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Behaviour of recurving cyclonic storms in Arabian Sea as a response to atmospheric interactions

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सार – वर्ष 1998 के दौरान अरब सागर में दो विशेष और असामान्य चक्रवातीय प्रणालियाँ देखी गई हैं। जहाँ तक अरब सागर की प्रणालियों का संबंध है जून 1998 में आया अत्यंत भीषण चक्रवातीय तूफ़ान पिछले पंद्रह वर्षों की अवधि का सबसे अधिक भीषण तूफ़ान था; जबकि अक्तूबर 1998 की प्रणाली की विशिष्टताएँ इस प्रकार थी (*i*) सउदी अरब के तट को लगभग स्पर्श करने के उपरांत असामान्य रूप से और अकस्मात इसका मार्ग पूर्वाभिमुखी होना। (*ii*) चक्रवात की चाल का बहुत तीव्र होना। (*iii*) सौराष्ट्र तट से सुदूर अरब सागर में विद्यमान अन्य भ्रमिलता से अन्योन्य क्रिया करना और उसमें विलीन होना।

इस शोध-पत्र में अरब सागर की प्रणालियों के विशिष्ट प्रकार के व्यवहार को समझने का प्रयास किया गया है। जो चक्रवात की अवस्था से अधिक की स्थिति में भी प्रचंड नहीं होती है अथवा वायुमंडलीय अन्योन्यक्रिया की प्रतिक्रियास्वरूप तट को पार करने से पहले उनके मंद पड़ने की प्रवृत्ति भी दिखाई देती है। 1975 से (उपग्रह युग) अरब सागर में सभी चक्रवातीय तंत्रों की विस्तार से जाँच की गई और इस अध्ययन से प्राप्त हुए मुख्य निष्कर्ष इस प्रकार हैं:

(*i*) एक ही समय में उत्पन्न होने वाली विभिन्न प्रकार की प्रचंडताओं वाले चक्रवातीय विक्षोभों के बीच होने वाली अन्योन्यक्रिया की प्रणाली के आगे चलकर अधिक तीव्र होने अथवा नहीं होने के तथ्य को निर्धारित करने वाली मुख्य कारक प्रतीत होती है।

(*ii*) चक्रवात की सीमांत अवस्था तक प्रणाली के मार्ग का पूर्वानुमान मुख्यत: मध्यस्तरीय वायुमंडलीय प्रतिवलन द्वारा संचालित प्रतीत होता है।

(*iii*) तूफ़ान के भीषण चक्रवातीय स्तर से प्रणाली के और अधिक भीषण होने की स्थिति की और ले आने में उपरिस्तरीय पवन संचालन महत्वपूर्ण पाया गया है।

उपर्युक्त परिणामों का चक्रवात की प्रचालानात्मक स्थिति के पूर्वानुमान से सीधा संबंध है।

ABSTRACT. During the year 1998, Arabian sea witnessed two distinct and unusual cyclonic systems. The very severe cyclonic storm of June1998 was the most severe storm since last fifteen years as far as Arabian Sea systems are concerned ; while October 1998 system was unique for, (*i*) Its unusual and sudden easterly track after almost touching Saudi Arabia coast, (*ii*) Very high speed of movement and (*iii*) Interaction and merger with another vortex present in Arabian Sea off Saurashtra coast.

This study is an attempt to understand the peculiar behaviour of the systems in Arabian sea which do not intensify beyond cyclone stage or even show a tendency to weaken before crossing coast as a response to atmospheric interactions. All the cyclonic systems in Arabian Sea since 1975 (Satellite era) have been examined in detail and the main findings of the study are :

(*i*) Interaction between cyclonic disturbances of different intensities simultaneously present, appears to be the key factor in determining the further intensification or not of the systems.

(*ii*) Track prediction for the systems upto marginal cyclone stage appears to be governed mainly by middle level atmospheric forcing.

(*iii*) Upper level wind steering is found to be important for movement of systems from severe cyclonic storm stage onwards.

The above results have direct relevance to operational cyclone forecasting.

Key words – Intensification, Arabian sea cyclone, Weakening, Movement of Arabian Sea cyclones, Merger of vortices.

1. Introduction

During the period 1976-1998, the Arabian Sea has experienced 8 'land falling' cyclones and all of them have crossed Gujarat coast. It is seen that some of these cyclones did not intensify to a severe cyclonic storm while some cyclones weakened before crossing the coast. This paper attempts to study the intensification/

TABLE 1

S.No.	Year	Type of storm	Storm steered by
1.	19–22 October 1975	Severe cyclone	Upper level anticyclone
2.	31 May to 5 June 1976	do	do
3.	29 October to 2 November 1981	do	do
4.	3 – 8 November 1982	do	do
5.	12–16 November 1993	do	Upper level westerly trough
6.	17–20 June 1996	do	Upper level anticyclone
7.	5 –10 June 1998	Very severe cyclone	do
8.	11 –17 October 1998	Cyclonic storm	Middle level westerly trough

weakening processes and recurvature of the cyclonic storms in Arabian Sea as a response to atmospheric interactions.

2. General characteristics of cyclonic storm

Tropical cyclonic disturbances are classified as per the associated maximum sustained surface wind speed. The new terminology of the cyclonic disturbances in the Indian sea used in India Met. Department is as under :

Classification of the cyclonic disturbances in the Indian sea

System		*Wind Speed* (kts)
Low	(L)	Less than 17
Depression	(D)	17 to 27
Deep depression	(DD)	28 to 33
Cyclonic storm	(CS)	34 to 47
Severe cyclonic storm	(SCS)	48 to 63
Very severe cyclonic storm	(VSCS)	64 to 119
Super cyclone	(SC)	120 knots or more

The genesis of a tropical cyclone (TC) is from a low pressure area. But every low pressure area does not intensify into a TC. Tropical cyclone behaves as a "Rankine Vortex" for its initial development. However its further intensification, weakening and movement are observed to be guided by the dynamic and thermodynamic conditions in the interacting environment.

3. Cyclonic storms in the Arabian Sea

3.1. *Climatology of tropical cyclones in the Arabian Sea*

There were 214 cyclonic disturbances in Arabian Sea during the period 1890-1998, out of which 12 systems crossed Gujarat coast after recurvature. 8 out of these 12 systems have occurred since 1975. The western most longitude of recurvature is observed to be 61.0° E. The recurving cyclones generally have a speed of 15-20 kmph on 50% occasions and 10-15 kmph on 50% occasions. (India Met. Department 1996).

3.2. *Data*

Table 1 gives the list of the 8 cyclones that crossed Gujarat coast since 1976 and their tracks are given in Fig. 1. These systems can be classified as

(A) Systems that intensify after recurvature and cross coast as VSCS/SCS.

(B) Systems that do not intensify after recurvature or even weaken before crossing coast.

The very severe cyclonic storm during 5-9 June 1998 and cyclonic storm 11–17 October 1998 are presented below in detail as typical examples of (A) & (B).

3.3. *Very severe cyclonic storm in Arabian Sea during 5-9 June 1998*

A low pressure area formed over southeast Arabian Sea and adjoining Lakshadweep area on 2 June at 1200 UTC. It became well marked on 4 morning at 0300 UTC.

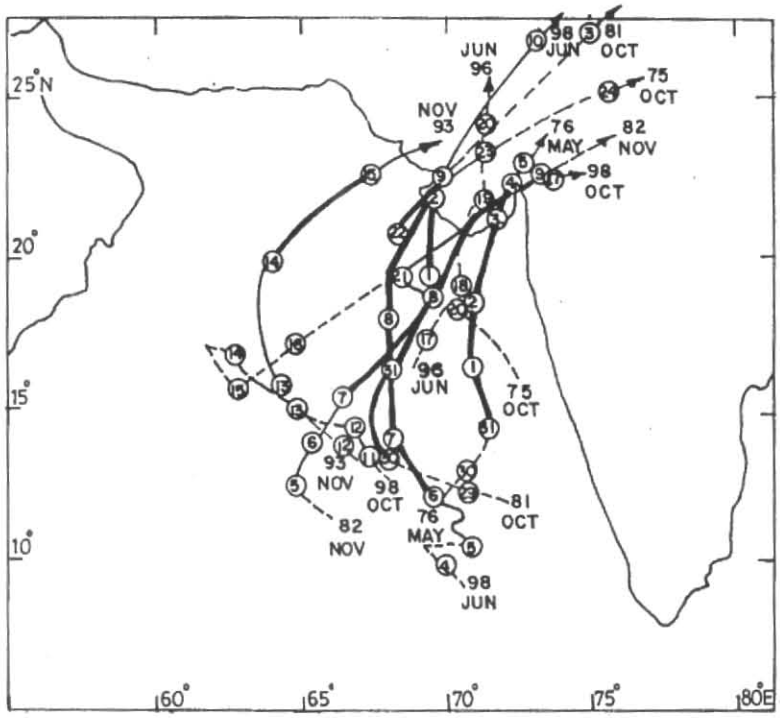


Fig. 1. Tracks of cyclone storm (1975-98) which moved/recurved towards Gujarat coast

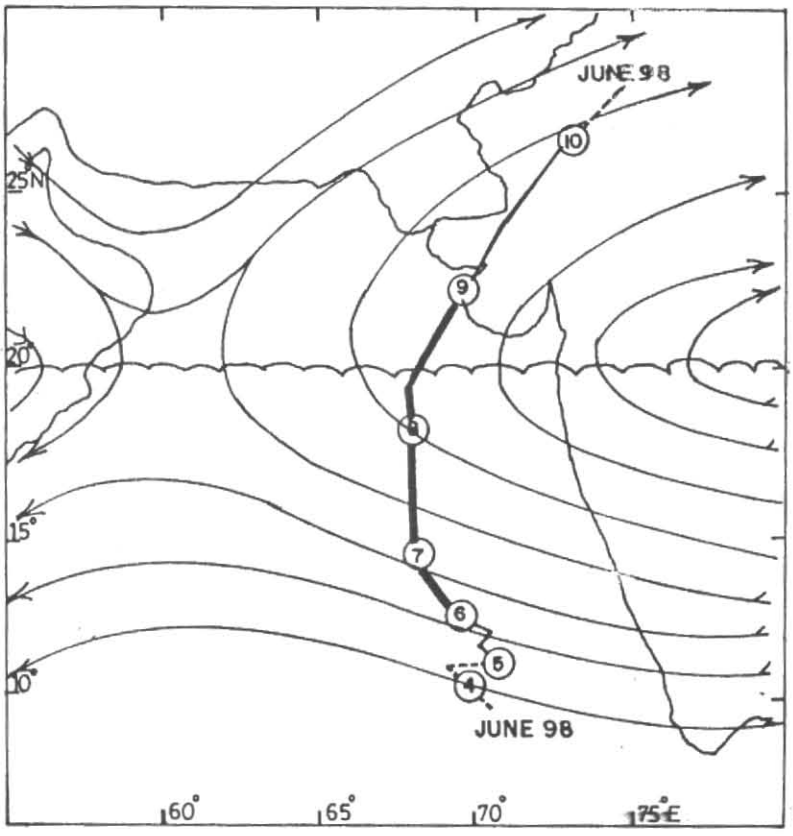


Fig. 2. Tracks of cyclone storm (June 1998) and the position of 200 hPa anticyclone during the period 6 June to 9 June

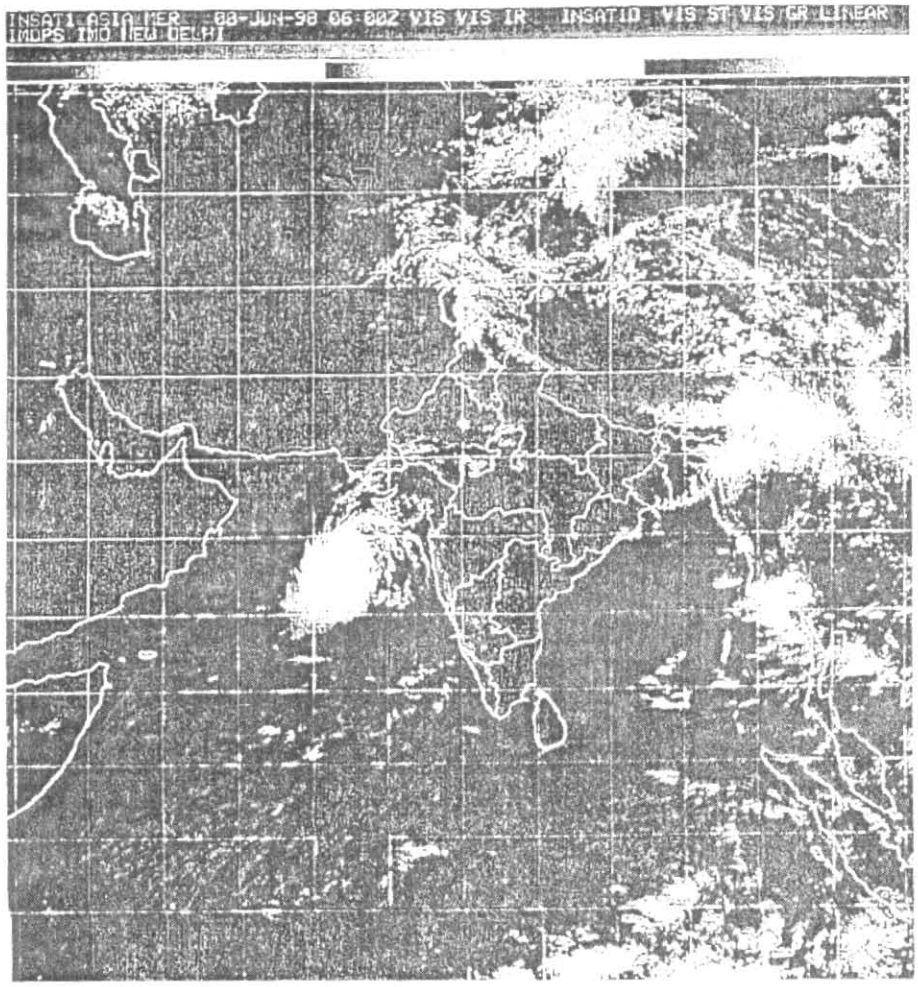


Fig. 3. INSAT imagery (vis) of 0600 UTC of 8 June 1998

It concentrated into a depression at 04/0600 UTC and into a deep depression near Latitude 11.0° N and Longitude 69.0° E at 04/1200 UTC. It further intensified into a cyclonic storm at 05/0900 UTC and was centred near Latitude 12.0° N and Longitude 70.5° E at 05/1200 UTC. At 06/0600 UTC it became severe cyclonic storm near Latitude 12.5° N and 69.5° E and was centered near Latitude 13.0° N and Longitude 69.0° E at 06/1200 UTC. The severe cyclonic storm further intensified into a very severe cyclonic storm near Latitude 16.0° N and Longitude 68.0° E at 07/1200 UTC. Moving northwards it was centered near Latitude 18.0° N and Longitude 68.0° E at 08/0300 UTC and near Latitude 19.5° N and Longitude 68.0° E at 08/1200 UTC.

Moving northeast, the Very Severe Cyclonic storm crossed Gujarat coast close to Porbandar between 09/0200 and 09/0300 UTC. It continued to be a very severe cyclonic storm at 09/0300 UTC about 50 km northeast of Porbandar. It continued its northeast-ward movement and weakened into a severe cyclonic storm at 09/1200 UTC, into a deep depression by 10/0300 UTC, into a depression at 10/0900 UTC and into a low pressure area by 10/1200 UTC over Punjab and neighbourhood.

Fig. 2 gives the track of the Very Severe Cyclonic storm. This system started showing northward movement from 07/0300 UTC and recurvature to northeast from 08/1200 UTC, under the influence of the western periphery of the 200 hPa anticyclone (Fig 2). It is also significant to note that the system continued as Very Severe Cyclonic storm after recurvature. Fig 3 is the satellite picture of the system at 08/0600 UTC, which clearly shows the presence of the very severe cyclonic storm. No other vortex is seen.

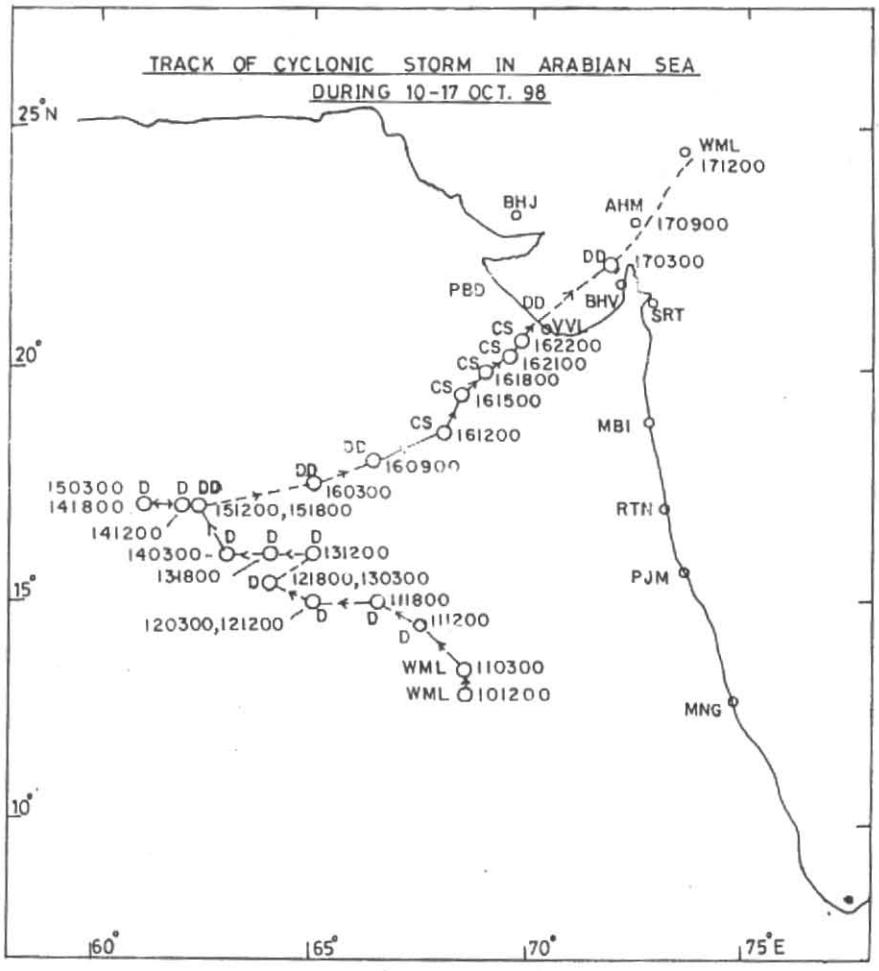


Fig. 4. Track of cyclonic storm in Arabian Sea during 10-17 October 1998

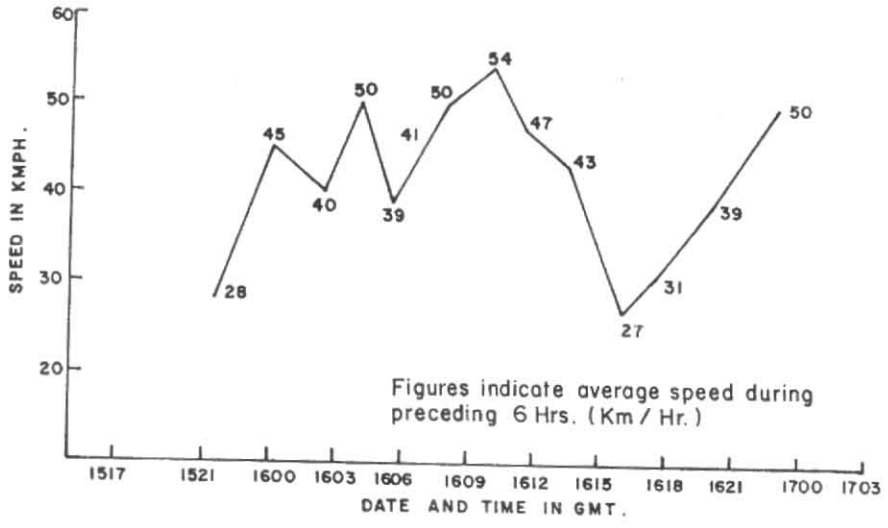
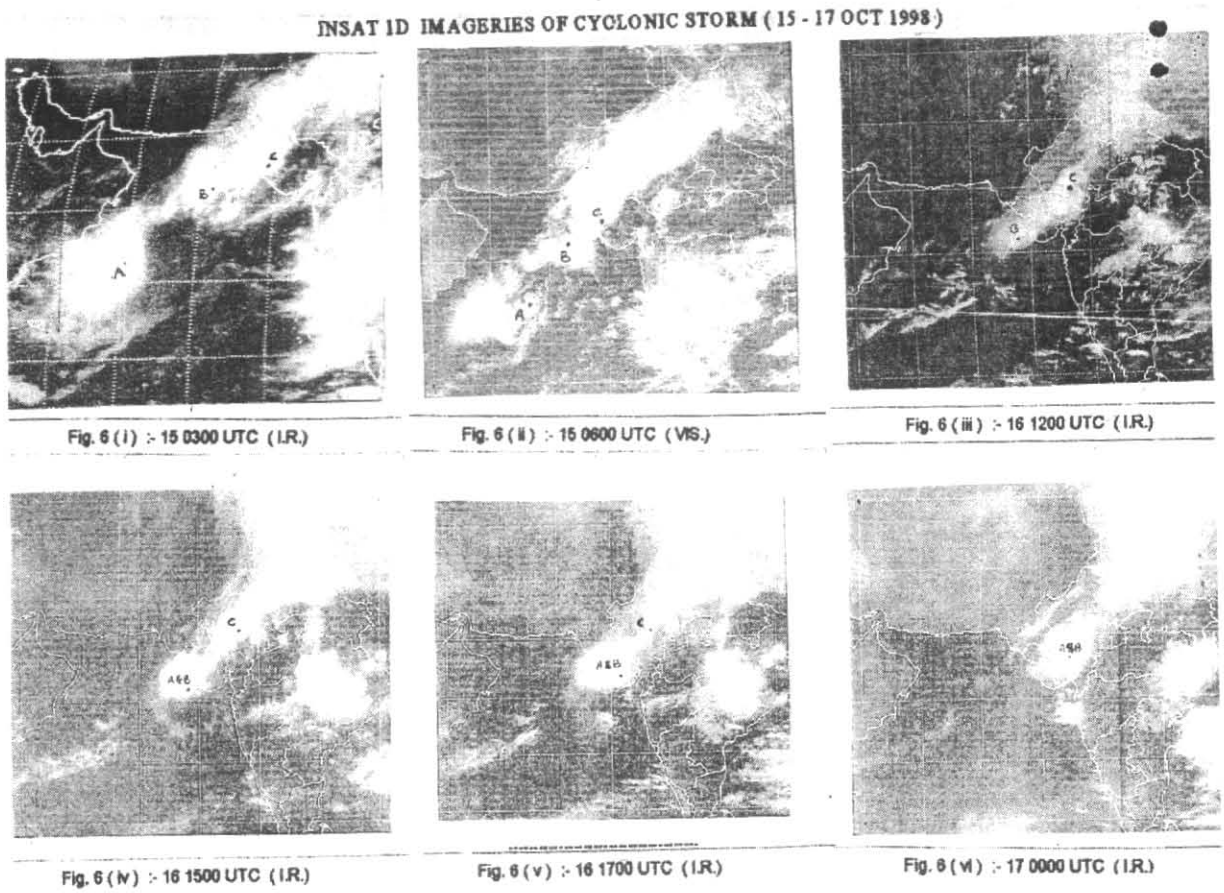


Fig. 5. Speed of movement



Figs. 6 (i-vi). INSAT-1D imageries of cyclonic storms (15-17 October 1998)

All the other 5 cyclonic storms (Sr.1,2,3,4,and 6 of Table 1) that intensified, recurved and crossed coast as SCS/VSCS were examined in detail. It was seen that the steering force in all the 5 cases was the western periphery of the upper level anticyclone. The above cases also showed that no other vortex was present simultaneously with the cyclonic storm.

3.4. *Cyclonic storm 11-17 October 1998 (marked as A in Figs. 6 to 10)*

A well-marked low pressure area formed over east central and adjoining southeast Arabian Sea on 10 October at 0300 UTC and intensified into a depression at 11/1200 UTC near Latitude 14.0° N and Longitude 67.5°E. The depression continued to move in a west/ northwest direction with a speed of 10 - 15 kmph till 15/0300 UTC when it was located near Latitude 16.0°N and Longitude 61.0° E. The track of the system is given in Fig. 4. The coastal observations of Masira in Saudi Arabia coast started reporting NE/15 knots at 15/0000 UTC being in the northwest periphery of the system. The satellite picture at 15/0300 UTC showed the clouding associated with the system covering coastal areas of Arabic Peninsula [Fig. 6(i)]. Till 15/0300 UTC the system was following climatological WNW/NW track with average speed of 15-20 kmph. It started moving in easterly direction and intensified into a deep depression at 15/1200 UTC near Latitude 17.0°N and Longitude 63.0°E. Continuing to move with a high speed of 30-50 kmph in east - north-easterly direction (Fig.5), the system intensified into a cyclonic storm at 16/1200 UTC near Latitude 18.5°N and Longitude 68.0° E. Subsequent behaviour of the cyclonic storm is given in section 3.4.1.

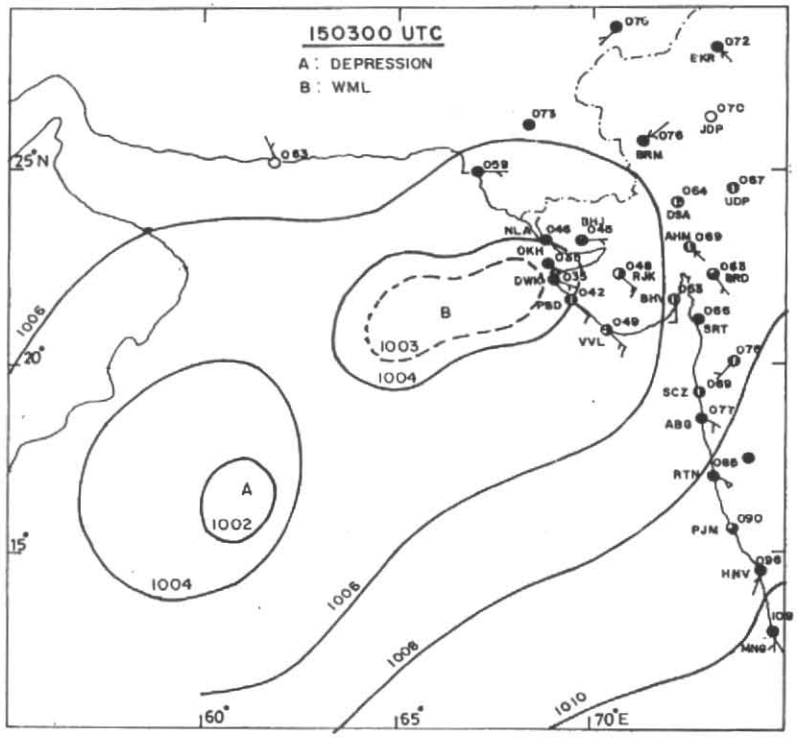


Fig. 7. Synoptic chart of 15/0300 UTC

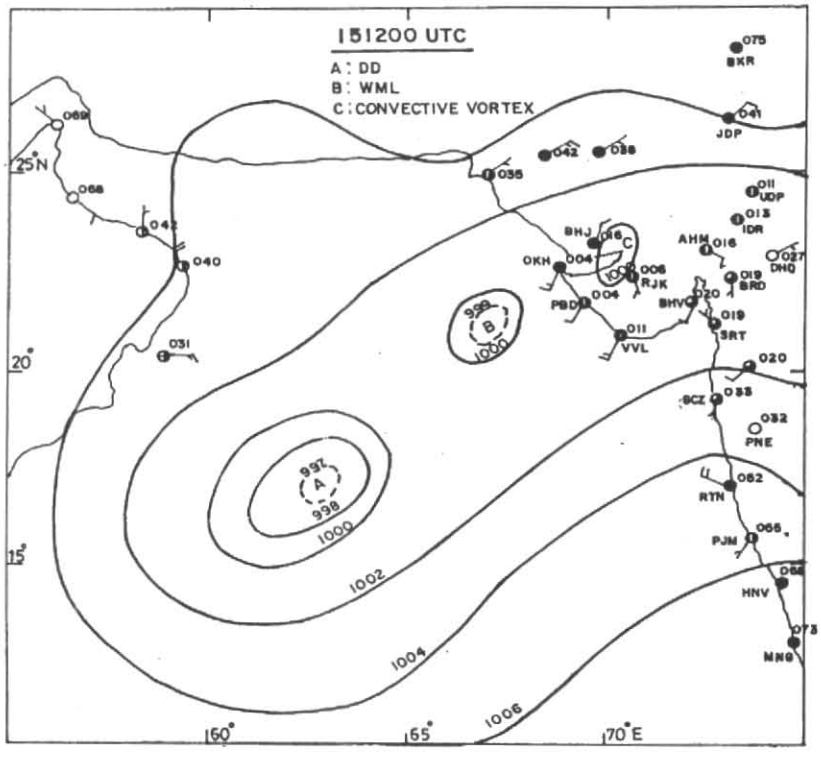


Fig. 8. Synoptic chart of 15/1200 UTC

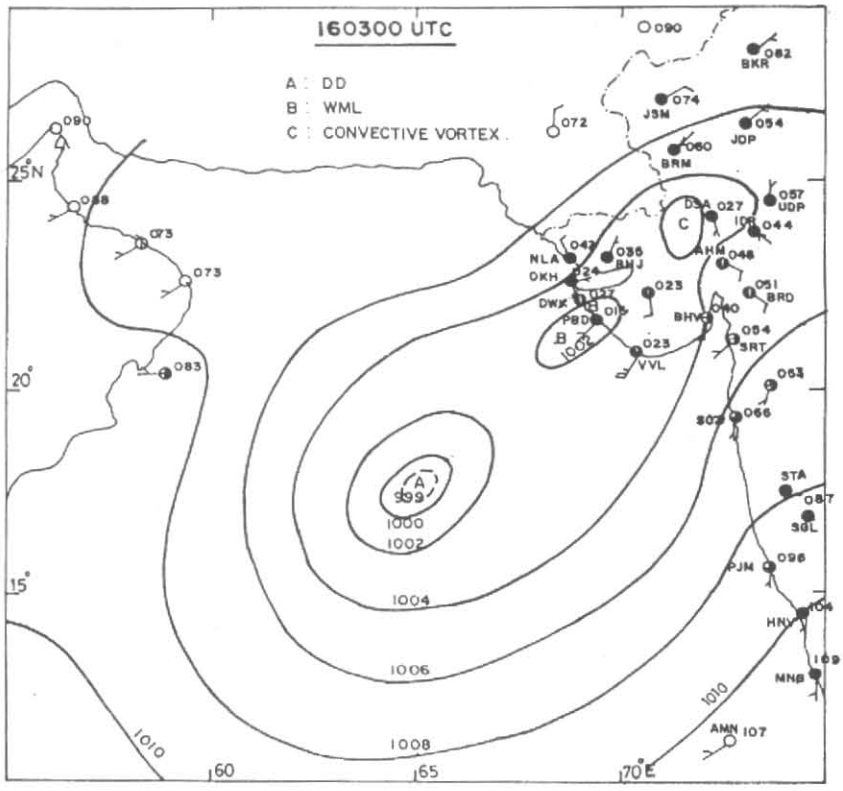


Fig. 9. Synoptic chart of 16/0300 UTC

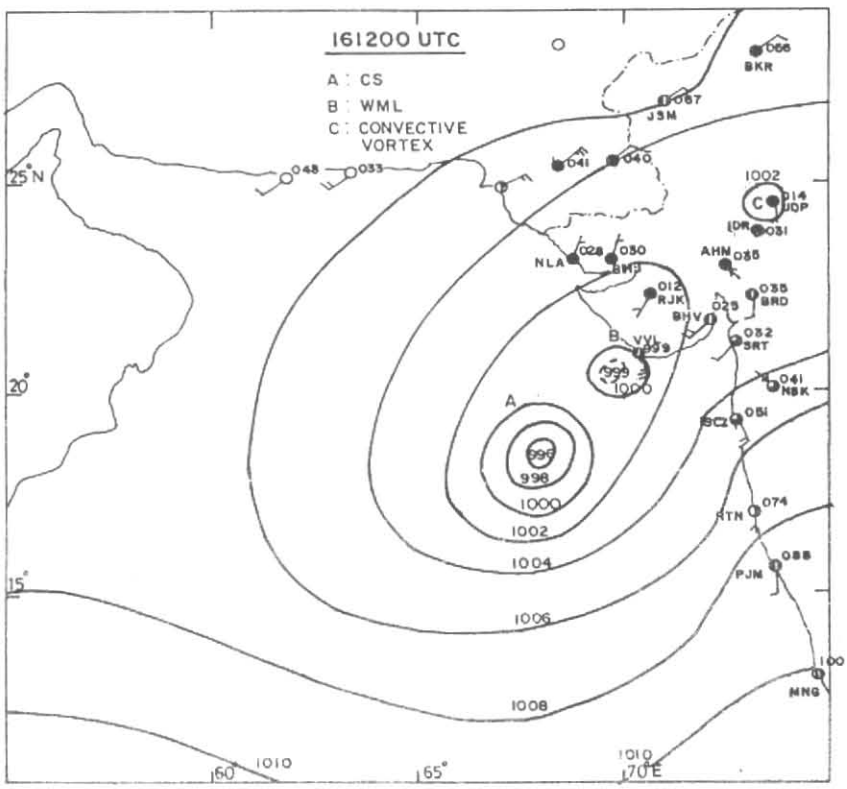


Fig.10. Synoptic chart of 16/1200 UTC

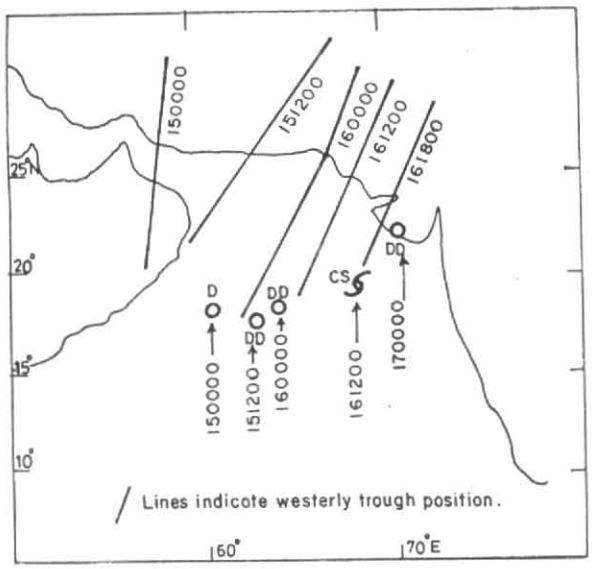


Fig. 11. Locations of westerly trough and October 1998 cyclone

3.4.1. *Presence of mesoscale convective vortex over Gulf of Kutch area during 15/0600 – 16/0000 UTC (marked as C in Figs. 6, 8, 9 and 10)*

As seen from the satellite picture of 15/0600 UTC [Fig.6(ii)] a small convective vortex was observed over Gulf of Kutch and adjoining Saurashtra and Kutch. This vortex was observed at 15/1200 UTC synoptic chart near Bhuj and adjoining areas of Saurashtra (Fig.8). The vortex moved inland and was located near Deesa at 16/0300 UTC (Fig.9) and near Udaipur at 16/1200 UTC (Fig.10) . The movement of this vortex resulted in northeast-southwest belt of heavy rainfall extending from Kutch and adjoining north Gujarat region even upto Himachal Pradesh.

3.4.2. *Presence of another synoptic scale vortex during 15/0300-16/1500 UTC (indicated as B in Figs. 5 to 10)*

As seen from the synoptic chart of 15/0300 UTC (Fig. 7) and the satellite picture of 15/0600 UTC [Fig.6(ii)], a well-marked low pressure area (WML) was located over northeast Arabian Sea off Saurashtra-Kutch coast as shown by pressure departure of –8.7 hPa at Okha at 15/0300 UTC. The well marked low pressure area persisted till 16/1200 UTC (Fig. 10) At the same time the cyclonic storm was located near Latitude 18.5° N and Longitude 68.0° E and was moving with a speed of 50 kmph and started approaching the WML. The cyclonic storm merged with the WML from 16/1600 UTC and maintained its intensity as a cyclonic storm.

3.4.3. *Behaviour of the cyclonic storm after combining with the WML*

The convection associated with the cyclonic storm was sheared to northeast and was located over land over Saurashtra at 16/1700 UTC [Fig. 6(v)] even though the main system continued to be over northeast Arabian Sea as cyclonic storm as per wind observation of Veraval of 16/1800 UTC of SSE/40 kts and ONGC rig M. Drill at 20.2°N/72.1°E reporting S/35-40 kts). The system started showing signs of weakening into a deep depression during 16/1800 & 16/2200 UTC (T=2.0 & C.I:2.5) with Veraval surface wind decreasing to S/25 kts at 16/2100 UTC from SSE/40 kts at 16/1800 UTC.

Hourly observations and veering of wind at Veraval to WNW/10 kts at 17/0000 UTC indicated that the system crossed coast as deep depression during 16/2300 & 17/0000 UTC. At 17/0300 UTC the system was seen as a depression near Ahmedabad. It weakened into a low pressure area over south Rajasthan and neighbourhood at 17/1200 UTC.

4. Atmospheric interactions

4.1. *Interaction between the three vortices*

From 15/0600 to 16/1200 UTC, it is seen that three vortices were simultaneously present and probably due to diversification of energy to the three systems, the cyclonic storm could not intensify further into a severe system.

4.2. *Interaction between the vortex and the environment*

Though the concept of upper level steering is one of the important factors considered in track prediction of tropical cyclones, it is seen in this study that the vortex moved eastwards under the influence of mid-tropospheric westerly trough, against the upper level, anticyclonic steering flow towards west. The location of the mid-tropospheric westerly trough from 15/0000 to 17/0000 UTC is given in Fig. 11.

Examination of the other severe cyclonic storm with core of hurricane winds SCS(CHW) during 12-16 November 1993 (Table 1, S.No. 5) also shows that this system weakened into a deep depression after recurvature before crossing coast due to the interaction with the westerly trough and sheering of convection to northeast of the system. Further as this system was an intense system SCS (CHW), the steering was by upper level environment.

5. Conclusions

Detailed examination of all the tropical cyclones in the Arabian Sea during 1976 - 98 show that

(*i*) Whenever more than one vortex is present, the systems do not intensify due to interaction between the vortices and the diversification of energy into more than one system. This is useful forecasting clue before issuing cyclone alert messages.

(*ii*) In case of the weak or marginal TC, the middle level (700-400 hPa) flow is the dominant steering mechanism. Steering and recurvature of such TC by middle level westerly trough to the west of the TC, leads to sheering of convection to northeast and hence weakening of TC into a deep depression or depression due to changing over of the TC structure from banding type/CDO type to shear type. In such situations there is a significant extension of rainfall belt in northeast direction extending upto even Punjab, Haryana and Himachal Pradesh. This also results in development of tongue of cold air over northwest India.

(*iii*) In the case of intense system (SCS/VSCS) upper level flow is the major steering force. In such cases, steering by upper level anticyclone leads to recurvature and further intensification of the system while steering by upper level westerly trough leads to recurvature but weakening of the SCS /VSCS to even a depression before crossing the coast.

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