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A preliminary study on the variability of post monsoon tropical cyclone activity over the north Indian Ocean

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सार – उत्तरी हिन्द महासागर पर मानसूनोत्तर (अक्तूबर-दिसम्बर) ऊष्णकटिबंधीय चक्रवात गतिविधि की अन्तःवार्षिक विभिन्नता से सम्बद्ध परिसंचरण विशेषताओं की जांच के लिए, सम्मिश्र पद्धित द्वारा दीर्घ तूफान गतिविधि और लघु तूफान गतिविधि की अवधियों के लिए समुद्र-सतह ताप विसंगति के ऊर्ध्वाधर पवन अपरूपण और मासिक (सितम्बर) मध्य चार्ट, 850 hPa (शत पास्कल) और 200 hPa पर प्रवाह विशेषताओं के दीर्घ अवधि मौसमी माध्य चार्ट निर्मित किए गए। यह पाया गया कि लघु तूफान गतिविधि की अवधियों के लिए प्रमुख परिसंचरण विशेषताएं हैं – 5° उ० के उत्तर 850 hPa पर आई टी सी जेड का अभाव क्षीण उपरिसतह उपउष्णकटिबंधीय पश्चिमाभिमुख 200 hPa रिज का दक्षिणाभिमुख हटाव अधिकांश सामुद्रिक क्षेत्र पर आपेक्षित बहुतर ऊर्ध्वाधर पवन अपरूपण सितम्बर के महीने के दौरान नकारात्मक समुद्र सतह ताप विसंगति भी तूफानों के निर्माण के लिए प्रतिकूल होती है।

इन परिसंचरण परिवर्तनों और समुद्र सतह ताप विसंगतियों के कारण के लिए एक परिकल्पना की गई है। मानसून परिसंचरण की तीव्रता के परिवर्तन के कारण समुद्र सतह ताप विसंगतियां विकसित होती हैं। समुद्र सतह ताप विसंगतियां बड़े पैमाने पर समुद्र वायुमंडलीय अन्योन्यक्रिया के द्वारा वायुमंडल को प्रभावित करती ह और इसलिए तूफान के विकास के लिए अनुकूल या प्रतिकूल वातावरण उत्पन्न करती है।

ABSTRACT. By the composite method, the long period seasonal mean charts of flow features at 850 hPa and 200 hPa, vertical wind shear and monthly (September) mean charts of SST anomaly for periods with large storm activity and small storm activity were constructed to examine the circulation features associated with interannual variability of post monsoon (October-December) tropical cyclone activity over the north Indian Ocean. It was found that the prominent circulation features for the periods with small storm activity are : Absence of ITCZ at 850 hPa north of 5°N, weaker upper level subtropical westerlies, southward shift of 200 hPa ridge and relatively larger vertical wind shear over most of the oceanic area. Negative SST anomalies during the month of September also tend to be unfavourable for the formation of storms.

A hypothesis is made for the causes of these circulation changes and SST anomalies. Changes in intensity of monsoon circulation cause to develop SST anomalies. These SST anomalies affect the atmosphere by large scale ocean-atmospheric interaction and thus creates an environment favourable or unfavourable for storm development.

1. Introduction

Annual frequency of tropical cyclonic storms (systems with maximum wind speed greater than 33 knots) in the north Indian Ocean is about six per cent of the annual frequency of tropical storms over the globe.

There are two seasons of cyclone formation in the north Indian Ocean. Post monsoon period (October-December) is the major period which accounts for 45% of annual total.

On an average about three cyclonic storms form over the north Indian Ocean during this three-month period. However, this number varies from year to year with coefficient of variation about 41%.

The interannual variation of tropical cyclone activity within each ocean basin is of great interest.

Several research studies concluded that the genesis frequency of tropical cyclones and cyclone paths are affected by the behaviour of the general circulation, in particular, by the abnormal characteristics of the centres of action of the atmosphere.

Namias (1954) emphasised the effect of large scale planetary waves on the genesis and paths of tropical cyclones through the creation of areas or conditions favourable or unfavourable for tropical storms.

Ding and Reiter (1980 a, b, c, 1981) discussed relationships between the large scale circulation patterns in the northern hemisphere and the variability in the formation frequency of tropical cyclones over the northwest Pacific and north Atlantic Oceans. It was found by them that the polar vortex, the planetary waves, the subtropical highs, the Tibetan high and Tropical Upper Tropospheric Trough (TUTT), the regime of the Indian summer monsoon, and Walker circulation were associated with the variability in typhoon frequency over the northwest Pacific and north Atlantic in different degrees of significance.

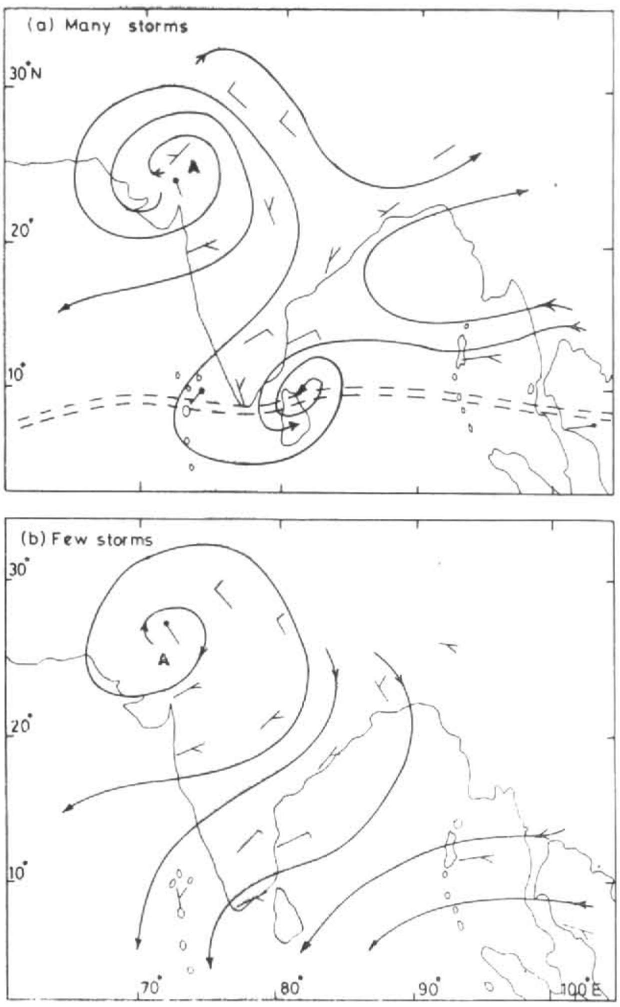

Fig. 1. Flow fields at 850 hPa for post monsoon season (a) for many storms and (b) for a few storms

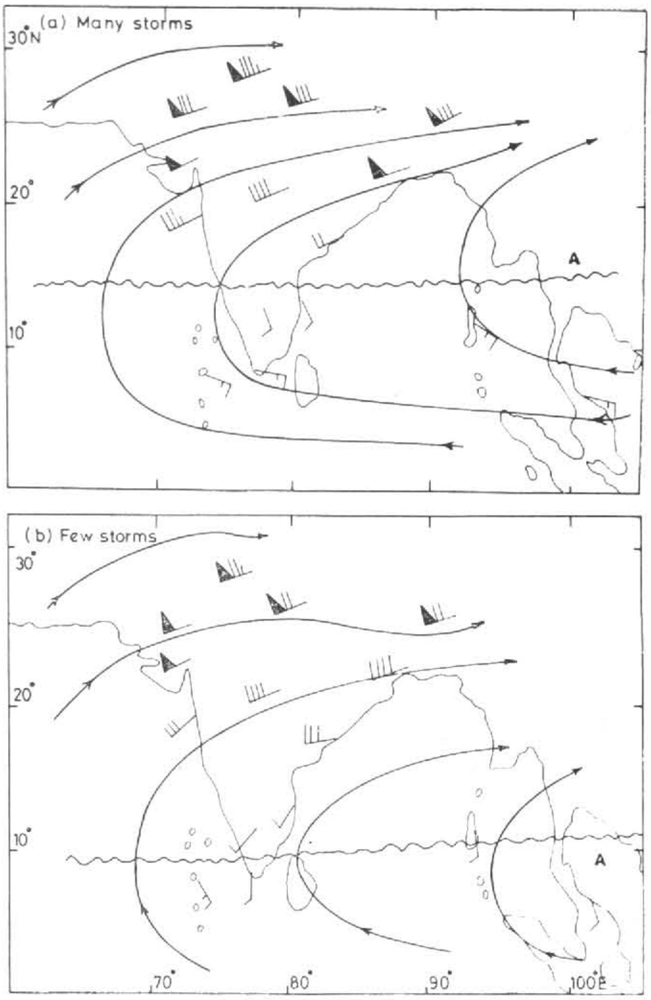

Fig. 2. Flow fields at 200 hPa for post monsoon season (a) for many storms and (b) for few storms

TABLE 1

The selected years with many storms and few storms

Many storms			Few storms		
Year	No. of storms	No. of storm days	Year	No. of storms	No. of storm days
1965	4	12	1961	0	0
1966	5	16	1970	3	7
1968	4	14	1974	1	3
1972	3	14	1979	2	2
1977	4	19	1980	3	4
Total	20	75		9	16

Gray (1977) in his paper on the genesis of tropical cyclones in the northwest Pacific, concluded that cyclone frequency although occurring on only a few days per season is, nevertheless, directly related to the large scale and long term shifts in the tropical general circulation and thermal energy content.

The relation between the frequency of tropical cyclone activity and sea surface temperature is also well documented (Takashi Aoki and Yashino 1984, Wendland 1977, Carlson 1971 and Nicholls 1984).

Shapiro (1982) using EOF analysis studied the relationships between large scale atmospheric circulation, SST and interannual incidence in the Atlantic basin.

The present study addresses the interannual variation of post monsoon tropical cyclone activity in north Indian Ocean in relation to changes in the atmospheric flow features over India and neighbourhood and SST anomalies over the north Indian Ocean and to the possible causes.

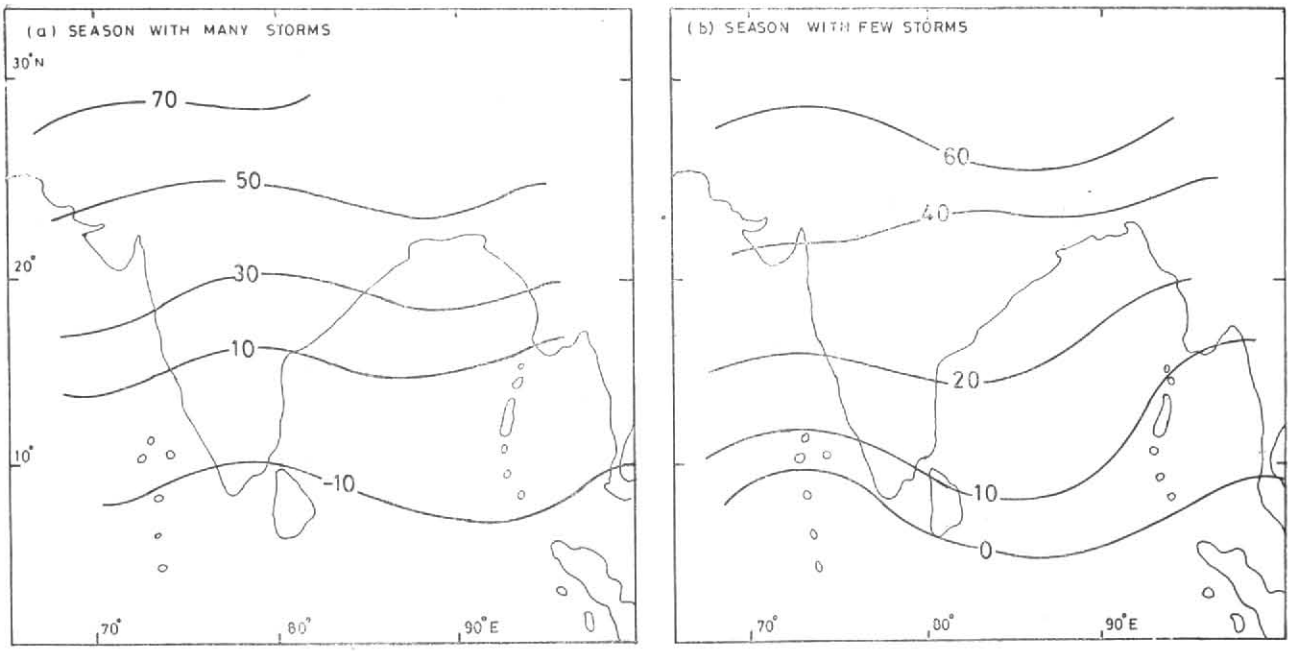

Fig. 3. Vertical wind shear (kt) of u component between 850 & 200 hPa. Negative shear indicates a stronger easterly wind at upper levels

2. Data and method of study

Monthly mean vector winds at 850 hPa and 200 hPa of 14 Indian stations and one Thailand station for the period 1961-1980 were taken from *"Monthly Climate Data for Indian Stations"* being published by India Met. Dep. and *"Monthly Climate Data for the World"* published by NOAA.

The list of stations considered is given below : (1) New Delhi (28° 34′ N, 77° 06′ E, (2) Jodhpur (26° 18′ N, 73° 01′ E), (3) Lucknow (26° 45′ N, 80° 53′ E), (4) Gauhati (26° 06′ N, 91° 35′ E), (5) Ahmedabad (23° 04′ N, 72° 37′ E), (6) Calcutta (22° 39′ N, 88° 26′ E), (7) Nagpur (21° 05′ N, 79° 02′ E), (8) Bombay (19° 05′ N, 72° 52′ E), (9) Visakhapatnam (17° 43′ N, 88° 13′ E), (10) Madras (12° 59′ N, 80° 10′ E), (11) Port Blair (11° 38′ N, 92° 44′ E), (12) Bangalore (12° 58′ N, 77° 35′ E), (13), Trivandrum (08° 28′ N, 76° 55′ E), (14) Minicoy (08° 18′ N, 73° 09′ E) and (15) Songkhla (07° 12′ N, 100° 36′ E).

Monthly sea surface temperature data of the north Indian Ocean averaged over a 5° × 5° square area for the period 1950-1980 was obtained from U.K. Met. Office.

The number of cyclonic storm days is taken mainly as a measure of storm activity of the season. A storm day is defined as a day when at 0300 GMT (0830 IST) a cyclonic storm was observed in the region. If two systems were observed at 0300 GMT on a particular day, such an occasion was counted as two storm days. The number of storm days and number of cyclonic storms in each season for the years before 1971 were taken from the *"Atlas of tracks of storms and depressions"* published by India Met. Dep. in 1979. These details for the years from 1971 were taken from post monsoon weather summaries being published by India Met. Dep.

Seasonal mean charts of 850 hPa and 200 hPa were constructed using the composite method for years with many and few tropical storms. Table 1 shows the cases selected from 20 years of data.

Five years with highest and lowest storm frequencies were chosen. According to Table 1, 30 months have been considered in the statistics which comprise half of all post monsoon months in the 20 years period 1961-1980. Thus resulting circulation patterns can be considered as typical.

Similarly composite charts of SST anomalies were prepared for the month of September (month prior to the storm season) for the years with more storms and with few storms. The years considered are for more storms : 1958, 1965, 1966, 1972, 1975, 1976 & 1978, and for few storms : 1953, 1954, 1956, 1957, 1961, 1974 & 1979.

3. Results

3.1. *Atmospheric flow features*

Figs. 1 (a & b) show the composite flow patterns at 850 hPa for post monsoon period with large and small storm activity. The most significant feature is the presence of ITCZ in Fig. 1 (a). Composite wind vector of Trivandrum, Minicoy and Songkhla clearly indicate the presence of the shear line roughly along 8° N in the composite chart for the period with large storm activity. From Fig. 1 (b) it can be inferred that either the shear line is shifted to lower latitude or it is not at all well marked.

Figs. 2 (a & b) show the composite flow patterns at 200 hPa for post monsoon lower period with large storm activity and small storm activity. Notable pattern

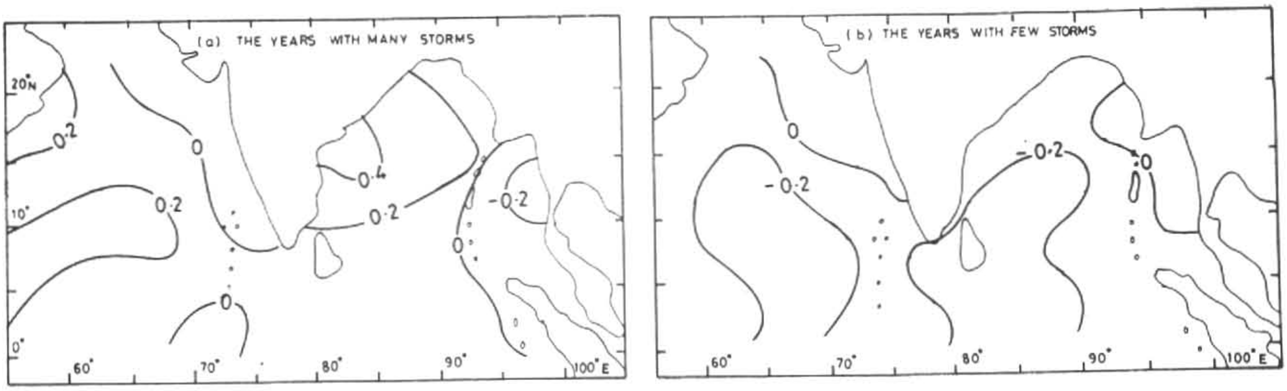

Fig. 4. The horizontal distribution of SST anomalies for September over north Indian Ocean: (a) for the years with many storms and (b) for the years with few storms

differences are the displacement of the subtropical ridge and strengthening of the subtropical westerlies. In the composite charts for the period with more storm activity the ridge is around 14° N and for the period with small storm activity the ridge is shifted southwards and is around 10° N. Such a southward shift allows a wider layer of westerlies to be established over the subtropics. Similarly, Figs. 2 (a & b) suggest the strengthening of the subtropical westerlies between 25° N and 30° N during the period of more storms.

Figs. 3 (a & b) indicate, that in seasons with small storm activity, a belt of stronger vertical wind shear (with magnitude more than 10 kt) between 200 and 850 hPa covers the oceanic area north of 8° N. The period with large storms activity reveals much reduced magnitudes.

3.2. *SST anomalies*

Figs. 4 (a & b) show the composite SST anomalies for the month of September for the years with large storm activity and small storm activity. For anomalies normals for each 5°×5° square grid was computed using the monthly SST data for 31 years (1950-1980).

Figs. 4 (a & b) suggest that there is a significant difference between anomalies in the years with large and small storm activity. During the years with large storm activity ocean is relatively warmer than the years with small storm activity. During the years with large storm activity, most of the Bay of Bengal and west Andaman Sea had positive SST anomalies, on the other hand during the years with small storm activity, most part of the ocean had negative anomalies of the order of —0. 2° C.

4. Discussion

Gray (1968), Malkus and Riehl (1960), Fisher (1958) discussed the important roles which low level relative vorticity, small magnitude of vertical shear of the horizontal wind, sea surface temperature and high magnitude ocean thermal energy play in determining regions of large tropical cyclone frequency. Later Gray (1977) directly related the seasonal tropical cyclone frequency to a combination of six physical parameters which are referred as primary genesis parameters.

In general, there is an agreement that a pre-existing disturbance over a warm ocean area located more than five-degree of latitude from the equator in a region of small vertical wind shear, through the troposphere, is necessary for tropical storm development. The large variability of tropical storms, year to year in an ocean basin, is to be related to the corresponding variability of these parameters about their climatological norms.

Presence of convergence zone over the ocean area gives necessary low level vorticity which is considered to be one of the important conditions for storm development. Figs. 1(a & b) clearly indicate the absence of shear line north of 5°N for the period with small storm activity and the presence of it for the period with large storm activity.

Similarly, Fig. 3(b) suggests the presence of relatively large vertical wind shear over the oceanic area, north of 10°N during the period with small storm activity. Large vertical wind shear indicate a large ventillation which in turn inhibits upper level enthalpy build up which is required for genesis. This large vertical shear is developed due to the southward shift of the upper level ridge, which in turn brings strong westerlies over the genesis area.

Thus it can be concluded in, general, that the absence of low level relative vorticity field (absence of ITCZ) north of 5°N and the presence of large vertical wind shear over the genesis area along with a cooler ocean which in turn provides less thermal energy, are the important possible causes for below normal activity over the north Indian Ocean during some years.

Recently Gray (1984) addressed to the causes in the general circulation which subsequently affect tropical cyclone activity. He found that *El Nino* event affects the hurricane activity over the Atlantic Ocean. He hypothesized that the decrease in activity is due to the anomalous increase in upper tropospheric westerly winds over the Caribbean and equatorial Atlantic.

Rajeevan (1989) found no significant relation with *El Nino* event and north Indian Ocean post monsoon cyclone activity. Thus SST anomalies and circulation pattern differences discussed in the earlier section cannot be attributed to *El Nino*/southern oscillation phenomenon.

But another hypothesis can be made on the basis of ocean-atmospheric interaction occurring on a seasonal scale over north Indian Ocean, as well documented by Joseph (1981, 1984, 1986). His studies showed that two consecutive monsoon failures warmed the entire north Indian Ocean. A poor monsoon produces a warm SSTs anomaly on account of weaker upwelling near the coasts of Somalia and Arabia, reduced wind mixing, reduced cloud cover and reduced evaporation. He found that significant correlation exists between Indian monsoon rainfall and SST during the post monson season. The net result of two consecutive monsoon failures will produce anomalously warm water in the north Indian Ocean to a depth of about 80 metres from the surface.

This anomalously warm equatorial water should activate the ITCZ and cause more liberation of heat of condensation. This additional heat of condensation will make the Hadley cell run faster than normal in the affected longitude sector. This variation in the strength of the Hadley circulation is transmitted to subtropical westerlies, to strengthen it by angular momentum transport. Fig. 2 (a) clearly indicates stronger westerlies during the period with large storm activity. This is well supported by the observational study of Bjerkness (1969).

In addition to this, the anomalous warm water is responsible for the formation of anomalous upper level easterlies over the warmer area and an anomalous anticyclone north of it. This is documented by Joseph (1981) and supported by numerical simulation studies by Julian and Chervin (1978) and Keshavamurty (1982). Anomalous upper level easterlies and anomalous anticyclone thus brought over the warm genesis area is responsible for low vertical shear, which is considered to be one of the important conditions for storm development.

On the other hand, the negative SST anomaly which is produced by strong monsoon due to stronger upwelling, stronger wind mixing, more clouding, does not activate ITCZ and causes anomalous upper level westerlies over the genesis area and increase the vertical wind shear.

5. Summary

Composite charts of 850 hPa, 200 hPa, vertical wind shear and SST anomaly revealed the following facts :

(*i*) During the period with large storm activity ITCZ is very much prominent and roughly along 8° N at 850 hPa whereas during the period with few storms, it is not seen at 850 hPa north of 5°N.

(*ii*) During the period with large storm activity, 200 hPa subtropical ridge is roughly along 14°N allowing wider layer of easterlies to be established equatorwards and during the period with small storm activity the ridge is shifted southwards and thus allowing wider layer of strong westerlies over the subtropics.

(*iii*) During the period with small storm activity relatively larger vertical wind shear persisted over most of the oceanic area. This large shear is due to the southward shift of the upper level ridge.

(*iv*) During the years with large storm activity, September month had positive SST anomalies which cover most of the ocean, whereas during the years with small storm activity, September month had negative anomalies.

Thus, the absence of a low level relative vorticity field (absence of ITCZ) north of 5° N and the presence of the large vertical shear over the genesis area among with a cooler ocean are the important possible causes for below normal storm activity over the north Indian Ocean during some years.

It is hypothesised that large ocean-atmospheric interaction occurring on a seasonal scale over the north Indian Ocean due to changes in monsoon activity, create an environment favourable or unfavourable for storm development.

The present study should be extended with more data to see the effects of planetary waves and other inter-hemispheric interactions.

After all, the utmost aim should be to understand the variability thoroughly and hence to develop a scheme (may be empirical) to forecast cyclone activity or threat, which can be utilised by State Government for prior planning of disaster management. The present study is far away from that goal.

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