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A study of the monsoon depression intensifying into cyclonic storm over land

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ABSTRACT. The monsoon depression which formed over the head of the Bay of Bengal and neighbourhood on 8 September 1970 and crossed West Bengal coast near Contai on the evening of 9th, showed some unusual features. It progressively intensified into a cyclonic storm over the land, although its development was rather slow. Further, it executed a loop around Kanpur. This system caused very heavy rainfall along its track, particularly over the southern parts of Uttar Pradesh. A study of this depression with the help of weather satellite cloud pictures has been presented in this paper.

1, Introduction

This paper presents a study of an unusual monsoon depression with the help of cloud imagery taken at the local afternoon time by the television camera (AVCS) on board the weather satellite ITOS-1. It formed over the head of the Bay of Bengal on 8 September 1970, intensified into a cyclonic storm 3 days after its landfall while centred more than 400 km inland, and subsequently executed a loop over Uttar Pradesh before moving away eastwards. This monsoon depression has earlier been studied on the basis of conventional data by Srinivasan *et al.* (1972).

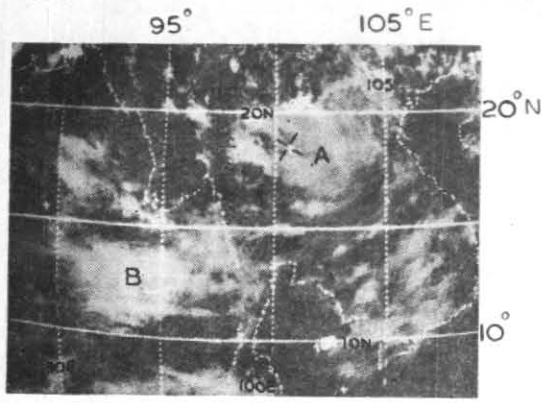
2, Satellite study of the depression

A low pressure area, which had earlier moved inland from South China Sea, existed over north Thailand and neighbourhood on 6 September 1970. The low had an associated cyclonic circulation up to 500 mb. It was seen in the satellite picture (Fig. 1a) as an area of intense convection around 'A', with curved banding towards its southeast. Another overcast cloud mass, indicating an area of active convection, was situated at 'B' over the north Andaman Sea and adjoining east Bay of Bengal corresponding to a low level trough over that area.

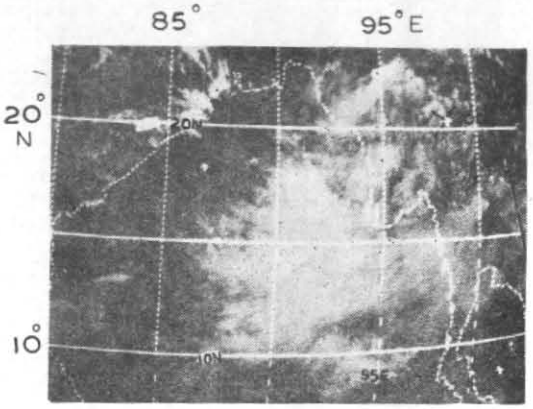
On 7th, the low moved westwards and the two systems merged into a single low pressure area lying over the central and north Burma and neighbourhood. The corresponding satellite imagery (Fig. 1 b) shows convective cloud elements loosely arranged into bands covering central and north Burma, whole of the Arakan coast and adjoining northeast and east central Bay of Bengal. These convective bands indicated the low level circulation but no circulation centre was defined. South of these bands there existed an extensive overcast cloud mass covering most of the Bay, north of Lat. 10° N and east of Long. 88° E.

On 8th, the low moved northwestwards and intensified into a depression over the north Bay of Bengal. The satellite picture shows small curved cumulus cloud lines organised in the form of a spiral at the northern edge of a dense convective overcast area 'A' (Fig. 1c). These curved cumulus lines defined the centre of low level circulation outside the overcast but close to its edge, and gave the first indication of the initiation of development. From these features the intensity of the disturbance was T1·5 in the classification of Dvorak (1975). The cloud mass associated with the disturbance appeared at the edge of the picture frame, causing some distortion and loss of details. Allowing for this positioning error, the satellite and the synoptic data, fixed the depression centre near 21°N, 90°E.

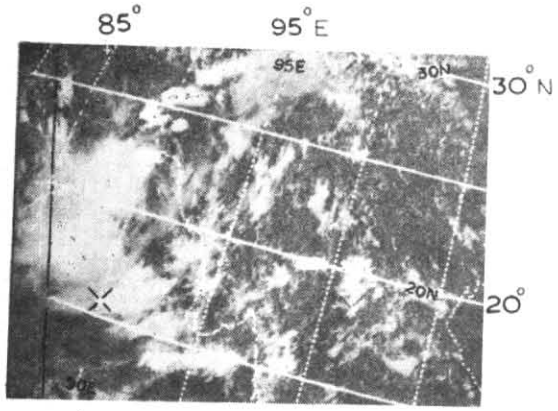
Subsequently, the depression crossed West Bengal coast near Contai and was located near 22·7°N, 87·1° E in the satellite picture of 9th afternoon (Fig. 1d). Although the dense overcast area to the south of the centre was reduced, individual convective cloud elements got organised into two loosely curved bands which appeared to curve around the



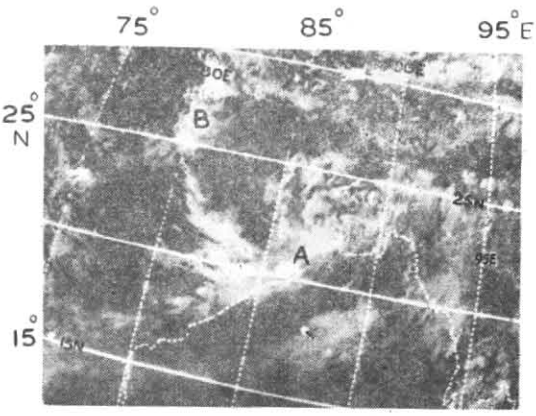
1(a). 6.9.1970 08.20.42 GMT



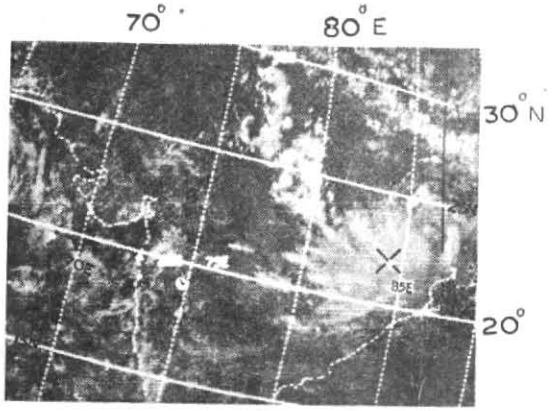
1(b). 7.9.1970 09.17.00 GMT



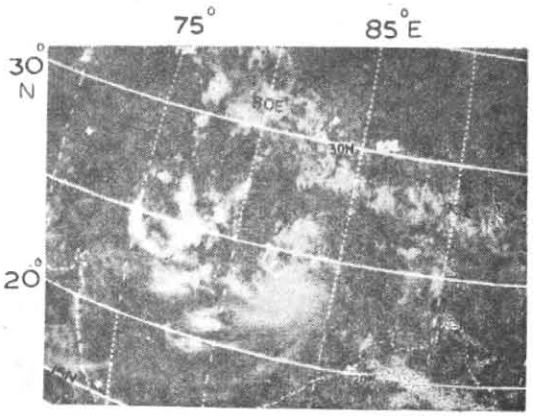
1(c). 8.9.1970 08.18.22 GMT
T 1.5 21.0°N, 90.0°E



1(d). 9.9.1970 09.14.37 GMT
T 2 22.7°N, 87.1°E



1(e). 10.9.1970 10.11.34 GMT
T 2.5 23.0°N, 85.5°E



1(f). 11.9.1970 09.16.34 GMT
T 3 23.7°N, 84.0°E

Figs. 1 (a-f). ITOS-1—AFCS satellite pictures of monsoon depression, 6-11 September 1970
Figures below each picture indicate date, time GMT, system intensity in Dvorak's classification and position of its centre (where applicable)

system centre. The appearance of convective bands to the north and west of the centre towards the direction of motion, and absence of any significant cirrus blow off indicating weak cirrus level winds, clearly showed conditions favourable for development. The rate of development was, however, slow. The system intensity was now T2.

On 10th, the depression moved westwards to 23·0°N, 85·5°E (Fig. 1e). In the satellite picture the depression was at the edge of the frame and lacked clarity. However, the convective cloud elements, aligned into curved narrow bands within the overcast, and the beginning of anticyclonic cirrus outflow indicated its development to T2·5. The cloud system centre was now within the dense overcast area.

The depression moved westnorthwest, intensified into deep depression and was centred at 23·7°N, 84·0°E on 11th afternoon. It has now developed an oval Central Dense Overcast (CDO) area, about 1¼ degrees in size, and surrounded by several small narrow bands (Fig. 1f). In Dvorak's classification the central feature (CF) was 3, banding feature (BF) was 0, and T-number, T3. The curved bands to the north of CDO consisted of the charateristic cumuliform clouds including *Cb*, while those towards south mainly consisted of cirrus outflow. The deep depression further intensified and moved northwestwards by 12th afternoon when it was centred near 26·0° N, 81·5° E, about 100 km southeast of Lucknow (Fig. 1g). By then the CDO developed a ragged eye with an imbedded distance of about ¾ degree (CF4) and a prominent convective band started organising towards its south and southwest (BF 0). The system thus attained intensity T4 corresponding to a cyclonic storm (Mishra and Hem Raj 1975). The behaviour of lower tropospheric winds of Lucknow on 12th supports this conclusion. By 0600 GMT the winds had strengthened to NE/40-50kt upto 1·0 km a.s.l., the highest level upto which data was available; at 1200 GMT they were NE-ENE/30-45 kt at all levels between 0·6 and 4·5 km a.s.l.

On 13th afternoon, the storm moved to 26·7°N, 80·3°E (Fig. 1h). The central feature showed little change (CF4) but the convective band intensified towards the south and west (BF 0·5), reaching the peak of its development and spiralling into the CDO, so that the system intensity was T4·5. Subsequently the storm executed a loop and started moving eastwards. It was centred near 26·0°N, 81·5° E on the 14th (Fig. 1 i). By this time the storm started showing indications of ongoing weakening. The convective feeder band earlier seen on 12th and 13th had weakened. Still the ragged eye with imbedded distance of ¾ degree (CF4), and a ½ degree wide curved band to the south of CDO (BF ½) were seen. The system intensity remained T4·5.

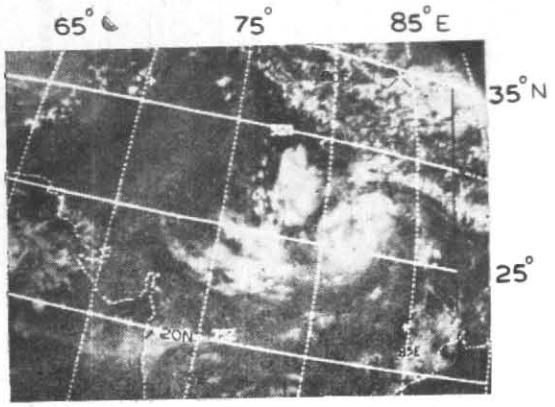
On 15th afternoon the storm moved on to 25·3°N, 82·5° E (Fig. 1j). It had an angular CDO of about 2° size without an eye (CF 4) surrounded by several small curved bands (BF ½) so that the system T-number was still T 4·5. Although eye was not seen, the system had distinct convective bands towards its north and cirrus outflow to its south. The filling up of eye indicated ongoing weakening.

On 16th the system weakened into a depression, centred near 26·0°N, 83·2°E (Fig. 1k). It had an irregular CDO of about 1° size (CF2) and a 1° wide band surrounding half the central feature (BF1), so that the system T-number was T3. The depression continued to weaken and moved eastwards. It was centred near 26.3°N, 84·2°E on the 17th afternoon when it had considerably reduced in size and was dissipating. The disturbance broke up over Nepal Himalayas during the next 24 hours.

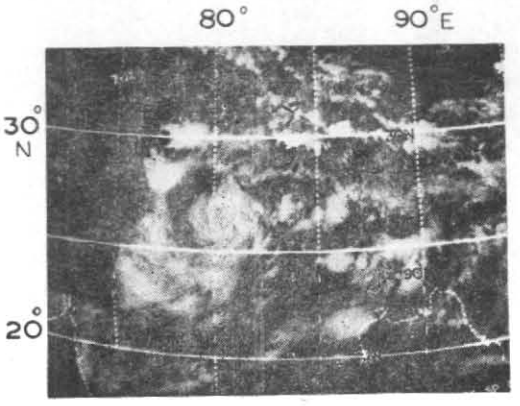
Fig. 2 shows the track of the monsoon depression derived from satellite cloud imagery as well as synoptic data. Differences in the satellite and the synoptic positions were partly due to the different times of observation and partly due to various sources of error inherent in the two systems of observation and analysis. For satellite derived positions alone, Sheets and Grieman (1975) have found that mean potential errors of tropical storm centres, as estimated from ESSA pictures, were 43 to 66 n.m. and larger values were associated with weaker systems. Fig. 2 also shows the system intensity in Dvorak's classification.

3, Intensification and movement

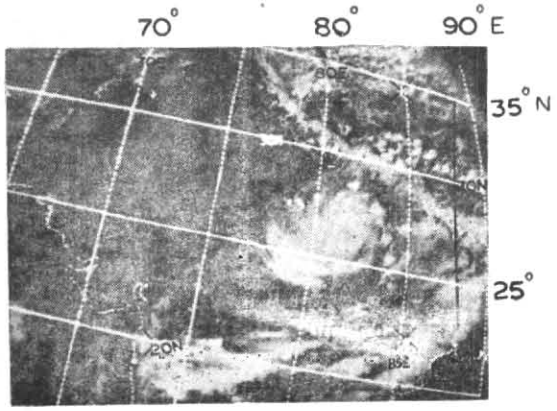
Cases of monsoon depressions intensifying into cyclonic storms, while over land, are very infrequent. The authors have, therefore, made an attempt to find reasons of intensification in this case. The depression under study moved along relatively northern latitudes than is usual with monsoon depressions in September. The synoptic evidence strongly suggests that over the land this depression progressively intensified under the influence of three successive westerly troughs in the middle and upper troposphere moving across northern parts of the country. Soon after crossing the coast, it came under the influence of a large amplitude westerly trough extending upto 200 mb, which in its rear caused incursion of cold northerly air into the depression at levels above 850 mb. As a result temperatures fell in the depression field by 6°C at 500 mb level and by 4°C at higher levels upto 200 mb, on 11th.



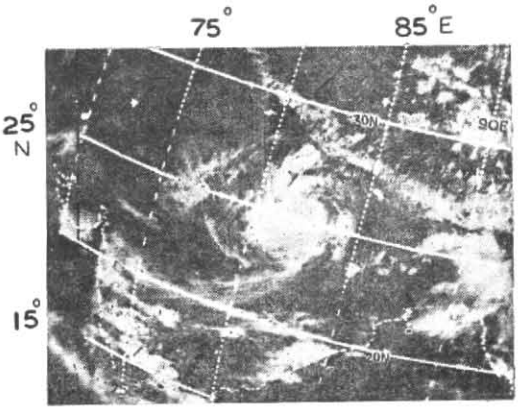
I(g). 12.9.1970 10.09.18 GMT
T 4 26.0°N, 81.5°E



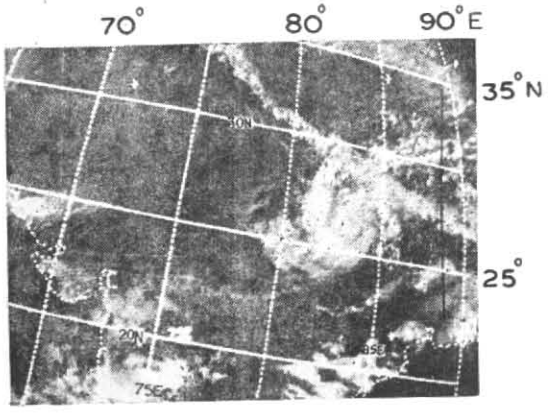
I(h). 13.9.1970 09.14.14GMT
T 4.5 26.7°N, 80.3°E



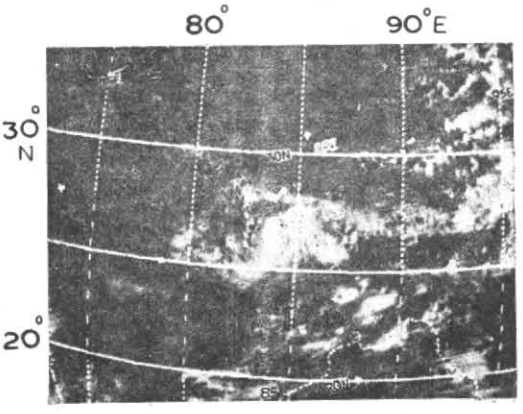
I(i). 14.9.1970 10.06.58 GMT
T 4.5 26.2°N, 81.5°E



I(j). 15.9.1970 09.11.52 GMT
T 4.5 25.3°N, 82.5°E



I(k). 16.9.1970 10.04.35 GMT
T 3 26.0°N, 83.2°E



I(l). 17.9.1970 09.09.32 GMT
26.3°N, 84.2°E

Figs. 1 (g—l). ITOSI—AVCS satellite pictures of monsoon depression 12-17 September 1970
Figures below each picture indicate date, time (GMT), intensity (Dvorak's classification) and position where applicable

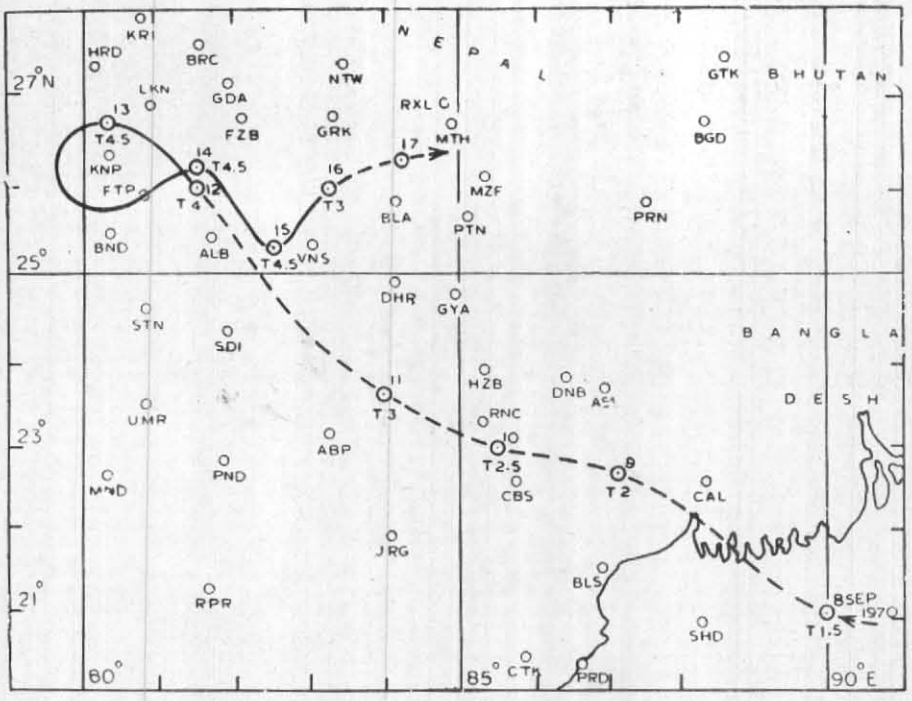


Fig. 2. Track of monsoon depression, 8-17 September 1970

Under the influence of the second trough the temperatures fell by 4°C at 700 and 500 mb and by smaller amounts at higher levels, on 13th. Thus, with little change in temperatures at lower levels and steep fall at middle and higher levels with each spell of cold air incursion, intense instability was created within the depression field, resulting in its progressive intensification into a cyclonic storm. Simultaneously the storm began to recurve by 13th. The system continued to move in easterly direction under the influence of the third trough, while it remained northward of the upper tropospheric ridge line. It moved southeastward between 14th and 15th when it lay on eastern periphery of the 200 mb anticyclonic cell. The satellite pictures (Fig. 1) show progressive intensification from T2 (initiation of development) on 9th to T4·5 (equivalent to cyclonic storm) on 13th. The intensification of the system, seen in the satellite pictures, was also borne out by surface pressure changes at the storm centre. By 13th morning the 24-hour pressure fall had reached 9 mb and the negative pressure departure was 11 mb. These were the highest values obtained during the life period of this storm.

During the development stage of the storm, its intensity exhibited a slow rate of growth. It changed at one-half T-number per day except between 11th and 12th when intensity change was one T-number. This broadly agrees with the model intensity change curve for slow development (Dvorak 1975).

4, Banding characteristics

The convective band associated with the depression showed an interesting behaviour. When the depression showed initiation of develoment (T2) on 9th, it also developed a conspicuous convective cloud band to the south and west of the system centre (from A to B in Fig. 1d), indicating lower level inflow. From 9th to 13th, when it was moving westwards, cloud imagery showed prominent convective bands ahead of the system. The storm stopped moving westwards on 13th and the convective band on the west disappeared soon after. Again, on 15th when it changed its course and started moving northeastwards, two convective bands appeared in the northern sector of the cloud system. These bands persisted on 16th when it was moving eastnortheast. The satellite pictures thus confirm the fact that in a recurving monsoon depression the rainbelt which is in its southwest quadrant initially, shifts to north and northeast with the change in the direction of movement (Rao and Desai 1973). This relationship between movement of the depression and position of the prominent convective band relative to its centre appears significant, and may give a prior indication of change in the movement when more frequent satellite pictures will be available in future.

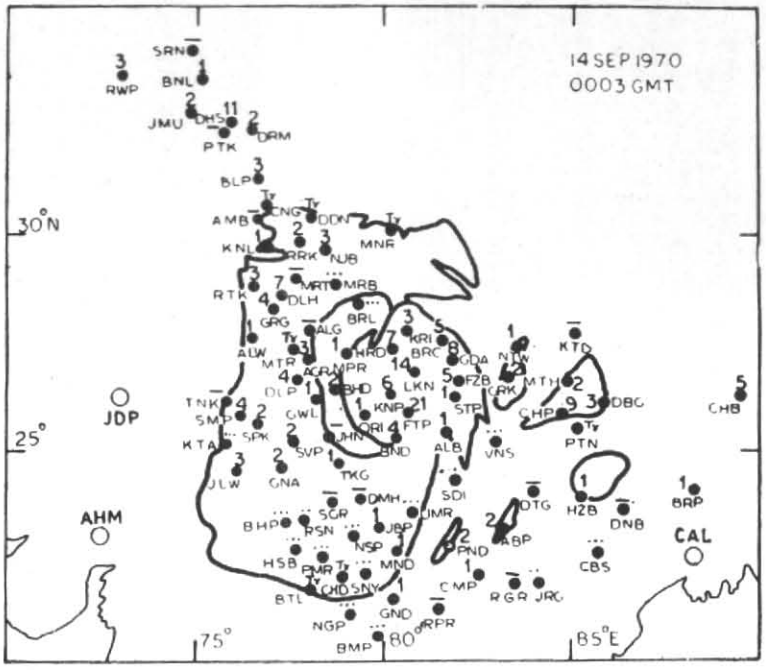


Fig. 3. 24-hr rainfall ending at 0300 GMT of 14 September 1970

An approximate outline of the storm cloud imagery of the previous afternoon has been superimposed on the rainfall chart

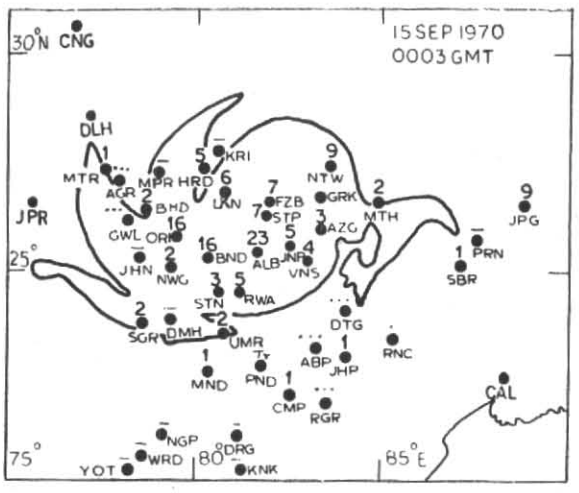


Fig. 4. 24-hr rainfall ending at 0300 GMT of 15 September 1970

An approximate outline of the storm cloud imagery of the previous afternoon has been superimposed on the rainfall chart

5. Rainfall distribution

This storm caused extensive heavy to very heavy rainfall over Bihar, north Madhya Pradesh and Uttar Pradesh, some notable amounts being 20 cm at Sidhi on 12th, 21 cm at Fatehpur on 14th, 23 cm at Allahabad on 15th and 30 cm at Kanpur (Chakeri) on 16th. In order to see the relationship between rainfall distribution and the satellite cloud organisation, the afternoon cloud imagery was superimposed on the next day's 24-hour rainfall recorded at 0830 IST. It was found that heavy and very heavy rainfall occurred only in the region of CDO and the intense convective band ahead of the centre. This is illustrated by the 03 GMT rainfall distribution of 14th (Fig. 3) and 15th (Fig. 4). The agreement between the rainfall and the satellite picture points towards the possibility of deriving reasonable estimates of the area and broad measures of quantity of rainfall for a 24-hour period — centred at the time of the satellite picture — from the expected movement of a depression/storm and the characteristics of CDO and banding features. However,

more detailed investigations will be required to be carried out in this regard.

6. Conclusions

The monsoon depression under study progressively intensified over land from a depression to a cyclonic storm, and finally recurved northeastwards after executing a loop, apparently under the influence of upper and middle tropospheric westerly troughs which caused the cold air advection in the depression field. The system broadly followed the model intensity change curve relating to slow development as given by Dvorak (1975).

The central dense overcast (CDO) and the prominent convective band were associated with heavy rains.

The locations of convective bands with respect to the centre of the depression changed with the change in its direction of movement, so that the bands always lay ahead of the depression.

Acknowledgement

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