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Satellite Study of an Inland Monsoon Depression

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ABSTRACT. This study describes and discusses an inland deep depression of the Indian southwest monsoon season with special reference to the associated cloud structure and rainfall pattern on 20 September 1962 and the considerations which governed the recurvature which was most pronounced on that date. In addition to the conventional synoptic data, use has been made of the observations obtained from TIROS VI satellite cameras. This is the first satellite study of an inland depression over India.

1. Introduction

The Indian Southwest Monsoon (June to September) is characterised by the passage of a number of depressions which form in the north and central Bay of Bengal and move inland in an approximately westnorthwesterly direction. The monsoon depressions are of special interest because a very large part of the rainfall over central and north India occurs in association with these depressions during their travel over land. Numerous studies have been made of the characteristics and behaviour of monsoon depressions (Pisharoty and Asnani 1957, Ananthakrishnan and Bhatia 1958, Koteswaram and George 1958, Parthasarathy 1958, Mulky and Banerji 1960, Koteswaram and Bhaskara Rao 1961). These studies suffered from the limitations imposed by the sparseness of the available observational network. The meteorological satellite provides an excellent means of spatial photography of the entire depression area. The use of satellite photographs in the study of a monsoon depression is discussed in this paper.

2. The monsoon depression of 16—21 September 1962 : Its life history and track

A depression formed in the west central Bay of Bengal on 16 September 1962 with its centre about 300 km southeast of Kalingapatnam. It intensified into a deep depression and, crossing the coast near Gopalpur on the night of 17-18 September 1962, moved inland and lay over west Madhya Pradesh and south Rajasthan on the morning of 20 September 1962. It later recurved northnortheast and was centred on the morning of 21 September 1962 about 185 km due south of Delhi. Thereafter it rapidly weakened into a low pressure area which finally filled up in the western Himalayas on 23 September 1962. The track of the deep depression is shown in Fig. 1.

3. Synoptic features of the deep depression on 20 September 1962

Widespread heavy rain occurred in association with the deep depression. The 24-hour rainfall amounts ending at 0830 IST of 21 September 1962 are shown in Fig. 1.

The upper air charts for 500 and 200-mb levels at 00 GMT on 20 September 1962 are shown in Fig. 2. It is seen therefrom that the cyclonic circulation, associated with this depression, extended up to at least 6 km a.s.l. (500 mb). This pattern got reversed, in higher levels, into a marked anticyclonic circulation at 12 km a.s.l. (200 mb). The 500-mb chart also shows a well marked trough in the westerlies over north Afghanistan and adjoining Pakistan.

4. Satellite study of the cloud structure associated with the deep depression on 20 September 1962

With the advent of meteorological satellites, meteorologists have obtained for the

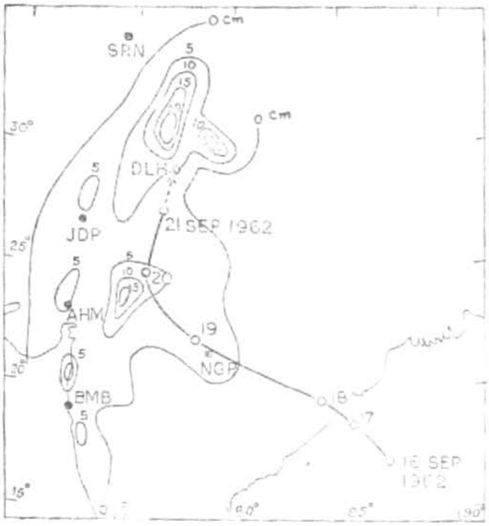

Fig. 1. Rainfall recorded during the 24-hour period ending at 0830 IST of 21 September 1962

(Unfilled circle denotes the position of the depression centre at 0830 IST on the date marked)

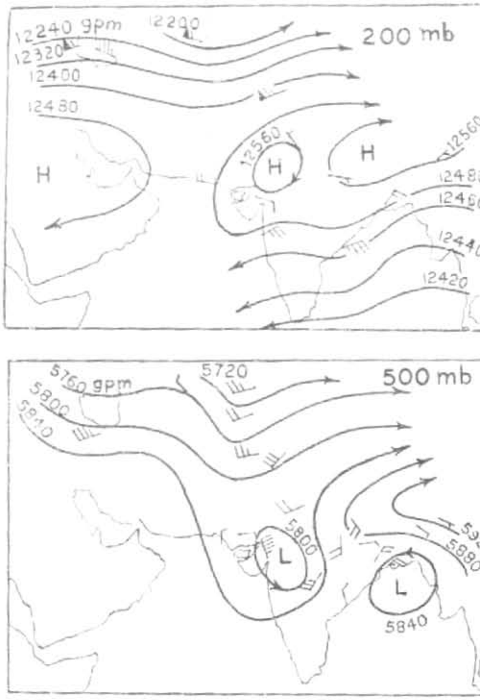

Fig. 2. Streamline analysis, 00 GMT of 20 Sep 1962

first time an observing device which is capable of viewing a wide area of the globe at a given instant. The earth-orbiting satellite gives photographs of the cloud cover over large areas, displays orderly cloud patterns (both large and small) which are of great value in interpreting synoptic systems like storms, fronts and depressions.

Numerous attempts have been made in the past to interpret the satellite photographs. Notable amongst these are those by Erickson (1961) who has presented a comprehensive study of the general factors underlying the process of interpretation of TIROS cloud pictures, and Koteswaram (1961) who has discussed the TIROS cloud patterns with special reference to those obtained in the Indian area.

Care has, however, to be taken in interpreting the satellite pictures in terms of specific types of clouds because of loss of detail in the reproduction processes, distortion caused by sphericity and other optical factors, which are inherent in a system like the TIROS vidicon equipment. The overall resolution of wide angle TIROS pictures is perhaps of the order of 3 miles.

It has been found that the brightness of clouds (in a TIROS picture) is an aid to interpretation only in a very general sense because of the many factors that control brightness in the TIROS pictures. Some very general rules have, however, been formulated. Extensive bright cloud masses, those of the order of hundreds of miles, are usually composed of dense stratiform clouds. Small bright cloud masses in the form of irregular patches often contain cumulonimbus or thunderstorms. Cloud masses of low brightness are usually composed of thick cirrus, or altocumulus, or perhaps small cumulus clouds. Thin cirrus apparently cannot be photographed.

In the present case, six photographs taken by TIROS VI on orbital pass W29/28R on 20 Sep 1962 at 0730 GMT (1300 IST) were made available by the U.S. Weather Bureau to the Director General of Observatories. Two of these were degraded by electronic noise but the remaining four were of excellent quality. These are reproduced in Fig. 3. A composite photograph of the depression area covered by the TIROS photographs is shown in Fig. 4. The NEPAN (short for Neph-analysis) obtained from the TIROS photos was plotted on a map and is shown in Fig. 5.

A close study of the TIROS photographs, the composite photograph and the Neph-analysis reveals the following noteworthy features of the cloud structure associated with the deep depression on 20 September 1962—

(1) The cloud system associated with the deep depression extended over a large area about 700 miles in diameter.

(2) The cloud system contained clouds of both the cumuliform and stratiform types.

(3) The centre of the vortex at 1300 IST on 20 September 1962, as determined by the NEPAN, was 25·5° N and 76·3°E. The position of the depression centre at about the same time, as obtained from the synoptic maps after interpolation, was 25·2°N and 76·0°E. It will be seen that the two positions of the depression centre, as determined by TIROS and synoptic maps, agree quite well.

(4) The cloud system consisted of spiralling bands around the vortex centre with large overcast areas to the northwest, the southwest and the far north of the vortex. These overcast areas are seen to be composed of both cumuliform and stratiform types of clouds.

There is an area of broken cumuliform clouds all round in the immediate vicinity of the vortex except to the southwest. The area of broken clouds extends to large ranges on the eastern side of the vortex; but on the west and north it is soon replaced by overcast areas containing both stratiform and cumuliform clouds. Towards the extreme west to northwest of the vortex, there is an area of scattered cumuliform clouds.

5. Discussion of the satellite and radar data

The spiral bands in the present case have been analysed and found to be very nearly in the form of an equi-angular spiral. The arms of the spirals follow a logarithmic equation of the form $\log_e r = A + B\theta$, where A and B are constants. The spiral bands occurring in a well developed cyclonic storm are known to follow such an equation. In inland depression, where the intensity of cyclonic circulation is much less, one does not always expect well defined spiral bands although evidence of cyclonic spiral motion is almost always present. It is, therefore, quite interesting to note that even in the case of this inland depression, well defined spiral bands occur.

It has been known that the resolution capability of the TIROS satellites is high enough to identify convection cells embedded inside the nephsystems which are free from large decks of overlying clouds. However when such overlying clouds are present in abundance or when the associated anvil clouds spread out considerably, the whole nephsystem observed by TIROS presents a white mass which may include a number of convective cells. Even a small plume on a satellite photograph is found to include several such cells. In view of this, it is hardly possible to delineate, with the help of satellite data, the areas of convective cells hidden beneath the deck of giant nephsystems. The radar helps in isolating the hard cores of such nephsystems. Some of the stronger convective cells, embedded in those nephsystems of the deep depression, which fell within the range of the CPS-9 radar at New Delhi, are indicated by the radar echoes denoted by black solid patches in Fig. 5. The alignment of these echoes, in a banded structure, is in conformity with the spiral band structure of the depression as revealed by the satellite photographs.

Attempts to investigate TIROS cloud patterns in combination with assosiated radar echoes were made by Blackmer Jr. (1961) and by Fujita and Ushijima (1961) who found

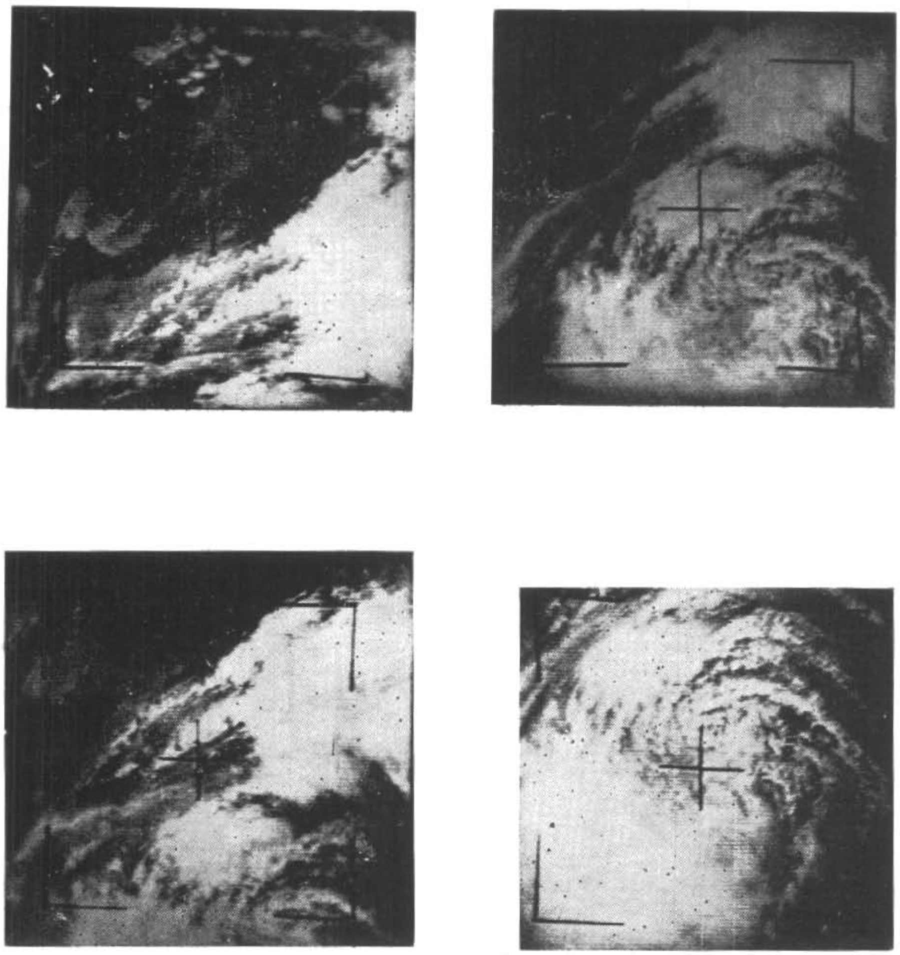

Fig. 3. Satellite photographs of the depression area

Fig. 4. Composite picture at 1300 IST of 20 September 1962

(prepared from photographs taken by TIROS VI)

Fig. 5. Radar Echoes

1. Circle round Delhi denotes area of radar coverage with 200 miles range
2. Radar echoes are depicted by black solid patches and dots

that the areas of radar echoes are much smaller than those of the clouds. This result is as it should be and is borne out in the present case also as mentioned in the preceding paragraph. Fujita and Ushijima also computed the ratio of the area of clouds to that of the radar echoes, and found that the area A_c of clouds appearing in TIROS pictures is one order of magnitude larger than the area A_e of the radar echoes embedded inside these clouds. This is confirmed in the present case also where the ratio A_c/A_e has been found to be of the order of 15.

6. Other interesting features of the depression

Under the influence of the deep depression, very heavy rainfall occurred in the northern parts of the Peninsula, central parts of the country and in the Punjab (India). Ratlam recorded 27 cm of rain and Ambala 20 cm during the 24-hour period ending at 0830 IST of 21 September 1962. The 24-hour rainfall amounts recorded at 0830 IST of 21 September 1962 are shown in Fig. 1.

The horizontal divergence at 5000 ft and 10,000 ft a.s.l. for 00 GMT of 20 September 1962 was computed by planimetric evaluation method (Saucier 1959) and the resultant convergence divergence patterns are shown in Fig. 6. A comparative study of Figs. 1 and 6 brings out the following significant features—

The maximum rainfall occurred in the southwest sector of the depression; the maximum amount of rainfall in this area being of the order of 15 cm although there was also the report of an extra heavy fall of 27 cm from Ratlam. In this sector is seen at 00 GMT on 20 September 1962, a strong convergence field at 5000 ft a.s.l. with a marked divergence field at 10,000 ft a.s.l. There was another pronounced rainfall area over and near Himachal Pradesh and the Punjab-Kumaon hills where the maximum rainfall was of the order of 20 cm. This area was located about 700 km to the north of the depression centre, and was characterised by a marked zone of convergence at 00 GMT in the lower levels. This well marked convergence is responsible for the very heavy rainfall in the hilly terrain in and near Himachal Pradesh and the Punjab-Kumaon hills. The absence of any rainfall to the west of the depression area and the existence of clear skies (as seen in the TIROS photographs) in this region are attributable to the divergence seen in this area in Fig. 6.

It is finally of interest to note that the depression was located at the periphery of a well marked upper air anticyclone at 200 mb. Such a situation is very favourable for the recurvature (Koteswaram and George 1958). There was also present a trough in the westerlies over Afghanistan and adjoining Pakistan (Fig. 2). This trough was fairly deep at the 500-mb level and extended upto 200 mb. The recurvature and the subsequent northnortheastward movement of the deep depression after 20 September 1962 was associated with the presence of the depression at the periphery of well-marked upper air anticyclone at 200-mb level. The recurvature was further augmented by the eastward movement of a trough in the westerlies to the north of the anticyclone.

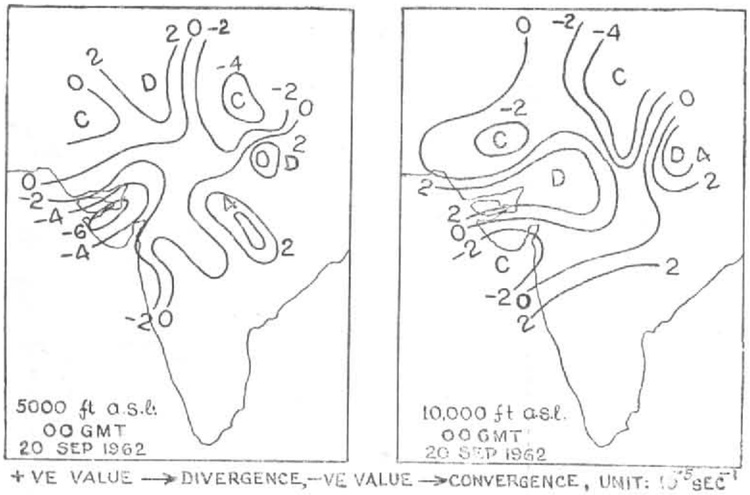

Fig. 6. Convergence/Divergence patterns on 20 Sep 1962

7. Conclusions

The main conclusions arrived at as a result of this study may briefly be summarised as follows —

(1) The structure of the deep depression was a cyclonic circulation in the lower levels upto 500 mb overlain by an anticyclonic circulation aloft.

(2) The cloud systems associated with the deep depression were very extensive, contained clouds of both cumuliform and stratiform types, and were arranged in characteristic spiral bands.

(3) It was confirmed that the area A_c of the clouds appearing in TIROS pictures is one order of magnitude larger than the area A_e of the radar echoes embedded in these clouds. The ratio A_c / A_e was found to be of the order of 15 in the present case.

(4) The southwest sector of the deep depression had the maximum amount of rainfall which was generally of the order of 15 cm. There was another area of pronounced rainfall, about 700 km north of the depression centre, over and near Himachal Pradesh and the Punjab-Kumaon hills.

(5) The convergence/divergence patterns in the lower levels were found to explain the general distribution pattern of rainfall associated with the deep depression on 20 September 1962.

(6) It was found that the recurvature and the subsequent northnortheastward movement of the deep depression after the 20th were associated with the presence of the depression at the periphery of a well marked upper air anticyclone at 200-mb level. This recurvature tendency was further augmented by the eastward movement of a trough in the westerlies to the north of the anticyclone.

8. Acknowledgements

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