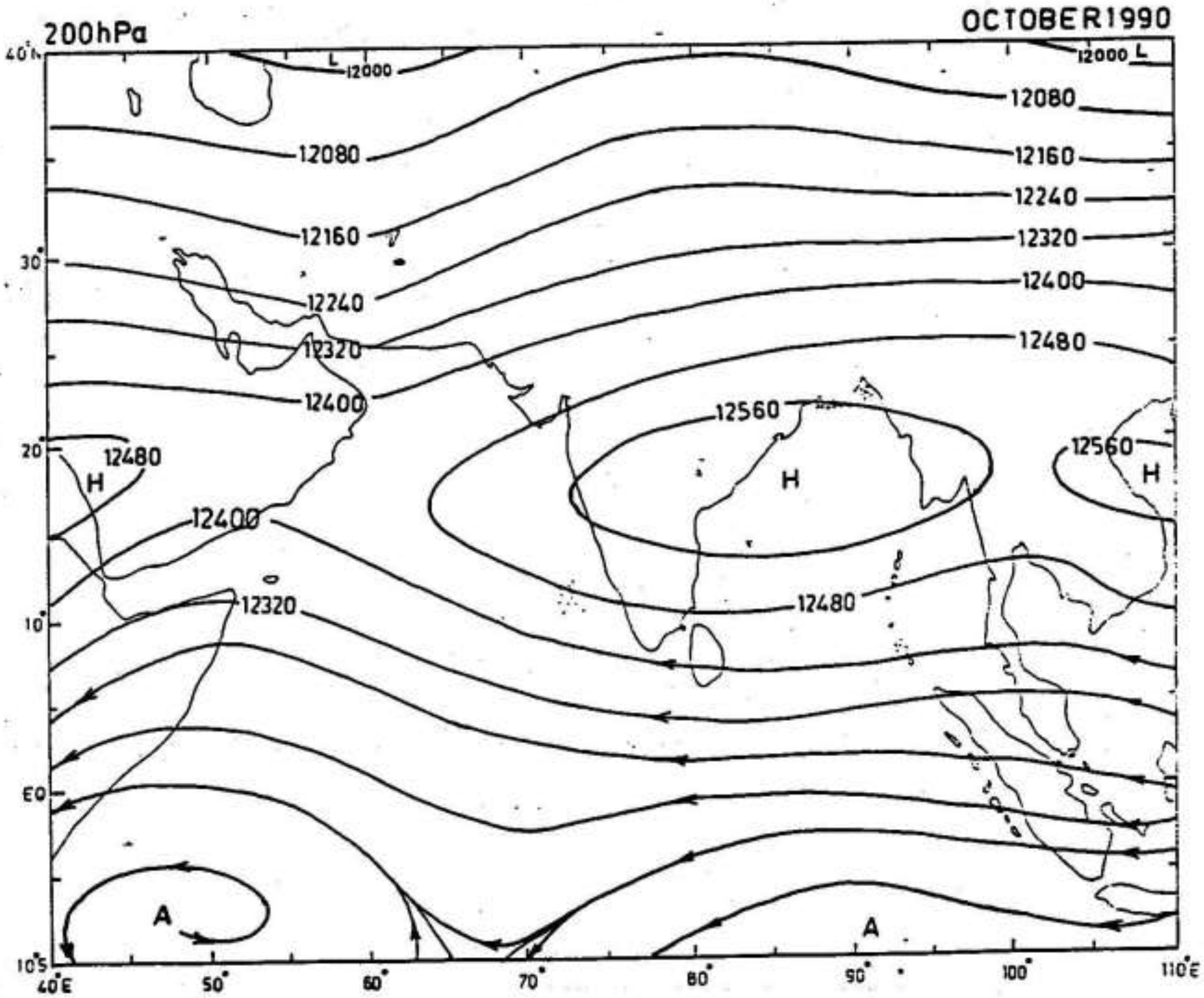

FIG. 31(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF OCTOBER, 1990.

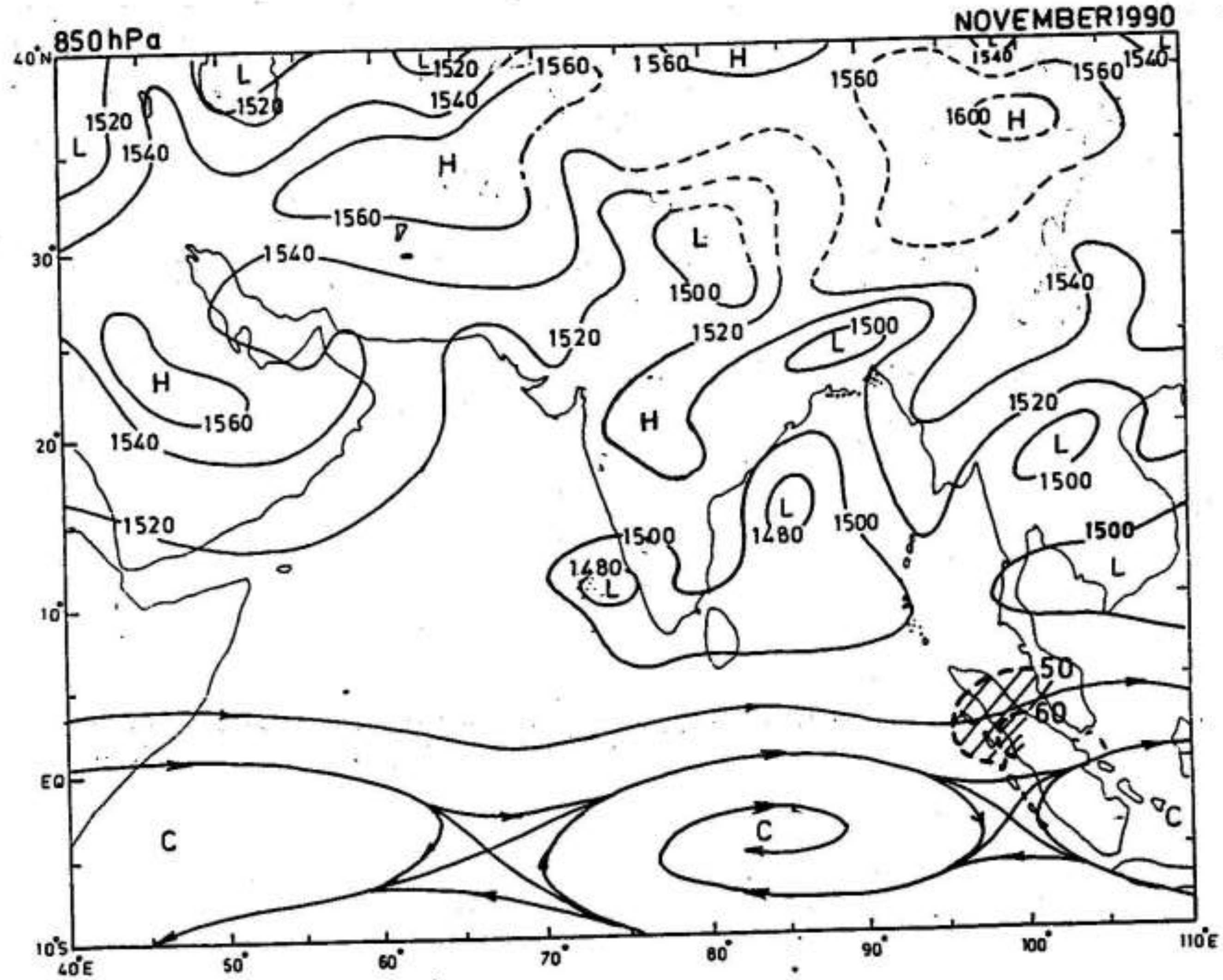

FIG. 32(a) - SAME AS IN FIG. 26(a) BUT FOR NOVEMBER, 1990.

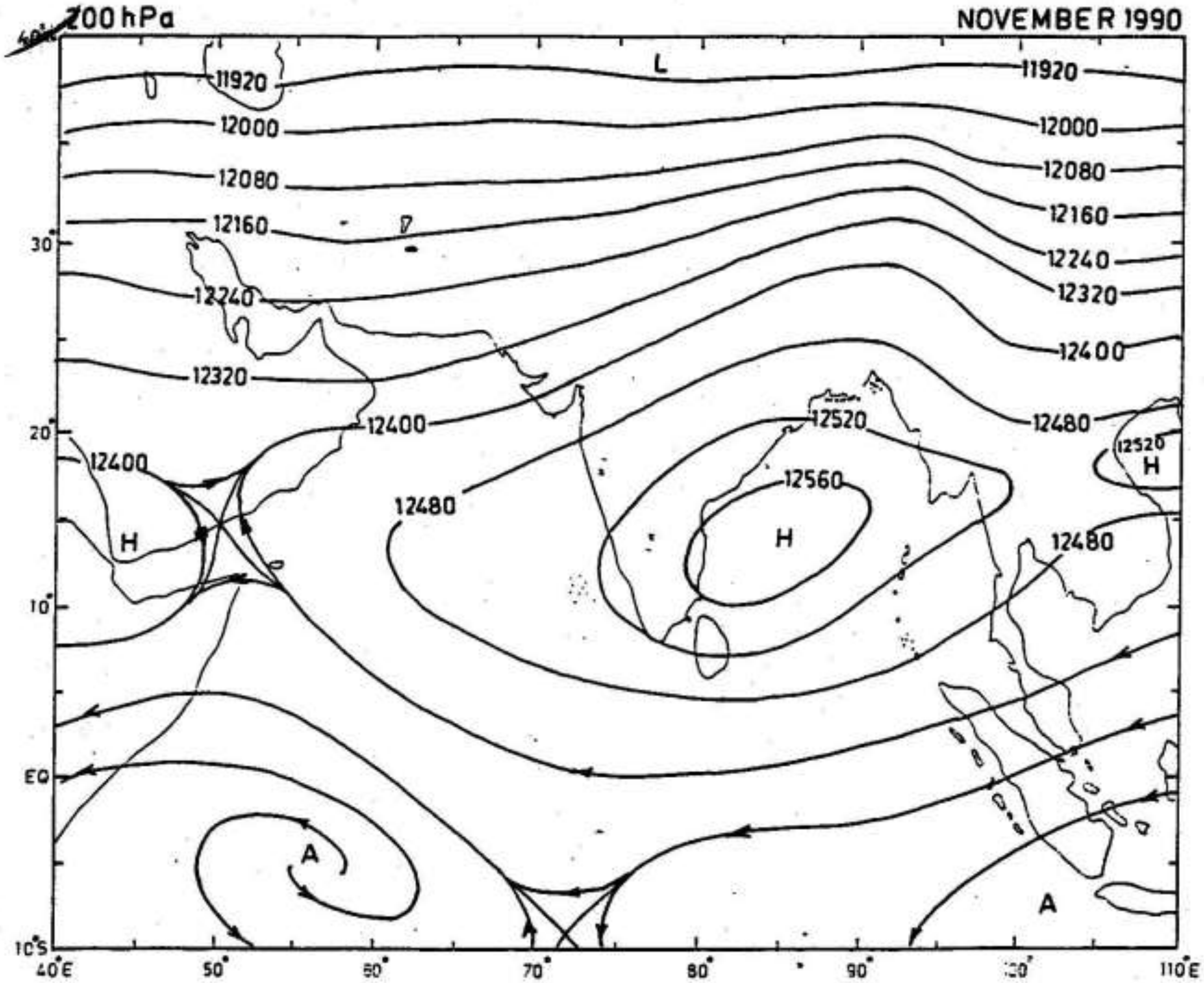

FIG. 32(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF NOVEMBER, 1990.

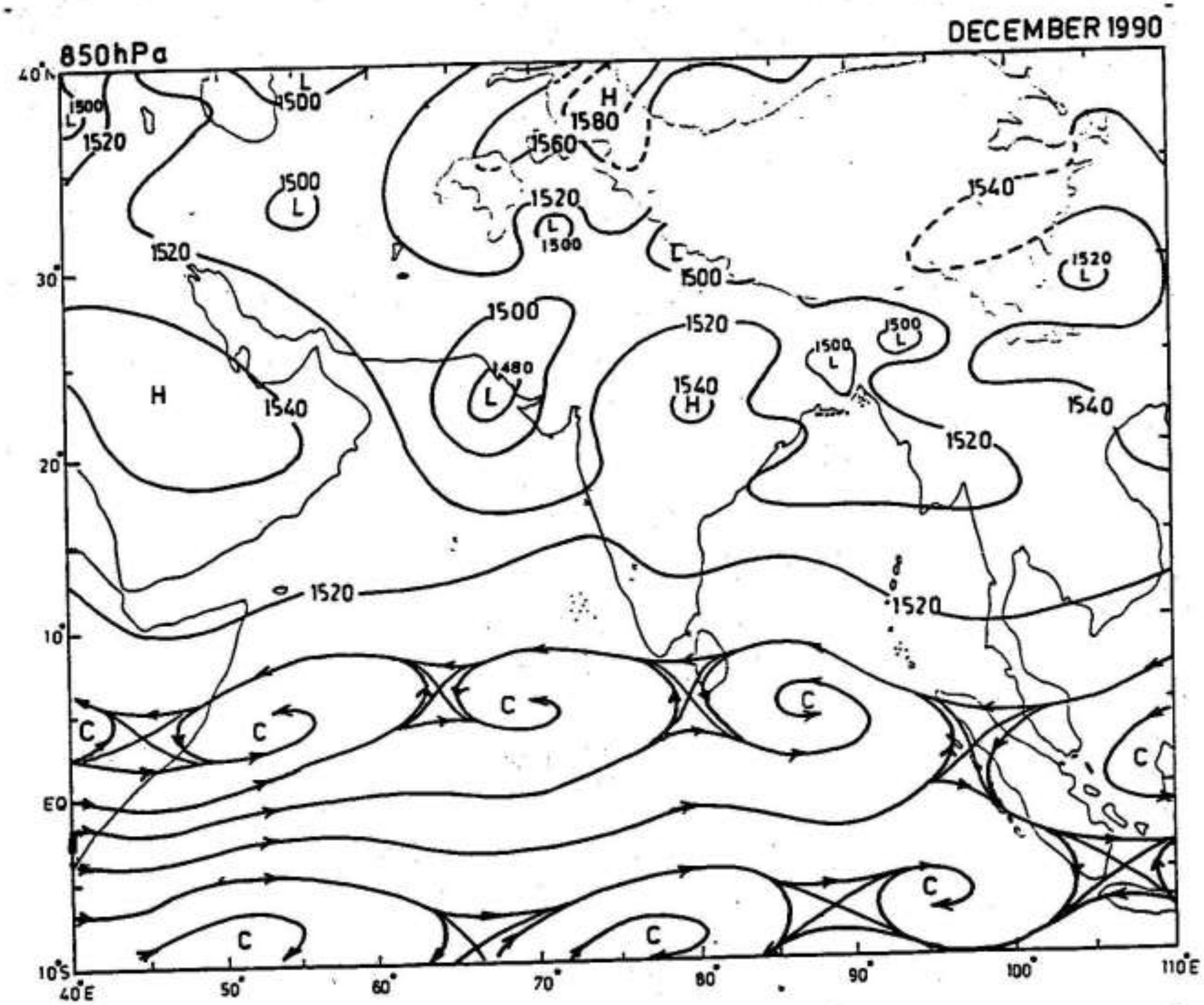

FIG. 33(a) - SAME AS IN FIG. 26(a) BUT FOR DECEMBER, 1990.

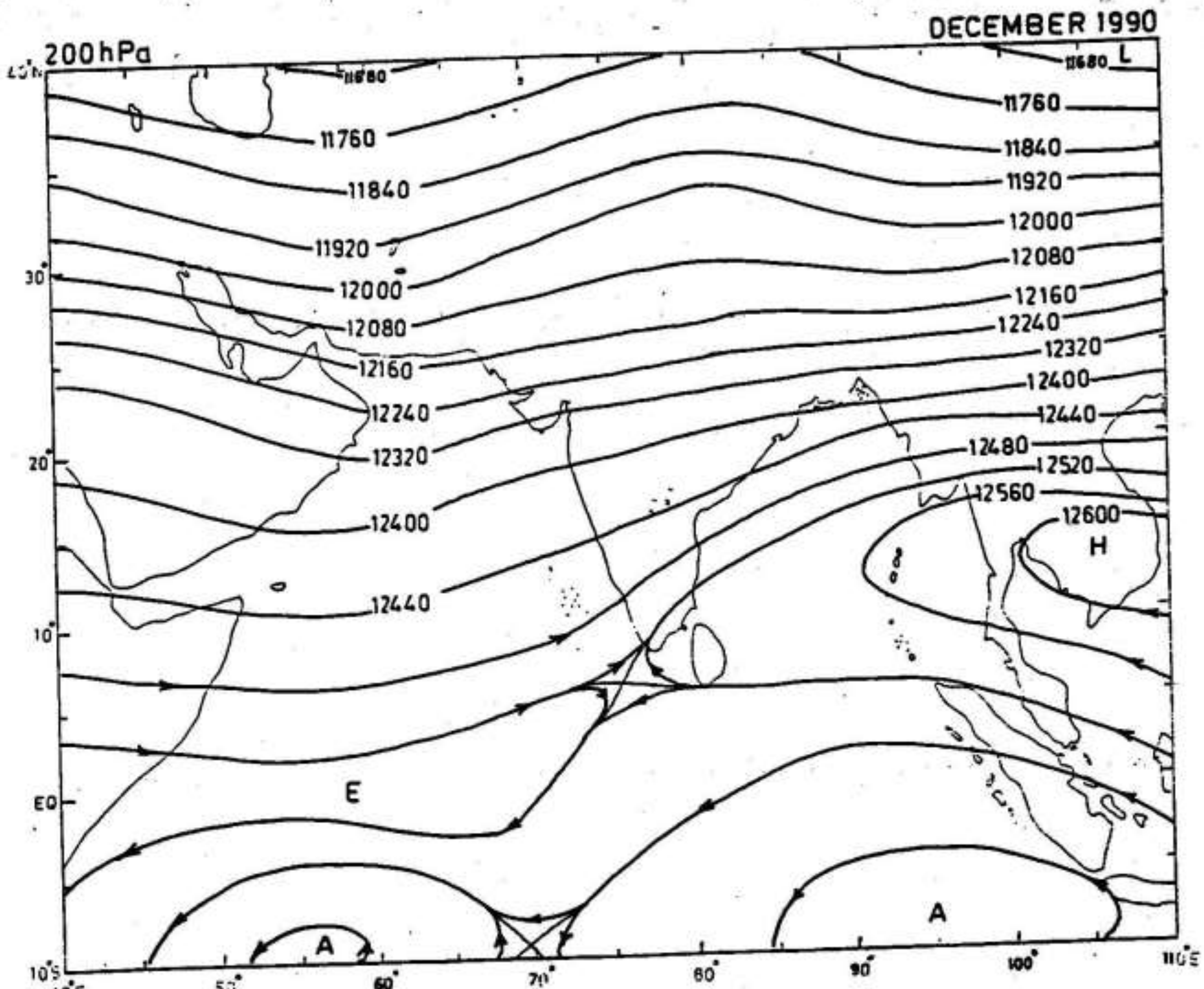

FIG. 33(b) - MONTHLY MEAN 200 hPa CONTOUR ANALYSIS OF DECEMBER, 1990.

Extract taken from Suo-Motto statement made by Shri Upendra Nath Verma, Minister of State for Rural Development in Lok/Rajya Sabha.

On 10.5.90

"Honourable Members may note that the Central and the State Governments have taken timely preparatory measures including timely warning but for which the loss to life and property would have been enormous".

Extract from Suo-Motto statement made by Shri Nitish Kumar, Minister of State for Agriculture in the Lok Sabha.

On 23.5.90

"On receipt of warning from the India Meteorological Department regarding the cyclone, the State Government of Andhra Pradesh took timely action in evacuating the people from the low lying areas. The evacuated people were kept in relief camps where feeding was also organised. Similarly, Government of Tamilnadu and Pondicherry had also taken the necessary preventive measures to meet the situation. Members may recall the huge loss of human lives numbering 10,000 during the 1977 cyclone in Andhra Pradesh. However, because of the timely preventive measures, the loss of human life could be minimised this time. The India Meteorological Department monitored the situation very closely and kept everybody informed about the development of this cyclone. Regular bulletins were issued to warn the people. Their efforts are praiseworthy".

Extract from letter dated 14.5.90 from Naval Headquarters, New Delhi.

"Naval Headquarters would like to place on record its deep appreciation for the regular reports rendered by the IMD with respect to the recent cyclonic storm in the Bay of Bengal, thereby providing an upto-date picture of the movement of the storm".

....

D.O.No MOS (S&T) 9[illegible] — 401 SNS

राज्य मंत्री
विज्ञान और प्रौद्योगिकी, परमाणु ऊर्जा,
अन्तरिक्ष, इलैक्ट्रॉनिकी एवं महासागर विकास
भारत सरकार, नई दिल्ली

PROF. M.G.K. MENON

MINISTER OF STATE
SCIENCE & TECHNOLOGY, ATOMIC ENERGY,
SPACE, ELECTRONICS & OCEAN DEVELOPMENT
GOVERNMENT OF INDIA

August 11 ,1990.

My dear Dr. Kulshrestha.

Thank you for your letter No. NA-B/01-90 dated 12th May, 1990, with which you have enclosed several items relating to the severe cyclonic storm during 4th to 9th May, 1990, on the Andhra Pradesh coast. I am very happy to have this material; and more particularly, to see the good work done by IMD in the area of cyclone detection, tracking and warning which has, undoubtedly, contributed significantly to saving lives, and precautionary measures to reduce losses.

With kind regards,

Yours sincerely,

M G K Menon

Dr. S.M. Kulshrestha,
Director General,
India Meteorological Department,
Lodi Colony,
New Delhi

CLONE

Killer Wind

oss of life contained

"T played a tantalising game of hide and seek—hovering just off the Madras coastline before abruptly veering off to unleash the devastating force of its fury on coastal Andhra Pradesh. Five districts—Krishna, Guntur, East Godavari, West Godavari and Visakhapatnam—bore the brunt of the cyclone.

The death toll is yet to come in but entire villages have been wiped out and the crop damage could run into crores. Gale winds with a speed of 220 to 250 km per hour did most of the damage. The major towns in Krishna and Guntur districts like Vijayawada, Machilipatnam, Pamarru, Guntur, Bapatla, Repalle and Tenali, which were not affected by the 1977 tidal wave, were also hit this time. Power supply broke down, road and rail communications were disrupted and over half the telephone exchanges damaged.

But if fewer people perished this time—particularly when compared to the toll of the 1977 killer cyclone—it was partially because of the advance monitoring of the cyclone as it built up in the Bay of Bengal.

Unlike 1977, people living in the likely path of the cyclone were continuously warned about the impending storm—thanks to over 100 disaster-warning systems and the dying INSAT-1B. (The disaster warning systems set up in the past five years permit direct audio-broadcasts from meteorological stations in Madras and Hyderabad.) The six newly-fitted cyclone detection radars all along the coastline also sent minute by minute progress of the cyclone's route.

But this route proved distinctly difficult to predict. Pre-monsoon cyclones are normal in the Bay of Bengal during this period. What upset the calculations was that when it was first classified as a cyclone on May 4, it was expected to hit the coast near Nagapattinam in Tamil Nadu. Within the next three days, however, it suddenly shifted course northwards and eventually struck the districts of Andhra Pradesh surrounding Machilipatnam town on May 9.

Because the Government had evacuated over one lakh residents of coastal villages, the loss of life was contained. The day before the cyclone struck, Dr S.M. Kulshreshtha, director general, Indian Meteorological Department, had warned in Delhi: "It will be a very severe cyclonic storm of hurricane winds that have touched extremely high wind speeds of 250 km per hour."

While Andhra Pradesh felt the full fury of the cyclone, residents of Tamil Nadu—which was initially expected to be hit—were not complaining. The rains that came as the cyclone moved northwards over the Bay of Bengal provided much needed water for the parched fields in the state—giving farmers good cause for rejoicing as the loss of life and damage to property in Tamil Nadu was quite minimal.

INSAT-1B picture of the cyclone (top); and the destruction that followed

For Madras city in particular, the rains proved a blessing. In the Tamil month of *Chitrai* when the mercury soars mercilessly, the uppermost thought on the minds of most citizens is how to survive in the heat and also whether the city's meagre water supply, which dwindles dangerously in the summer months, will last till the monsoon. In fact, for over 50 years now, it had never rained in Madras in the month of May and there was little hope of the water lasting out. So when over 23 cm of rains lashed the city sending the mercury plunging down and filling up the water reservoir in the Red Hills, residents heaved a sigh of relief.

They were obviously giving little thought to their neighbours in Andhra Pradesh. For even if many lives were saved by the timely warning and evacuation, by the time the waters recede and stock is taken of the damage, it could still be devastating.

ANAND VISWANATHAN with bureau reports

THE HINDUSTAN TIMES

NEW DELHI, FRIDAY MAY 11 1990

VP assurance to victims of cyclone in A-P

HT Correspondent

NEW DELHI, May 10

Prime Minister V. P. Singh, while expressing his deep grief over the loss of life and property caused by the cyclonic storm in Andhra Pradesh, assured the people that the Army was keeping a constant vigil on the situation and was taking necessary steps to render timely assistance.

In a message, the Prime Minister appealed to all the people who are affected by the cyclone in Andhra Pradesh to carefully heed the instructions issued by the meteorological department so that their hardship and suffering were lessened. He also sent his condolences to the bereaved families and his deep sympathies to those who have lost their valuable property.

Meanwhile, the Crisis Management Group (CMG) in the Department of Agriculture and Cooperation has been meeting regularly to monitor the situation caused by the cyclonic storm that hit the coastal districts of Andhra Pradesh. Assistance required by the State Government was being extended for carrying out relief operations in the affected areas. Various Ministries of the Central Government had been keeping in continuous touch with the State Government authorities and all necessary steps had been taken to ensure the availability of essential commodities in the affected areas.

THE HINDU, Friday, May 11, 1990.

Invader from the Bay

HOPES THAT THE cyclonic storm which took birth as a low pressure trough on May 4 would weaken during its 700 km. journey from the south west Bay of Bengal crashed when it crossed the Andhra coast at Hamsaladivi in Krishna District on the evening of May 9. Reports of the number of people who have been killed and of towns and villages reeling under the fury of the cyclone are still coming in and do not yet give a full picture of the devastation wrought by the storm. The advance early cyclone warning system available to the present generation meteorologists and the high resolution photographs of cloud formation beamed by the satellites leave governments in a far better state of readiness to take measures for mitigating the hardship caused to the vulnerable population than could have been dreamt of two decades ago. The weather satellites which took the meteorologist on the trail of the recent cyclone gave the alerts broadcast by the electronic media a chilling tone more appropriate to the grim announcements of an advancing army than a weather forecast. When it was stated that the velocity of the cyclone on hitting the coast could accelerate from 120 to 250 kilometres per hour the imagery of an invasion backed by high speed bombers about to rain down destruction and death became complete. Densely populated Madras breathed in relief when the cyclone veered away and it did give rise to hopes that its stretched out journey would rob the cyclone of its fury and that it might fade out or turn back to the sea. Instead it headed doggedly towards the coast and the hopes began to ebb. The determined invader from the Bay could not be kept out and the news readers of the electronic media came out with grim portrayals of the cyclone devastation.

The great strides achieved in weather; and specially cyclone, forecasting in recent years thanks to the unerring detection of atmospheric turbulences by the orbiting satellites have vastly improved preparedness. It is now possible for the disaster managers to organise the evacuation of sizable sections of the population running into several thousands to safe locations away from the coast. Two decades ago, the cost paid in terms of human lives because of the non-existence of the early warning facilities was heavy. The recurrence of cyclones now seems to be fitting into a pattern and has made the construction of cyclone shelters where people could be housed before they could return to their dwellings a necessity. The proposed expansion of the existing 100 stations of the Disaster Warning Systems by installing another 100 in the country's coastal regions will enhance preparedness further. But there is no getting away from the fact that large numbers of people — mostly fishermen and their families — still remain vulnerable and it is dismaying to know that a good number of them still venture into the sea in the face of repeated warnings. The fisherman's abiding faith in the sea as a great provider, it appears, makes him ignore or discount the dangers held out by weather forecasters. Among the herculean tasks facing the governments of the coastal States is that of providing for the fishermen permanent and safe dwellings which could replace their existing huts and hovels on the seashore which are exposed to the fury of the elements. This task merits some priority because of the large population which depends wholly on fishing. While it is not possible to achieve anything very dramatic to mitigate the misery being caused by cyclones, apart from ensuring that lives are not lost, the long-term tasks involved in making the world less cyclone prone will have to be faced with some determination. Attention has been repeatedly drawn to how global warming brought about by the choking of the atmosphere with chlorofluorocarbons and the ripping of the ozone layer could lead to an increased frequency of cyclones. Governments and private industry will have to heed the ecologist whose voice has become hoarse from the endless repetition of warning against environmental vandalism. The world will have to become greener and will have to be saved from the suicidal vested interest headed towards making it a less hospitable planet.

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Cyclone and after

THANKS to the effective operation of the disaster warning system and the extensive precautionary measures taken by the state administration, the cyclone that hit Andhra Pradesh on Wednesday evening did not take a massive toll of life. The number of people killed is estimated at 97. Information about the devastation it wrought is still incomplete because of the break-down of communications. But there can be no doubt that the damage has been on a very large scale. Six hundred villages in the districts of Krishna, Guntur and East and West Godavari, which by all accounts bore the brunt of the cyclone, have been severely hit. Over a million people have been rendered homeless. Several localities in towns like Kakinada, Machilipatnam, Vijayawada, Pamarru, Gudivada, Guntur, Tenali, Rapalle and Bapata, have been inundated by the heavy rains which followed the cyclone. Winds, blowing at speeds between 220 and 250 kilometres per hour have uprooted power transmission lines and disrupted telecommunications. Most of the towns and villages in the four affected districts have been plunged into darkness. Roads have been badly breached or blocked by uprooted trees; railway tracks are under sheets of water. Several trains and bus services on a number of routes have been cancelled. While no crop loss has been reported as harvesting was completed recently, the cyclone has ravaged garden crops like banana and coconut apart from extensively damaging the booming poultry industry.

Officials at the State Secretariat and in the four affected districts, who acted with remarkable alacrity in shifting over 1.5 lakh people to safer areas, were no doubt helped by INSAT tracking of the cyclone despite the latter's erratic movement in a serpentine path. Nevertheless, they deserve to be congratulated for their work. Meanwhile, the task of reaching relief supplies to the victims should begin immediately. Army and Navy personnel who are trying to render all possible help to the affected villagers, should continue to be deployed as long as necessary. Simultaneously, rehabilitation of the victims will also have to be planned. The Chief Minister, Dr M. Chenna Reddy, who postponed his tour of the United States to personally supervise relief activity, will have his hands full for quite some time.