*Mausam*, (1990), **41**, 3, 365-370

551.515.1 : 551.553.21 : 551.576

# Wind and cloud structure of monsoon depressions

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(*Received 3 June 1988*)

सार – संयोजन की विधि का प्रयोग करते हुए मानसून अवदाबों के आस-पास पवन वितरण के विस्तृत अध्ययन को प्रस्तुत किया गया है। एक-संवृत-समदाब रेखा स्तर से चार-संवृत-समदाब रेखा स्तर तक अवदाबों के तीव्रीकरण सहित पवन क्षेत्र के विकास पर विचार विमर्श किया गया है। उनके विकास की विभिन्न अवस्थाओं पर उर्ध्वाधर में अवदाबों के ढलान में विभिन्नता का परीक्षण किया गया है। निदर्श वितरण के रूप में प्रेक्षित संयुक्त पवन वितरण का विचार करते हुए इससे व्युत्पन्न पवन आंकड़ों का प्रयोग वास्तविक समय स्थितियों में वस्तुनिष्ठ विश्लेषण के लिए प्रेक्षणात्मक आंकड़ों की संपूर्ति के उद्देश्य के लिए किया जा सकता है।

कुछ विशेष मामलों में मानसून अवदाबों के विकास की विभिन्न अवस्थाओं में इनसैट (भारतीय भू-उपग्रह) मेघ बिम्बों में देखे गये मेघों की संरचना के विकास का भी परीक्षण किया गया है।

ABSTRACT. A detailed study of the wind distribution around monsoon depressions using the method of compositing is presented. Evolution of the wind field with intensification of the depressions from one-closed-isobar stage to four-closed-isobar stage is discussed. The variation in the slope of the depressions in vertical at different stages of their development is examined. Considering the observed composite wind distribution as a model distribution the wind data so derived may be used for the purpose of supplementing the observational data for objective analysis in real time situations.

Evolution of the cloud structure as seen in INSAT cloud imageries at different stages of development of monsoon depressions in a few typical cases is also examined.

## 1. Introduction

Data sparseness in the tropical oceanic regions is one of the most serious handicaps in the numerical analysis and prediction systems. The problem of correct representation of tropical disturbances in the objectively analysed initial fields is particularly serious when they are located in the data sparse areas out at sea. The only way to get over this problem is to artificially generate the vortex by feeding some observations in the area of interest through manual intervention. However, subjectively generated data would have their obvious limitations besides being time consuming. It would also not be possible by a human analyst to bring out the detailed structure of the systems for the fine resolution numerical analyses. The aim could best be achieved by introducing a predefined detailed structure of the disturbance in question and moduling it with the analysis program.

One of the important disturbances, which interests the Indian meteorologists, is the monsoon depression. Various attempts have been made to define the structure of monsoon depressions. Sikka *et al.* (1980) and Nitta & Murakami (1980) have analysed the wind field of a monsoon depression using aircraft and conventional data collected during MONEX. Recently Sarker and Chowdhury (1987) have constructed an averaged composite structure of monsoon depressions with reference to the tangential and radial components of wind.

The objective of this study is to construct a detailed composite structure of monsoon depressions so as to define the wind distribution around it at closely spaced points, at different levels, at different stages of its development, and to compile the information in a form usable for objective analysis. Attention is focussed on the wind distribution alone for the present study as the wind analysis is considered to be more important in the tropics. The technique of compositing several cases has been adopted. Attempt has also been made to correlate the visual satellite cloud imagery with the intensity of depressions in a few typical cases in the light of existing knowledge of intensity of tropical disturbances *vis-a-vis* satellite cloud features.

## 2. Data and methodology

The cases of monsoon depressions for the period during FGGE year 1979 and recent three years, 1984 to 1986, have been considered for this study. The wind data plotted on the upper air synoptic charts of 00 and 12 UTC prepared at the Northern Hemisphere Analysis Centre (NHAC), New Delhi were picked up manually for the period 1984-86. These data were supplemented by the dropwindsonde data of 1979 available in the published form.

The data were picked up with the help of a circular grid overlay moving with the centre of the depression. The data were placed in 160 grid segments formed by

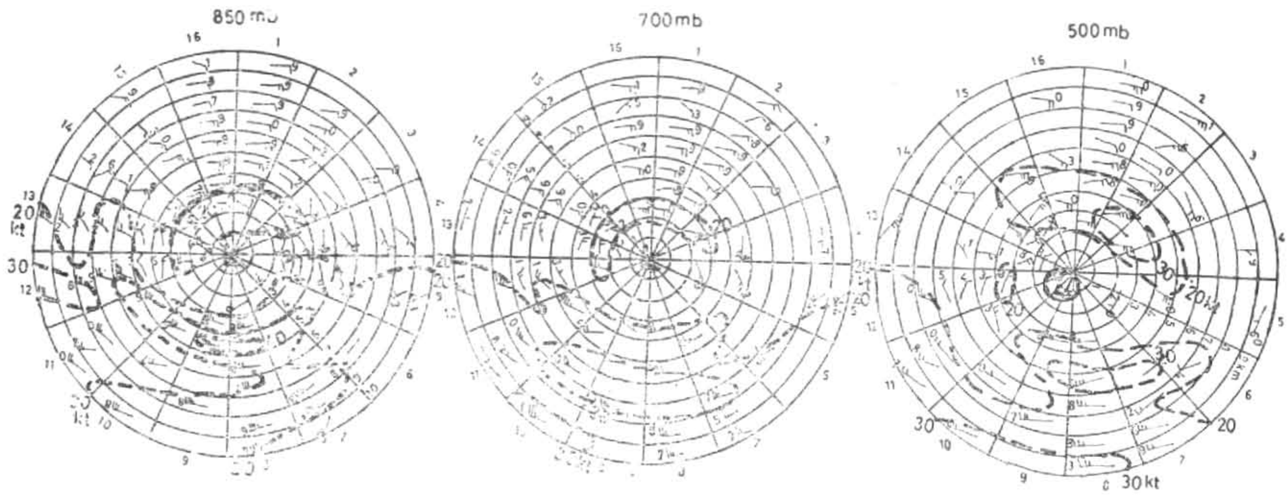


Fig. 1. Composite wind field around monsoon depressions (Isobar-1). Depression centre at mean sea level; (Wind speed in knots). Figures plotted near wind barbs are the middle digits of wind direction

L—Position of associated upper air vortex at the level

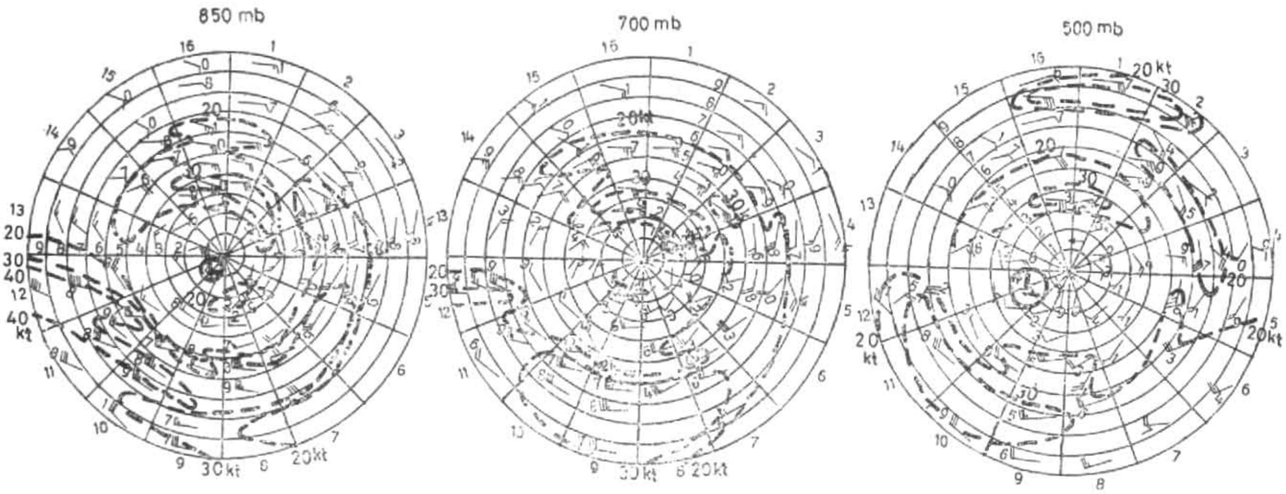


Fig. 2. Composite wind field around monsoon depressions (Isobars-2). Depression centre at mean sea level; (Wind speed in knots). Figures plotted near wind barbs are the middle digits of wind direction

L—Position of associated upper air vortex at the level

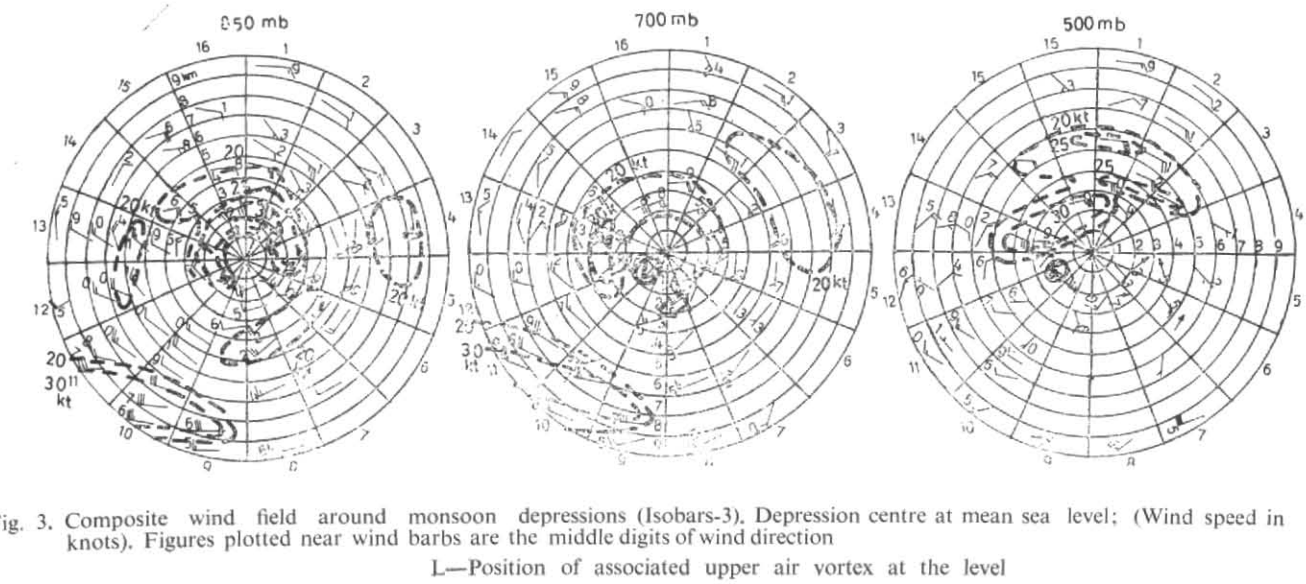


Fig. 3. Composite wind field around monsoon depressions (Isobars-3). Depression centre at mean sea level; (Wind speed in knots). Figures plotted near wind barbs are the middle digits of wind direction

L—Position of associated upper air vortex at the level

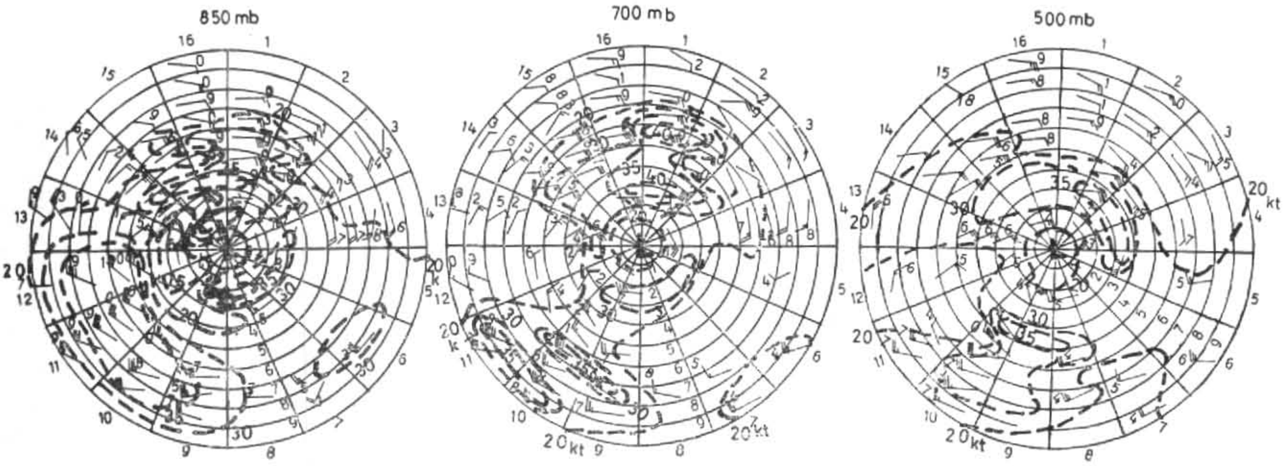


Fig. 4. Composite wind field around monsoon depressions (Isobars-4). Depression centre at mean sea level; (Wind speed in knots). Figures plotted near wind barbs are the middle digits of wind direction
L—Position of associated upper air vortex at the level

16 points of compass and intervals of 1 deg. radial distances up to 10 degrees. The wind data at three standard isobaric levels 850 ,700 and 500 mb (hPa) were tabulated. In the first instance the data of up to 500 mb only are considered in this study as the monsoon depressions are known to generally extend up to that level. It is proposed to extend this study to higher levels in due course. While fixing the overlay at each level the grid centre was placed at the point corresponding to the surface position of the depression, and not the centre at the upper level which would be generally different from the surface centre due to slope of the monsoon depressions. This procedure was adopted to examine the wind distribution at each level with reference to the surface centre, and to evaluate objectively the slope of the monsoon depressions in the composite picture. In all about 40 depression events were compiled.

For the purpose of defining the intensity of the system we took the number of closed isobars in the field of the disturbance as the criterion. The data were tabulated in four separate categories corresponding to one, two, three and four closed isobars. The depressions from beginning to end of their life history were taken into consideration, even after crossing over to the land. This was necessary to maximise the data to the south and southeast of the depressions which is our main interest. Since we are considering only those levels which are above the boundary layer the errors in assuming the wind distribution over land being valid over the sea would not arise.

Each wind observation was resolved into its $u$ and $v$ components. The segment averaged $u$ and $v$ components were then converted back to wind direction and speed. Isotach analysis was performed.

## 3. Structure of monsoon depressions

The composited charts of resultant winds for the four categories of monsoon depressions (isobars one, two, three and four) at three levels 850 mb, 700 mb and 500 mb are shown in Figs. 1-4. We find some well defined features of the wind flow around the depressions which stand out vividly and distinguish the four categories from each other. The composites reveal interesting facts about the slope of the monsoon depressions. The distribution of winds may be looked at from the following two aspects :

(*i*) Wind flow within the field of closed vortex which may be taken to have an average diameter of about 4-5 deg. around the centre and

(*ii*) Environmental flow away from the direct field of vortex.

In the discussion that follows the distribution of winds is sketched with reference to the above two aspects.

### 3.1. *Well marked low pressure area* (*Fig.* 1)

(a) *Wind circulation*

Two distinct wind maximas are seen. An east wind maxima of 20-30 kt occurs at all the three levels within the field of the low on its northern flank between the radial distances 2 & 5 degrees from the centre. There exists a broad belt of strong westerly wind flow away from the field of the low to its south at radial distances outward of 4-5 degrees. A wind maxima with a core of 40 kt occurs between the radii 4 and 5 degrees due south of the centre at 850 mb. The strong westerly flow decreases with height and the strong wind zone shrinks in extent.

(b) *Slope*

The wind vectors in the western segments, numbered 12 and 13, close to the centre of the low show a marked veering with height between 700 mb and 500 mb indicating slope of the vortex southwestward. However, between surface and 700 mb the vortex centre appears to be vertical.

### 3.2. *Depression with two isobars* (*Fig.* 2)

(a) *Wind circulation*

The westerlies to the south of the depression field are seen to extend northward on the eastern side of the depression and merge with the strong east winds to the north. The wind circulation becomes stronger and the area covered by strong winds expands. A belt of strong winds thus nearly circumscribes the vortex in this case.

The east wind maxima of the depression field in the northern sector expands farther north out to about 6-7 deg. radial distance. The core of east wind maxima has a strength of 30-40 kt and occurs at a radial distance of 2-4 deg. at all the three levels. At 500 mb a secondary east wind maxima is found in northeast sector at the outer periphery.

(b) *Slope*

In this case enough wind observations are available so that the vortex at all the three levels can be unambiguously drawn. It is seen that the vortex centre at 850 mb is about 1 deg. to the southwest of surface position; from 850 mb to 700 mb it is further 1 deg. to the southwest and another half a degree slope exists between 700 mb and 500 mb. Thus the total slope between surface and 500 mb is about 2 and a 1/2 deg. to the southwest, *i.e.* about 1 in 40. This is in conformity with the findings of earlier workers (Rao 1976).

3.3. *Depression with three isobars* (*Fig.* 3)

(a) *Wind circulation*

There is a remarkable change in the wind circulation. Surprisingly the strong westerly wind circulation to the south of the depression field is very much shrunk at 850 mb and 700 mb confined to a small zone away from 7 deg. radial distance to the southwest. The corresponding circulation at 500 mb totally breaks down and is much weaker.

The east wind maxima of the depression field in the north moves closer to the centre. The core extends southwards on the western side and in the lower level circulation 850 mb and 700 mb tends to form a ring around the centre. Another wind maxima of 20-30 kt develops at 850 mb in the southeast sector of the depression at a distance of 4-5 deg. radius.

(b) *Slope*

The centre of the vortex at 850 mb appears to be nearly coincident with the surface centre. Between 850 mb and 500 mb the slope is about 2 deg. to the southwest. Thus the slope of the vortex is milder than the 2-isobar case.

3.4. *Depression with four isobars* (*Fig.* 4)

(a) *Wind circulation*

The circulation considerably strengthens at all the levels. The area of strong winds in the north expands out to 7 deg. radius. The east wind maxima of the depression field is stronger than case (c). There are more than one cores of maxima separated latitudinally at 850 mb and 700 mb. The southeast sector wind maxima which was seen at the 3-isobar stage strengthens to 30-35 kt, extends to 700 mb level and moves closer to the centre to a radial distance of 2-3 deg. In the southwest the zone of strong winds with core maxima of 35-40 kt at 850 mb and 700 mb extends from about 5 deg. radius up to the outer periphery.

(b) *Slope*

It is interesting to see that the circulation is nearly vertical in this case.

#### 4. Results and discussion

It turns out from the observations made in the foregoing section that the circulation within the field of depressions and the surrounding environment seems to evolve in a set pattern with the development of the system. The wind field can be divided into two distinct zones — the environmental field away from the depression and direct field of the depression. Strong wind appears to the southwest and south away from the disturbance field, in all the stages, which characterize the strengthening of zonal westerly monsoon flow over Peninsula and Bay of Bengal at the time of formation of the depressions. The wind distribution within the field of the depressions is highly asymmetric. The wind maxima occurs in the easterlies in northern half of the circulation at all the stages of development of monsoon depressions. However, as the system intensifies to a 3-isobar stage the core of wind maxima moves closer to the centre of the depression and tends to form a ring around it in the lower tropospheric levels. Another wind maxima develops in the southeast sector at 850 mb. With its further intensification to 4-isobar stage the winds strengthen considerably. The belt of strong easterlies expands northward and two cores of maxima, widely separated from each other latitudinally, occur in this zone. The maxima in southeast strengthens, extends upward to 700 mb level and moves closer to the centre of the depression.

The slope of the depressions in the vertical as observed in this study is revealing. The monsoon depressions are believed to slope southwestward with height towards colder air as a rule. Srinivasan *et al.* (1972) have presented several cases showing the slope phenomenon of monsoon depressions. It is seen here that this is not true in all the stages of development. We find that the slope is maximum when the depression has two isobars. At the low stage the slope is mild. At the 3-isobar stage the slope is a little less than the 2-isobar stage. At the 4-isobar stage the depression is nearly vertical.

#### 5. Wind field for objective analysis

The wind data required for feeding into objective analysis may be picked up from the composited structure obtained in this study. Taking the composited structure as a model, the winds can be fed into the objective analysis system. The coordinates of the points of observations may be worked out with reference to the centre of the depression in each case. The centre and intensity of the depression may be known from a preliminary analysis of the synoptic chart and satellite cloud imagery. Features of cloud structure from INSAT imagery in respect of the cases selected for this study are described in the following paragraph.

#### 6. Features of cloud cover associated with monsoon depressions

Monsoon depressions are relatively weak atmospheric disturbances which are embedded in a highly sheared environmental flow. Their characteristic cloud pattern is a shear pattern in which dense overcast gets displaced in the direction of the vertical shear in the layer in which the convection is embedded. Satellite signatures of monsoon depressions have been studied by Srinivasan *et al.* (1971) and Chowdhury *et al.* (1985).

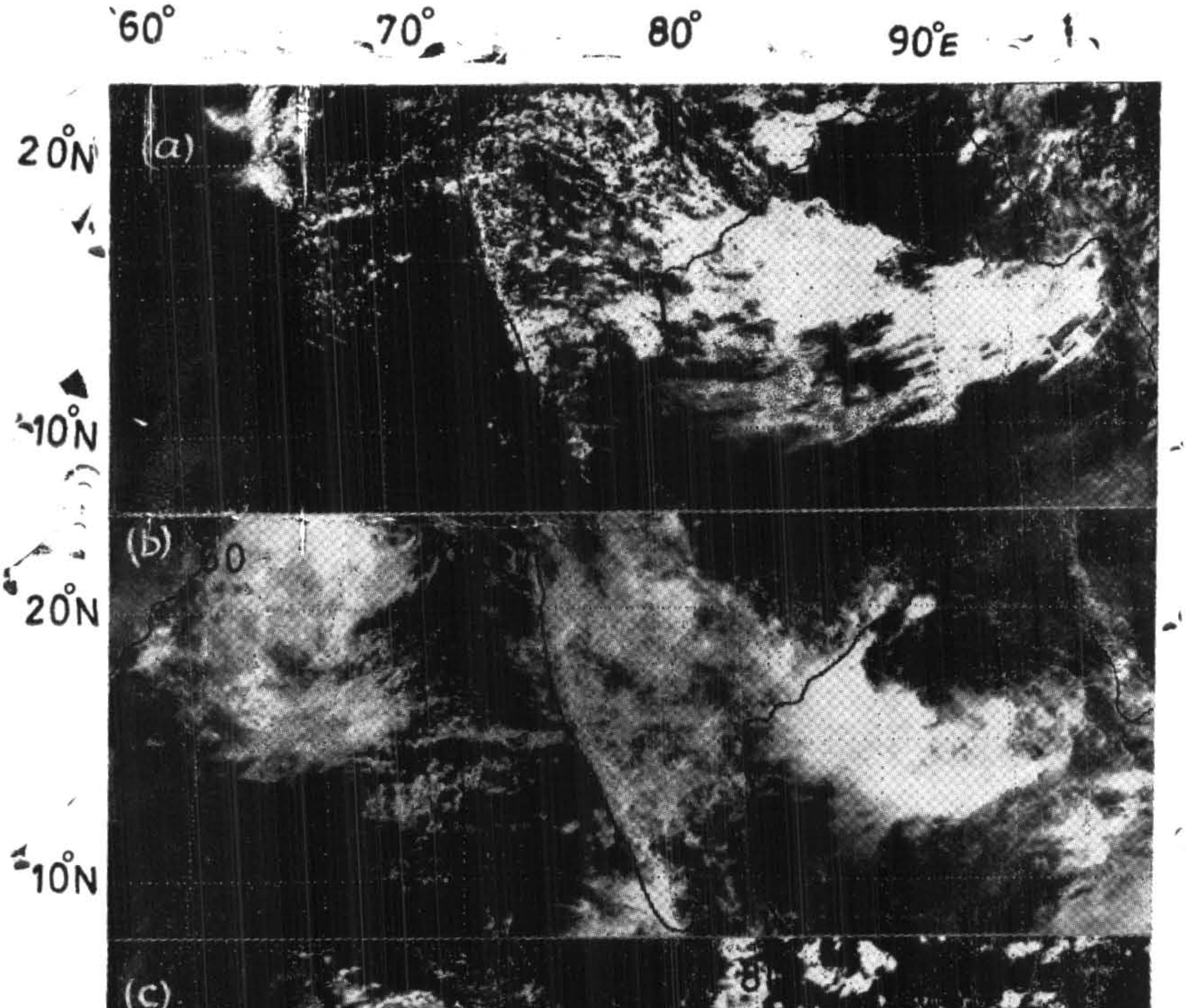


Fig. 5. INSAT-1B VIS imagery for typical cloud patterns associated with monsoon depressions at different stages of development

(a) 09 UTC on 29 July 1984 for initial genesis (well marked low/depression)

(b) 06 UTC on 10 August 1986 for intermediate stage (depression/deep depression)

(c) 09 UTC on 31 July 1984 for intense stage (deep depression/intense deep depression)

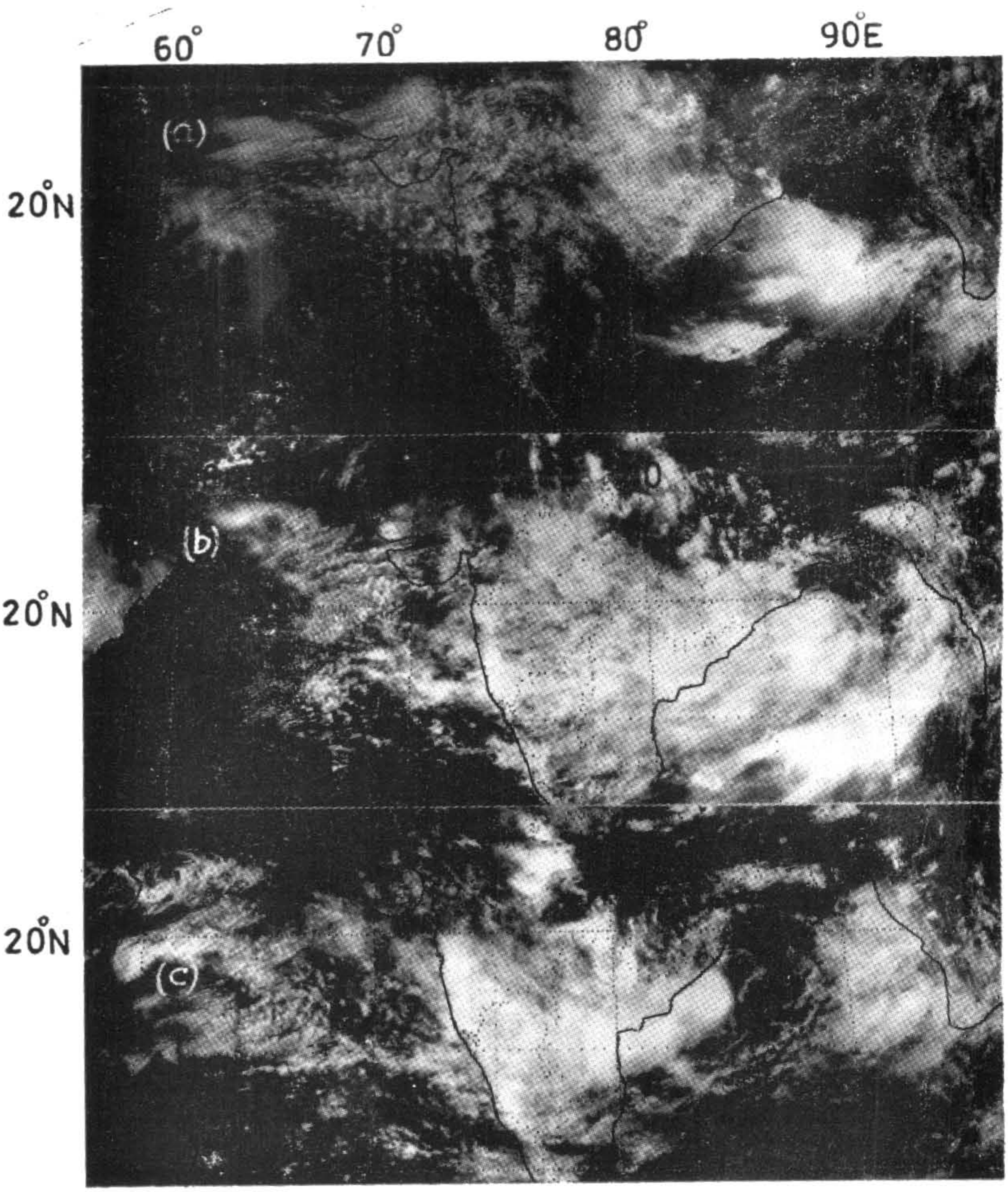


Fig. 6. INSAT-1B VIS imagery for typical cloud patterns associated with monsoon depressions at different stages of development

(a) 06 UTC on 18 August 1986 for initial genesis (well marked low/depression)

(b) 09 UTC on 21 July 1986 for intermediate stage (depression/deep depression)

(c) 09 UTC on 12 August 1986 for intense stage (deep depression/intense deep depression)

The characteristic feature of a monsoon depression is a shear pattern also seen in week stages of tropical cyclones (Dvorak 1975) in which the dense overcast is always seen displaced down shear from the low level centre. The other features of these depressions at different stages of development as seen in the 3-hourly INSAT-1B satellite imagery are described below.

(a) *Initial genesis*

Genesis stage is characterised by a long west to east band, south of the centre of the evolving vortex. The band consists of deep layer convective masses not showing any rotation at this stage. The centre of the evolving vortex may or may not get revealed but is near the deep layer cloud masses in the relatively clear area north of the band. The cumulus lines which define the centre of any monsoon depression in the satellite imagery are generally not present at this stage. Figs. 5 (a) & 6 (a) refer to the initial genesis in the case of monsoon depressions (30 July - 3 August 1984 and 18 - 21 August 1986). In these two cases very faint cumulus lines are present in the clear area around the centre and the deep layer cloud band is extensive, running west to east, south of the centre of the vortex. This defines the initial pattern categorised by one isobar. After the initial genesis further development of monsoon depression could be very rapid and within 24 hours, a sufficiently advanced pattern could appear in satellite imagery.

(b) *Intermediate stage*

The zonal band seen in the initial stages reorganises itself and a cut off is seen in this band just to the south of the centre of the monsoon depression. The truncated cloud cluster/band shows an increase in the organisation suggestive of concentration of vorticity at the depression centre and lies to its southwest. This cluster also sometimes extends northwestwards and is quite deep layered. The cumulus lines usually appear in this stage and define centre of the monsoon depression. This centre is about 1 to 2 deg. away from the centre of the monsoon depression as fixed in the surface isobaric analysis. The initial pattern generally evolves into this relatively improved shear pattern in about 24 hours and sometimes may switch over into most advanced pattern of the monsoon depression as happened on 11 August 1986. Figs. 5 (b) & 6 (b) show satellite imagery corresponding to this pattern. Faint cumulus lines are seen on 10 August 1986 around the system centre at 16.5°N, 87.0° E and also on 21 July 1986 when the centre is defined at 20.0° N, 87.0° E close to the edge of the convective cluster.

(c) *Intense stage*

This is the most advanced pattern in a monsoon depression in which the centre of the depression is increasingly involved with the dense overcast lying to the west or southwest of the centre. There is an increase both in the curvature of the cumulus lines and also the deep layer convective mass. The proximity of intense cluster with the circulation suggests that a change over from shear pattern into an early stage of Central Dense Overcast (CDO) pattern as in a tropical cyclone is taking place. The centre of the vortex is closest to the edge of the overcast and this shows that the tilt of the system with height which is a manifestation of the vertical shear is the least in this category. This is consistent with the observations made earlier about the slope of depressions in 4-isobar stage. The size of the overcast and its structure are important in determining the intensity of the depression and at this stage 3 to 5 deg. diameter dense overcast with embedded overshooting tops which penetrate the tropopause are seen. Figs. 5(c) & 6(c) show this most advanced pattern on 31 July 1984 and 12 August 1986. In both the cases the heavy dense overcast is just to the west/westsouthwest of the centre of the circulation defined by cumulus lines. The cumulus lines sometimes become deep layer bands and the displacement of the satellite imagery centre from the surface centre is least in this category.

**7. Phase difference between the convective surge and the intensity of monsoon depressions**

Monsoon depressions are sub-synoptic scale tropical disturbances which are driven by cumulus convection. In association with the ongoing changes in the evolution of the monsoon depressions, convection develops on various time and space scales. According to Warner (1984) distinction, *a priori,* between different scales is difficult to make. Only broad conclusions could be drawn regarding the large scale aspects from the satellite imagery. Each burst in the convection field shows itself within about 24 hours in the circulation presumably through the CISK mechanism. Decay in the convection field also does not immediately lead to simultaneous decrease in the current intensity of the depression. But after 24 hours decrease in intensity does take place. This point is being further looked into.

**8. Conclusions**

The following facts emerge from the analysis :

(*i*) The lower tropospheric wind circulation to the south away from the depression is seen to be strong in the initial stages of development and at the peak stage of development (4-isobar) stage, being comparatively weaker in the intermediate stages.

(*ii*) An east wind maxima exists in the northern sector of the depression which is seen to move closer to the centre with intensification of the depression. Another core of wind maxima develops in the southeast sector of the intense stages (3 and 4-isobars) which shows a similar behaviour.

(*iii*) The slope of the disturbance with height decreases with increase in the intensity of the depression being nearly vertical at the 4-isobar stage.

(*iv*) A long zonal band comprising deep layer cloud clusters is usually associated with early stage genesis of a weak depression. In the intense stage, the centre is clearly defined by spiral, close to the edge of the dense overcast which has sharp edges and also embedded overshooting tops.

*Acknowledgements*

The authors express their gratitude to Dr. R. P. Sarker, Director General of Meteorology and Dr. N. Sen Roy, Additional Director General of Meteorology for their encouragement. They convey their thanks to Shri G. R. Gupta, Director Northern Hemisphere Analysis Centre, New Delhi for providing facilities and interest shown by him in this study.

Authors sincere thanks go to Smt. Usha C. Balani for wordprocessing of the manuscript, S/Shri Arora and Sharma for help in preparation of diagrams, and Shri Brahma Singh for the duplication work.

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