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Bay depressions during monsoon 1978

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सार — बंगाल की खाड़ी के मुहाने पर बनने वाले और पश्चिम-उत्तर-पश्चिम दिशा की ओर आते हुए भारत के मध्य भाग को पार करने वाले अवदाबों का सक्रिय मानसून वर्षा पर बहुत गहरा प्रभाव पड़ता है। कुछ अवदाब बंगाल की खाड़ी में ही स्वतः बनते हैं। अन्य कुछ अवदाब दक्षिण-पश्चिम प्रशान्त महासागर में चक्रवातों के अवशेष के रूप में थाईलैंड और बर्मा को पार करके क्षीण उष्णकटिबंधीय दाब की स्थिति में बंगाल की खाड़ी में आ जाते हैं और मानसून के अवदाब बनते हैं। इस शोधपत्र में ऐसे ही मानसून के अवदाबों के बनने, तीव्रतर होने और आगे बढ़ने की दिशा के बारे में सिनॉप्टिक विशेषताओं के आधार पर अध्ययन किया गया है। अवदाबों के बनने आदि की पूर्व-स्थिति की जो जानकारी दी गई है वह पहले की खोजों से मिलती-जुलती है।

ABSTRACT. Depressions forming in the head Bay of Bengal and moving westnorthwards across central parts of India exert a profound influence on monsoon activity over the country. Some depressions form *in situ* in the Bay of Bengal. Some others originate in south China Sea or are remnants of typhoons in the southwest Pacific, which travel westwards into the Bay from across Thailand and Burma as weak tropical disturbances. The paper presents the synoptic features that favour formation, intensification and movement of such depressions during June to September of 1978. These pre-conditions are in conformity with earlier findings.

1. Introduction

Monsoon depression form over the north and central Bay of Bengal, cross coast and move westnorthwestward and the rainfall activity is carried by the depression all along its track (generally WNW-wards) over the land before it weakens into a low and merges with the seasonal trough. Some of these depressions recurve towards the north and break-up in the Sub-Himalayan region. Generally, it is noted that with the formation and movement of a depression the monsoon activity increases and after the passage of a depression it weakens and the rains slacken.

The authors discuss here some interesting synoptic features associated with the formation and movement of the depressions in the Bay of Bengal during the summer monsoon of 1978. The pre-existing salient synoptic features favourable for the formation and movement of a monsoon depression have been listed and these are consistent with the findings of Palmen (1956), Riehl (1954), Rao (1976), Raman *et al.* (1978, 1979 & 1981) and Mandal *et al.* (1981).

2. Formation, movement and intensification of the monsoon depression

Several possible mechanisms have been suggested by various authors for the formation of a monsoon depression as well as for its intensification and movement based on synoptic and theoretical considerations. The synoptic conditions associated with five cases of monsoon depressions during June-September 1978 are summarised in Table 1.

The following primary synoptic factors emerge :

2.1. For the formation of a monsoon depression, the most important large scale feature in the lower troposphere, is that the monsoon trough should extend out into the head Bay of Bengal. This is where cyclonic vorticity, moisture convergence and vertical motion exist. A prime pre-requisite for the formation of a depression is the incidence of active cyclogenesis over the area and its persistence for a period of time in the lower troposphere. This could be in the form of (*i*) an extended monsoon trough or (*ii*) an upper air cyclonic circulation/low pressure area or (*iii*) a remnant low pressure system of a typhoon emerging from across the Arakan coast. In the upper troposphere the circulation in the region is anticyclonic as well as divergent.

2.2. Another important factor for the formation of a depression in Bay of Bengal is the appearance of a favourable thickness pattern of 850-500 hPa layer. The advection or otherwise of thermal vorticity by thermal wind can give rise to intensification or weakening of pressure systems (Hartiner 1971). The thickness chart shows appearance of a warmer zone over the probable area of depression formation, well in advance. That this warm zone over the depression field persists whether the system is over the sea or over land. The protrusion of the tongue of warmer air often seems to be in the direction of movement of the depression and thus, is an indicator of a depression's direction of movement in the ensuing twenty-four hours. Simpson (1946) had similar finding for the movement of a tropical storm.

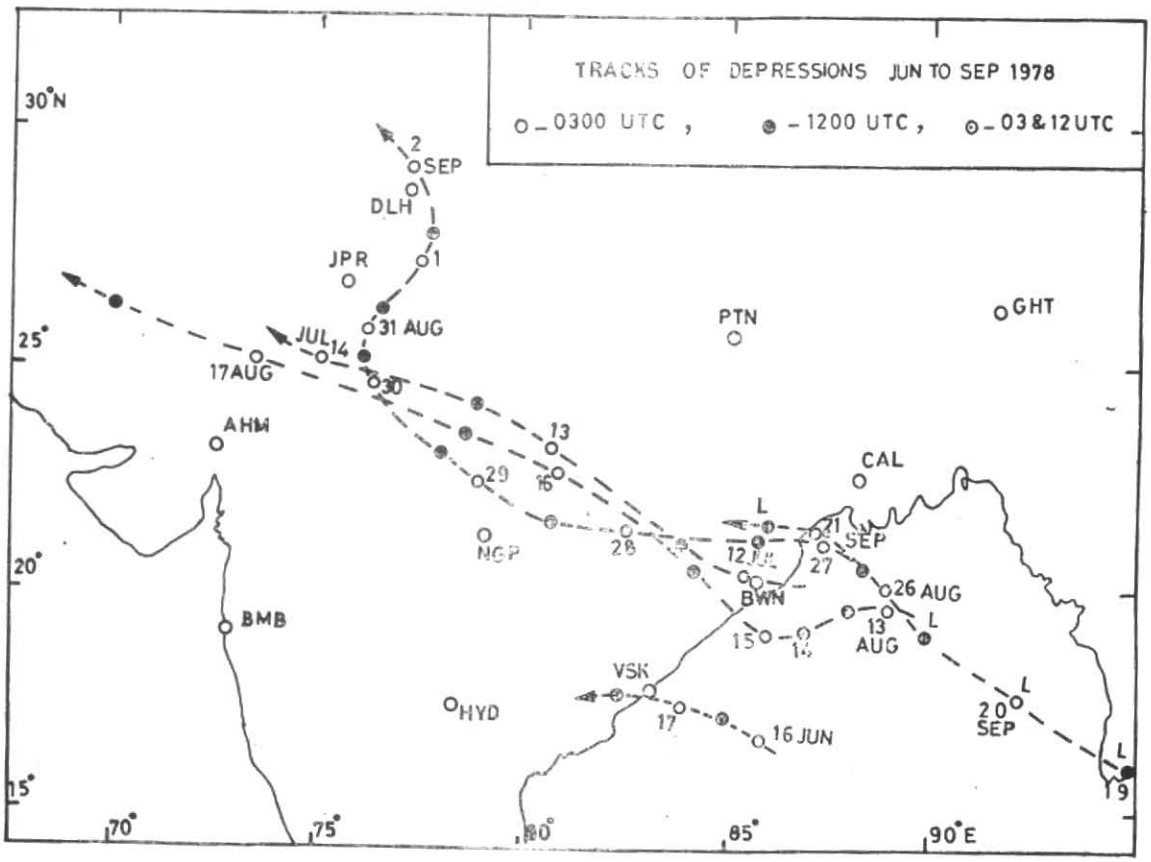


Fig. 1. Tracks of depressions during June to September 1973

TABLE 1

Detailed examination of pre-conditions for formation and movement of monsoon depressions, June-August 1978

List of favourable synoptic/ satellite conditions	Monsoon depression cases pertaining to the period		
	16-17 June	12-14 July	13-17 August
1. *Pre-existing area of active cyclogenesis*			
(a) As a low pressure/trough	Seasonal monsoon trough extended in west central Bay on 13 June & on 14th a low on MSL chart & concentrated into depression 500 km eastsoutheast of Visakhapatnam on morning of 16 June	On 8 July the monsoon trough extended up to north Andaman Sea and a low pressure area formed on 9 July & became well marked on 11th, concentrated into a depression at 00 UTC of 12th near 20.0N, 87.0E	On 10 & 11 August a well marked trough of low extended over the head Bay on MSL chart and a low formed on 12th and depression on 13th morning near 19.5 N and 89 E
(b) As a lower tropospheric cyclonic circulation	Low level circulation formed around 17.0N & 87.0E between 850 & 500 hPa sloping southwards with height on 13th	Low level cyclonic circulation extended up to 850 hPa on 9 July. It extended up to 400 hPa on 11th and up to 300 hPa on 12th with trough aloft in easterlies up to 250 hPa	Lower tropospheric cyclonic circulation tilting southward with height was present since 10th it became vertical on 12th and extended up to 300 hPa on 14th and a trough aloft up to 200 hPa
(c) As an interactive remnant of typhoon emerging through Arakan/Malaysia coast	—	A vortex in lower troposphere moved into the east central Bay from Burma coast on the morning of 10 July	The upper air cyclonic circulation, a remnant of tropical depression over south China Sea, emerged into Bay on 14th and interacted with Bay depression and intensified it into a deep depression at 12 UTC of that day
2. Warm pool on thickness chart 850-500 hPa	A warm pool formed on 13th and continued over the area	A tongue of warm air oriented northeast-southwest existed along the east coast of India over the Bay and cold air existed over the remaining area of Bay till 10 July (Fig. 8a). On 12 July a warm pool was located over depression field (Fig. 8b)	Cold pool existed on 10th over head Bay and warm pool on 12th onward

TABLE 1 (*contd*)

List of favourable synoptic/ satellite conditions	Monsoon depression cases pertaining to the period		
	16-17 June	12-14 July	13-17 August
3. Location of easterly jet axis such that the area of cyclogenesis is far from it	The axis of easterly jet on 13th passed along 12°N and it shifted to 8°N on 16th, the day of depression formation	Area of depression formation was between two easterly jet-axis (*i*) along 25° N and (*ii*) along 18° N and thus it was in the anticyclonic shear zone of the 2nd easterly jet as shown in Fig. 7. Whether or not the persistence of jet axis north and south of the depression field inhibited early formation of the depression and was also responsible for its short life and fast movement needs to be supported by more number of such cases	An anticyclonic shear of easterly jet existed over the depression field as the jet axis had shifted equatorward before its formation
4. Vertical wind shear $U_{200}-U_{850}$ becoming low over depression field prior to its formation	Low wind shear of —15 mps existed on 13th and —8 mps on 15th and —18 mps on 16th (Fig. 6a), sudden change to +10 mps at 12 UTC of 16th caused its slow movement and intensification; rapid increase to —20 mps by 12 UTC of 17th caused its quick dissipation	Wind shear at Visakhapatnam did not show a low value. However, over Bhubaneshwar values between —10 mps and + 5 mps were observed from 9th to 12th morning (Fig. 6b)	Wind shear was found to be low of the order of ±10 mps at Calcutta (Fig. 6c)
5. Fall in 24 hr pressure changes/ departures around and ahead of the depression field	Not significant	Negative pressure changes and departures were noted over and ahead of the depression field especially to the west and north	These were observed along and ahead of the depression track
6. SST in depression zone being warmer than surrounding coastal waters and occasionally above those of the air above	1° to 2° C warmer than air temperature. These were also 1°C above normal	SST over west central Bay and adjoining area were warmer by 2° C than the air temp. just on and after the day of the formation of depression. These were also above normal by 2°C	SST were higher than air temperature in the depression field. These were near normal
7. Upper tropospheric features	A trough in upper tropospheric easterlies existed up to 200 hPa	The track (Fig. 1) showed that the depression moved along the periphery of the anticyclone at 200 hPa. The ridge line of the anticyclone remained practically stationary roughly along 32° N	The moisture supply in the depression field was maintained both from Bay and Arabian Sea as an anticyclone appeared over northeast India in the mid-troposphere (600 to 400 hPa) maintaining its position northeast of depression from 00 UTC of 16 to 00 UTC of 17th. This could help maintain the intensity of the system and also the well distributed rainfall all along its track. Ahmedabad wind at 0.9 km a.s.l. was SW/50 kt at 00 UTC of 17th suggesting temporary strengthening over Rajasthan area
8. Characteristic cloud features in satellite imagery	Satellite imagery on 14th showed convective cloud cluster which got more organized on 16th and continued till its landfall. Dense overcast area weakened on 17th and disintegrated the next day	Satellite pictures of 9 and 10 July showed convective cloud cluster with diffused band structure over the west central Bay and around. On 12 July curved convective lines developed at the edge of the dense overcast, showing the formation of the depression (Fig. 2)	Convective cloud cluster was seen in north and adjoining central Bay between 12th and 14th. Another convective cluster with indication of an associated vortex in its curved banding was seen emerging into the east central Bay from Burma. The two cloud masses merged on 15th (Fig. 3)

TABLE 1 (*contd*)

Detailed examination of pre-conditions for formation and movement of monsoon depressions, August-September 1978

List of favourable synoptic/satellite conditions	Monsoon depression cases pertaining to the period	
	26 August to 2 September	21 September 1978
1. (a)	An active monsoon trough extended into head Bay and a low pressure area formed on 24th morning and concentrated into a depression at 00 UTC of 26th around 20°N, 89°E and into a deep depression at 12 UTC of 26th around 20.5° N and 88.5°E	Monsoon trough extended into east central Bay on 18th
(b) & (c)	Another low with lower troposphere circulation moved into head Bay after crossing Burma coast on 25th morning and merged with the low existing here	(b) & c) A low pressure area which lay over Thailand on 18th emerged into east central Bay on 19th and moved northwestward as a low pressure area in the Bay and later concentrated into a depression on 21 September off Orissa coast. The system after crossing Orissa coast moved inland. This low pressure had an associated cyclonic circulation extending up to 500 hPa slightly tilting eastwards with height. The duration of this system as depression was about 3 hours
2.	A warm pool formed over north Bay on 24 August. The pool continued over the depression field all along its track. Before the northward movement of the system on 30th the warm pool started spreading north of the depression field since 27 August	A warm pool existed over east central Bay on 19th and continued to be associated with the low pressure area
3.	The tropical easterly jet axis shifted from Lat. 15° N on 24th to 10° N on 25th and 26th	Before formation of the depression the easterly jet axis remained far to south of the system. On 19th it was roughly along 8°N
4.	Low wind shear (mps) as shown below was observed :	Low wind shear (± 10 mps) from 18 to 20 September (Fig. 6e) existed over the depression field
	Date / Calcutta / Bhubaneshwar	
	21 / +3 / −8	
	22 / −2 / −13	
	23 / +3 / −5	
	24 / +9 / −3	
	25 / +3 / −10	
	26 / +5 / +2	
5.	Negative pressure changes and departures were noticed over and ahead of the depression field during its movement	The pressure changes did show a falling trend in the northwest Bay and Orissa coast
6.	Not significant	SST were slightly above normal and observed to be warmer than air temperatures close to the depression field
7.	The westnorthwestward movement on 29 & 30 Aug was steered along the southern periphery of the anticyclone at 250 hPa level, and on 31st by the upper tropospheric flow over the depression field at 300 hPa. The movement in a northerly direction on 1 September was again guided by the steering level at 250 hPa	The movement of the system as a depression northwestwards was noted to be steered along the periphery of the anticyclone at 300 hPa
8.	Satellite imagery indicated a convective cloud cluster in the north and adjoining central Bay up to 25 August. Thereafter the cloud system developed rapidly. On 26th curved cumulus lines developed at the edge of the dense overcast clearly defining the centre . The dense overcast became circular and the system intensified into a deep depression on 27th as it moved westward. Satellite imagery showed weakening of system after crossing coast. On 29th it showed a typical pattern of well organised curved cumulus lines at the eastern edge of dense convective overcast area (Fig. 4) due to fresh supply of moisture from Arabian Sea	The satellite imagery showed a progressive initial westnorthwestward movement of a well organised vortex from south China Sea and its emergence into east central Bay. It also indicated northwestward movement of this vortex in the Bay and its development. Curved cumulus lines developed on 20th afternoon which defined the cloud system centre near 19° N, 90° E. The system further developed by 21st when it had a Central Dense Overcast (CDO) area with ragged edges and surrounded by curved cumulus lines (Fig. 5)

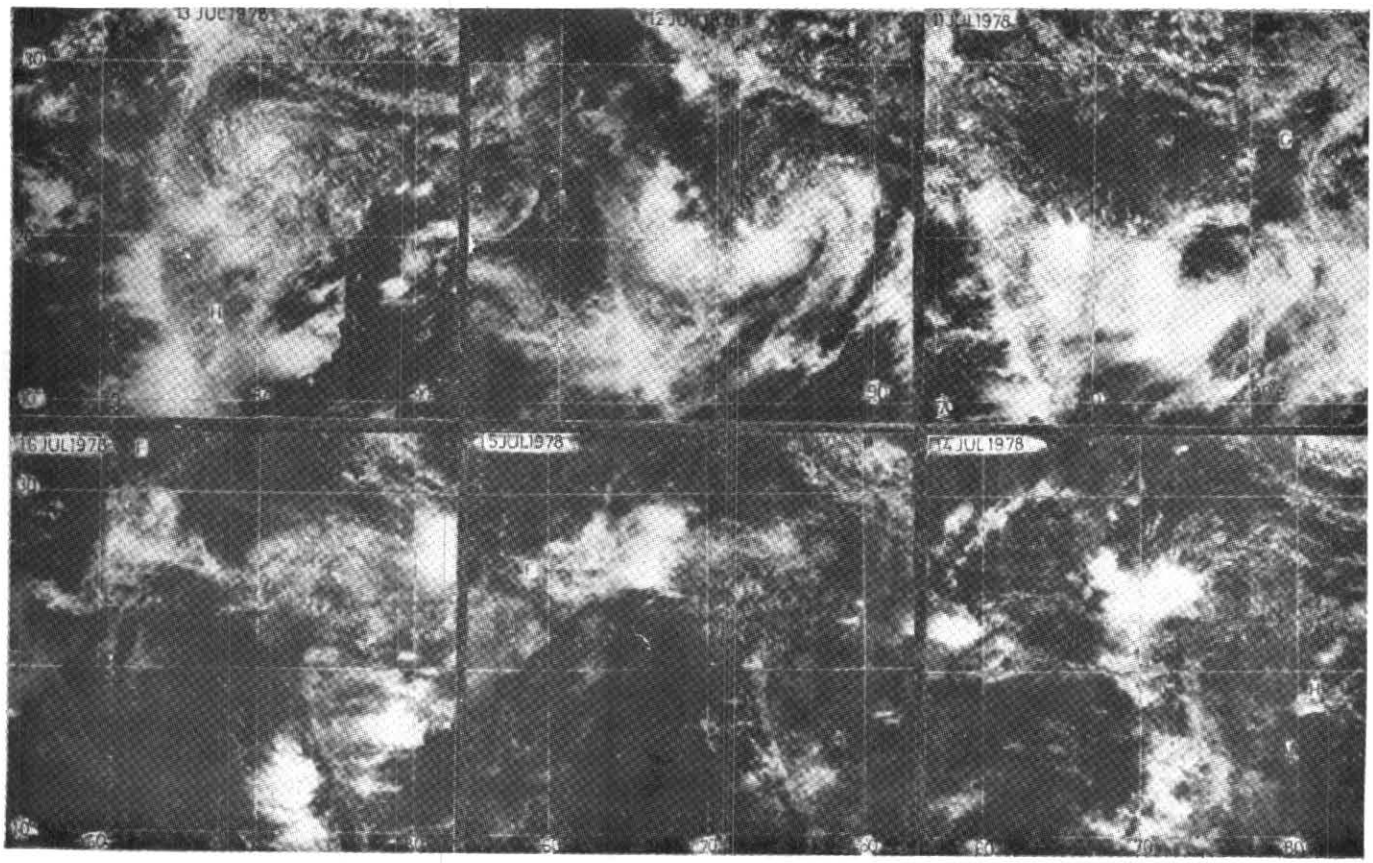


Fig. 2. Satellite cloud patterns showing curved convective lines and also the dense overcast area associated with the monsoon depression, 11-16 July 1978

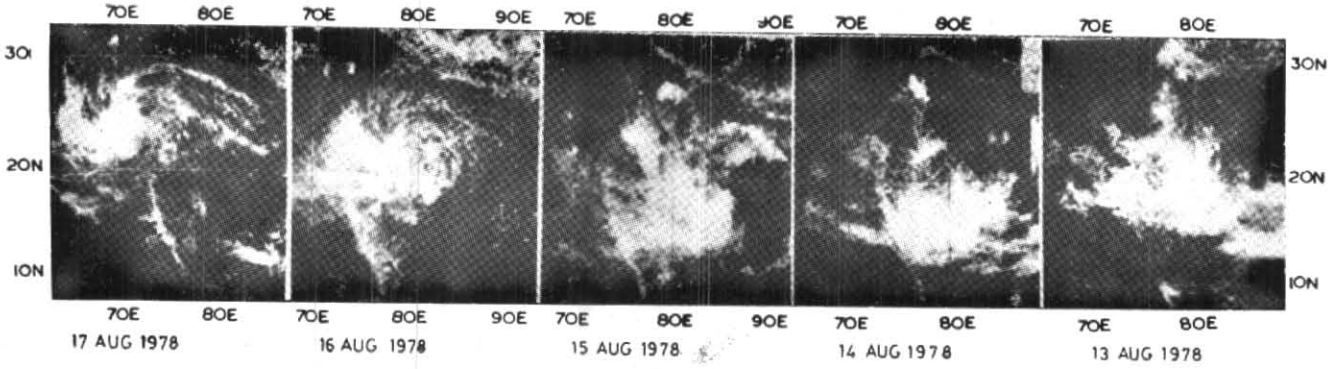


Fig. 3. Satellite cloud pattern showing curved banding features and cumulus lines associated with the monsoon depression, 13-17 August 1978

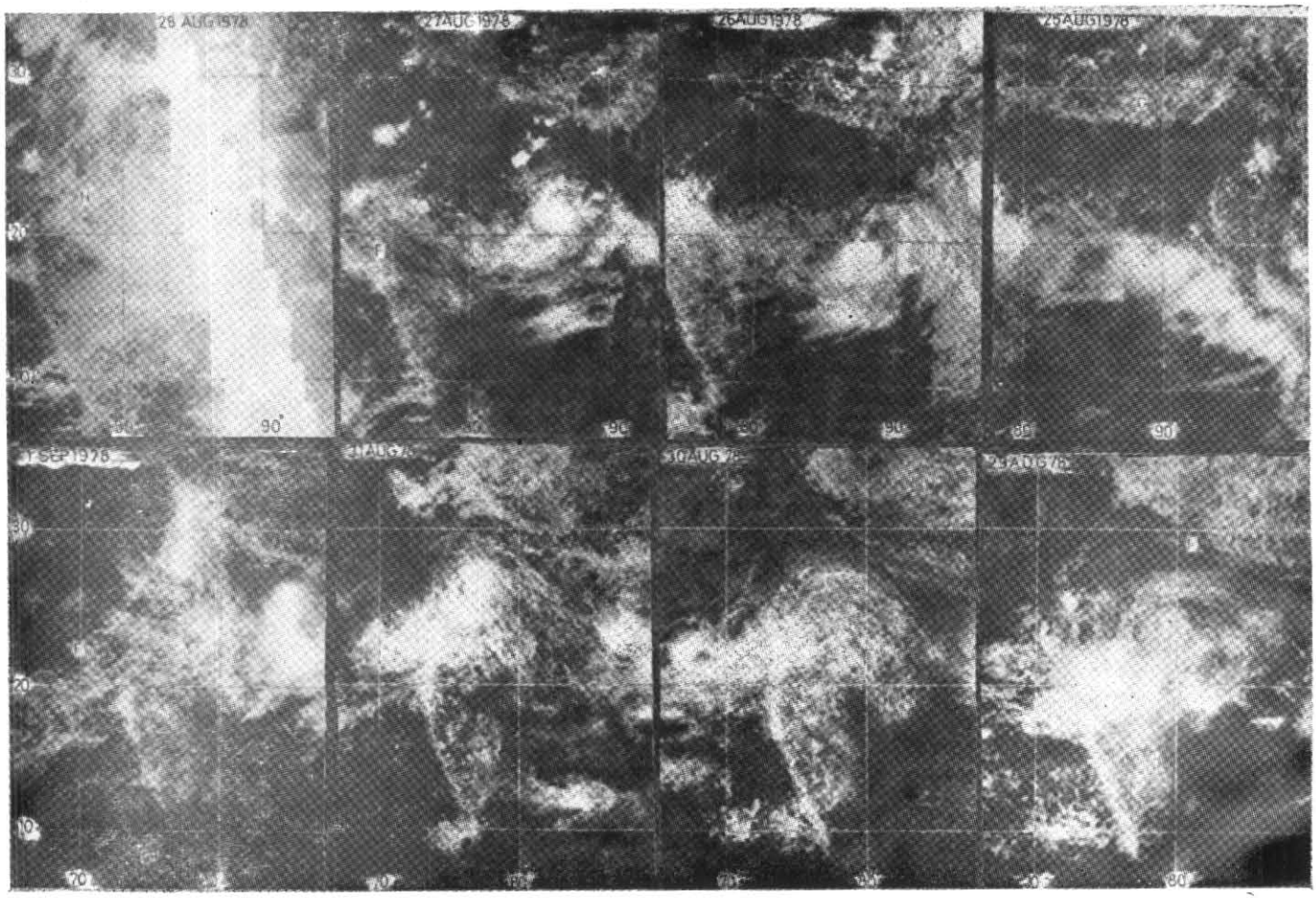


Fig. 4. Satellite cloud patterns showing developing features from cloud cluster stage up to curved cumulus lines at the edge of the dense overcast convective cloud mass associated with monsoon depression, 25 August to 1 September 1978

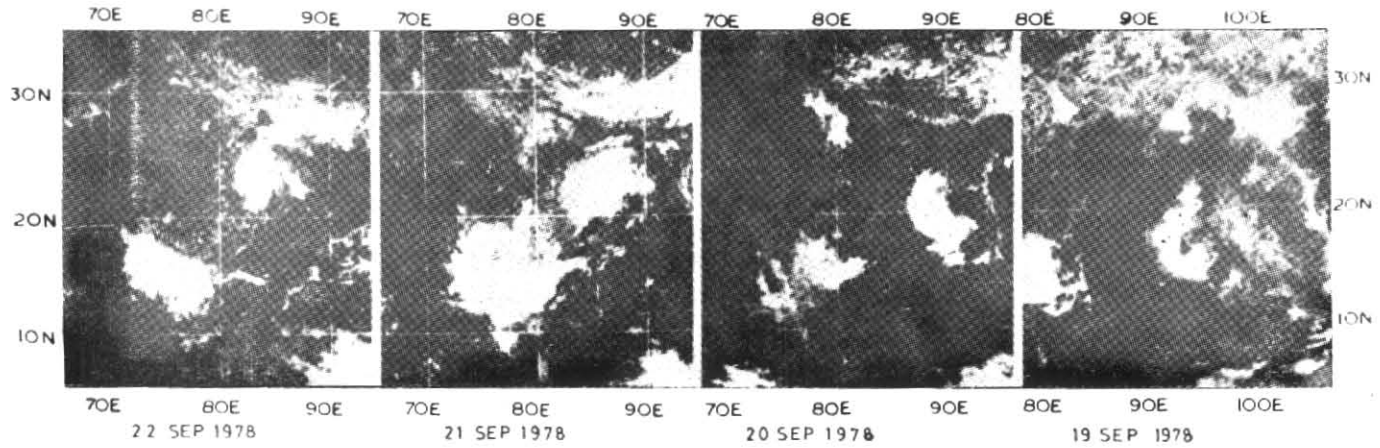
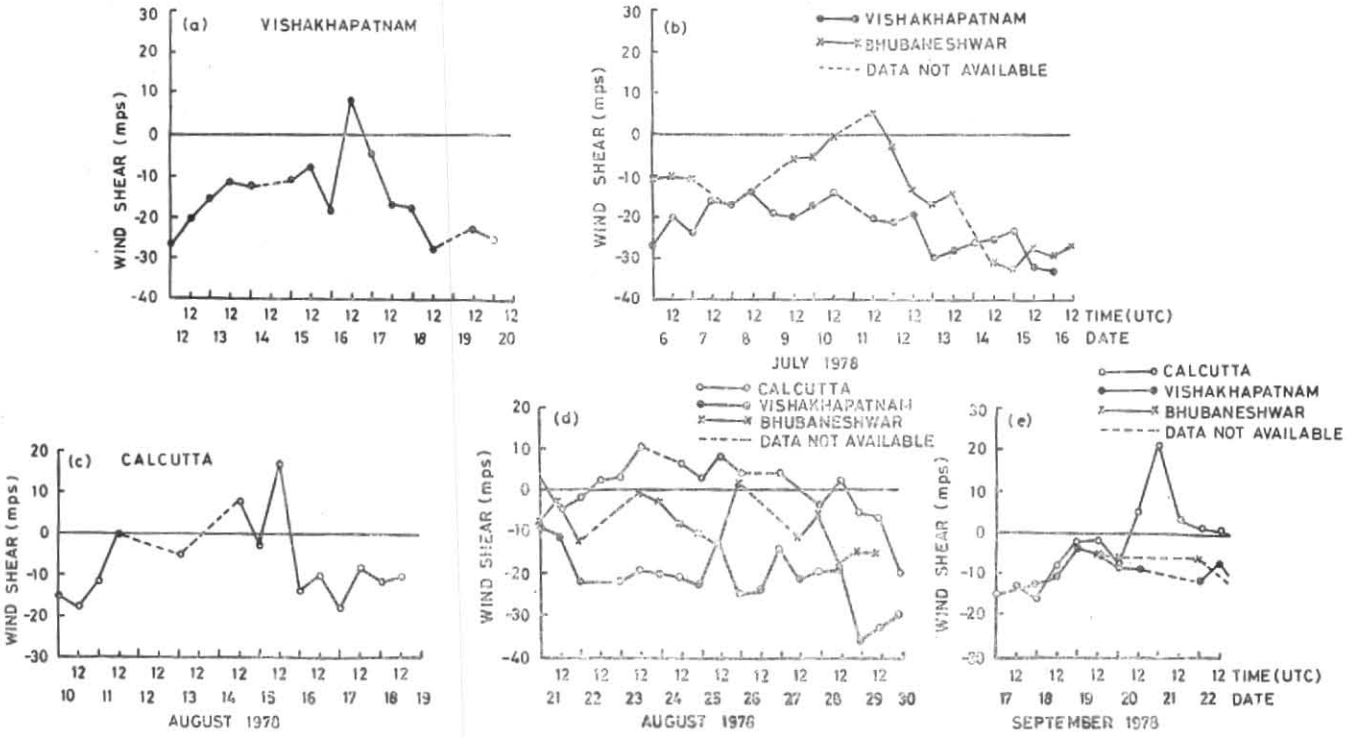


Fig. 5. Satellite pictures showing progressive cloud features from curved cumulus lines to the well developed stage giving pattern with central dense overcast area and ragged edges and cumulus lines associated with the monsoon depression, 19-22 September 1978



Figs. 6 (a-e). Wind shear at Visakhapatnam and Calcutta during July-September 1978

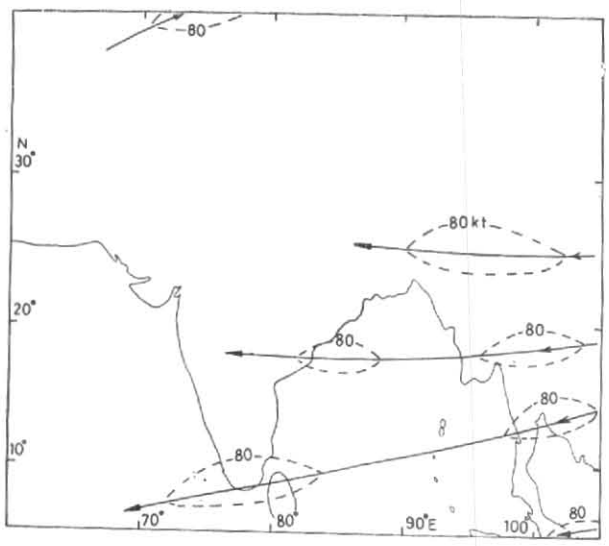
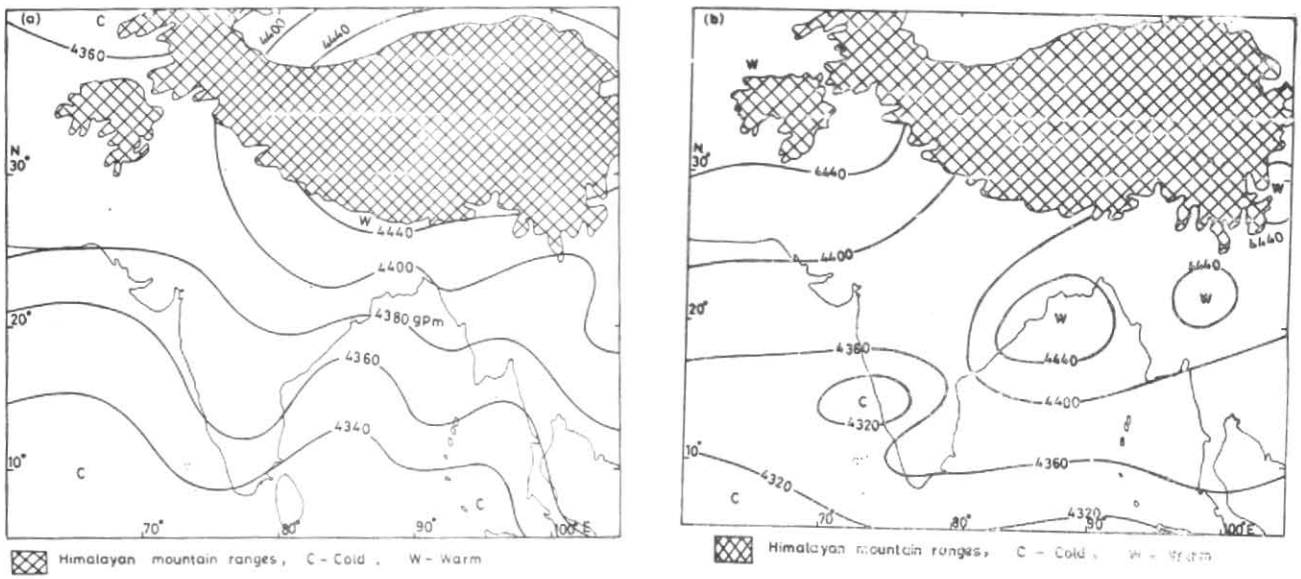


Fig. 7. Maximum wind chart of 00 UTC on 12 July 1978

2.3. Yet another synoptic feature favouring the formation of the Bay depression is the existence of the incipient cyclogenetic area poleward of the axis of the easterly jet stream. Actually, before the formation of a depression it is observed that the jet axis shifts equatorwards of the probable depression regime. If, for some reason, the jet axis does not shift equatorwards of the probable depression field, the process of development of the depression is observed to be delayed, as happened in the case of the depression of 12 July 1978 (Fig. 7). Another interesting role of the easterly jet is observed to relate to movement of a depression. After the formation of a depression, if the easterly jet axis shifts polewards or reappears over the depression field, the synoptic readjustment appears to accelerate the movement of the depression or sometimes, even contributes to the quick dissipation/ curtailment of its life, as happened in the case of the depression of 16 June 1978.

2.4. Vertical wind shear in the tropospheric layer (U_{200}-U_{850} hPa), reduces in and around the zone of depression field prior to or at the time of formation of a depression. In some cases, the low shear values of the order of 10 mps or less are recorded by the coastal stations in the outer periphery of the depression field. Detailed analysis of wind shear (U_{200}-U_{850}) indicates that the wind shear in the depression field starts decreasing in magnitude even 3 to 4 days in advance of the formation of the monsoon depression. During the period prior to the formation of the depression, Calcutta mainly had positive wind shears ranging from zero to about 23 mps, whereas Bhubaneshwar and Visakhapatnam had negative wind shear up to —15 mps. The decrease in the magnitude of wind shear with the development of the monsoon depression is also clearly shown by these data. After the formation of the monsoon depression, a falling negative wind shear close to the depression field indicates fast movement of the system as seen in the depressions of 12 July 1978 and of 13 August 1978 (Fig. 6). Our presentation goes with Gray's (1968) observation that tropical cyclogenesis is favoured in the domain of small vertical wind shear.



Figs. 8 (a & b). Thickness patterns for 850-500 hPa layer at 12 UTC : (a) 10 July 1978 and (b) 12 July 1978
C=Cold, W=Warm, Contour height in gpm

Raman *et al.* (1978, 1979, 1981) had drawn attention to the lowering of vertical shear as an important factor in monsoon depression formation in the head Bay of Bengal, where its value is normally large.

The other important synoptic features in addition to the above mentioned conditions that the are required to be looked into before the formation of a depression are as follows :

2.5. Pressures start falling over and around the area and the trend of the falling pressures continues in the direction of the movement of the system.

2.6. Sea surface temperatures are comparatively higher than that of air and of the surrounding coastal waters. SST is also observed to be near normal to above normal by 1° to 2° C in the depression field for all Bay depressions (Gray 1968, Raman *et al.* 1978).

2.7. Out of five depressions during 1978, two developed *in situ* over the Bay of Bengal; three depressions developed from weak tropical disturbances which moved westward into the Bay of Bengal from across Burma (one of which had earlier originated in the south China Sea).

2.8. Some depressions strengthen over Madhya Pradesh and east Rajasthan areas, under the influence of renewed moisture supply from Arabian Sea in the lower troposphere as observed in satellite imagery.

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