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Satellite observed cloud distribution over the Indian Ocean during the southwest monsoon season

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सार—नोआ (एन० ओ० ए० ए०)-2 अन्तरिक्षयान की दृश्य एवं ताप अवरक्त चैनलों से प्राप्त मेघचित्रों की सहायता से सन् 1973 और 1974 के वर्षों की दो क्रमिक दक्षिणपश्चिमी मानसून ऋतुओं में हिन्दमहासागर के ऊपर मेघ वितरण का अध्ययन किया गया है। मेघ वितरण औसतन एक रोचक प्रारूप दर्शाता है और दक्षिण गोलार्द्ध में भूमध्यरेखीय द्रोंणी की स्थिति का निर्धारण करता है। इस ऋतु में कमजोर ऊष्ण-कटिबन्धीय विक्षोभ हिन्द महासागर के भूमध्यरेखीय क्षेत्र के निकट छा जाते है। ये खाहीन संवहनी मेघों के झुंड के रूप में दिखाई पड़ते हैं। अध्ययन से पता चला है कि भारत पर दक्षिणपश्चिमी मानसून की सक्रियता और दक्षिण गोलार्द्ध में भूमध्यरेखीय द्रोंणी में ऋणात्मक साहचर्य है। भारत के ऊपर दुर्बल मानसून के दौरान हिन्दमहासागर में भूमध्यरेखा एवं 10° द० अक्षांश के मध्य दक्षिण गोलार्द्ध में सक्रिय भूमध्यरेखीय द्रोंणी के साथ मिलकर संवहन तीव्र हो जाता है।

ABSTRACT. The cloud distribution over the Indian Ocean has been studied for the two consecutive southwest monsoon seasons of the years 1973 and 1974 with the help of cloud imagery received from NOAA-2 spacecraft in the visible and thermal infrared channels. The cloud distribution shows an interesting mean pattern and demarcates the position of Southern Hemispheric Equatorial Trough (SHET). Weak tropical disturbances which appear as amorphous convective cloud clusters are predominant in the near equatorial regions of the Indian Ocean in this season. The study reveals a negative association between the southwest monsoon activity over India and the intensity of SHET. During weak monsoon conditions over India there is intense convective activity over the Indian Ocean between equator and Lat. 10 S in association with active SHET.

1. Introduction

The existence of east-west oriented double convergence zones in the equatorial Indian Ocean during the southwest monsoon season over south Asia has been reported by several workers (Fletcher 1945; Flohn 1960; Koteswaram 1960; Raman 1965, etc). Hubert *et al.* (1969) computed seasonally averaged brightness from satellite observations during the period February 1967-February 1968 over the tropical belt and showed that Indian Ocean does not exhibit any double tropical convergence zone. Saha (1971) using APT cloud photographs relating to Indian Ocean for the period July 1966 through September 1970, concluded that double cloud bands associated with double Intertropical Convergence Zone (ITCZ) are of fairly frequent occurrence. Out of these two convergence zones, the one which lies over the Indian sub-continent during southwest monsoon season is commonly known as "Monsoon trough". The gradual shift of this trough to the north with the advance of the southwest monsoon and its intimate relation with the activity of the southwest monsoon over India is fairly well documented. But the convergence zone in the south Indian Ocean is not well understood mainly due to the lack of adequate meteorological observations over the ocean area. In the present paper the cloud distribution over the Indian Ocean north of 20 S for two consecutive southwest monsoon season, *i.e.*, 1973 and 1974 has been studied. Location of SHET is derived from the cloud distribution and its relationship with the activity of the southwest monsoon over the Indian subcontinent is discussed.

2. Data used and method of analysis

The basic cloud cover data were extracted from the daytime cloud imagery in the visible and thermal infrared channels, received from scanning radiometer sensors of the U.S. weather satellite NOAA-2. The average cloud distribution was derived from the satellite cloud imagery over the ocean area extending from Lat. 25 N to 20 S and Long. 40 E to 100 E. The ocean area was divided by a grid having latitude interval of 2 degrees and longitude interval of 5 degrees. The smaller latitude interval of 2 degrees was chosen in order to bring out the finer details of cloud distribution in the different latitude belts. The cloud cover was estimated from the daily satellite picture for each grid box. If more than 50 per cent of an individual grid area was covered with clouds the grid box was taken as cloudy, otherwise it was considered cloud free. As clouds occurring in the ITCZ are mainly convective in nature, the cloudiness has been divided into three types : (*i*) heavy cumulus and cumulonimbus, (*ii*) cumulus in combination with stratus and stratocumulus and (*iii*) cellular patterns. The percentage

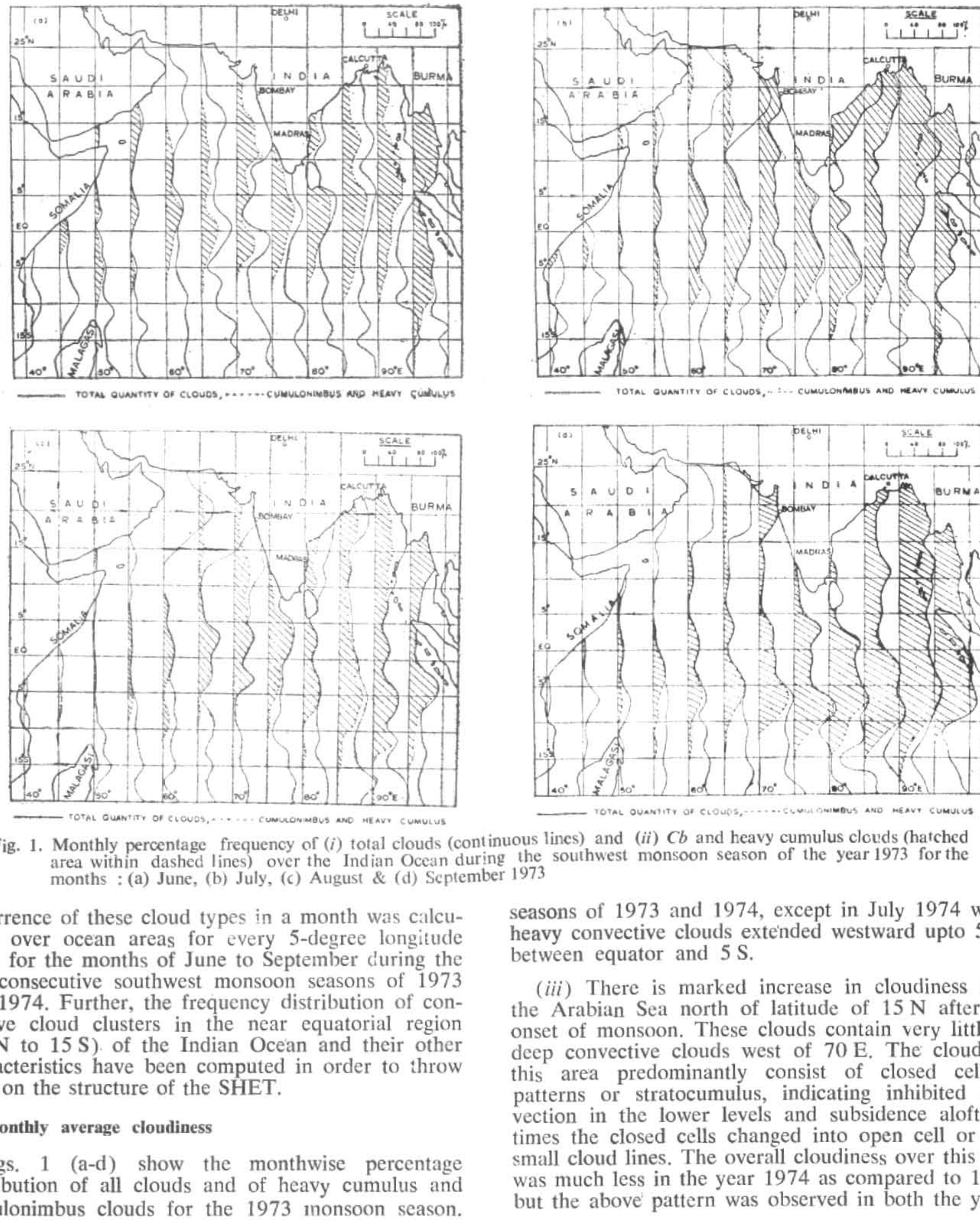

Fig. 1. Monthly percentage frequency of (*i*) total clouds (continuous lines) and (*ii*) *Cb* and heavy cumulus clouds (hatched area within dashed lines) over the Indian Ocean during the southwest monsoon season of the year 1973 for the months : (a) June, (b) July, (c) August & (d) September 1973

occurrence of these cloud types in a month was calculated over ocean areas for every 5-degree longitude strip, for the months of June to September during the two consecutive southwest monsoon seasons of 1973 and 1974. Further, the frequency distribution of convective cloud clusters in the near equatorial region (15 N to 15 S) of the Indian Ocean and their other characteristics have been computed in order to throw light on the structure of the SHET.

3. Monthly average cloudiness

Figs. 1 (a-d) show the monthwise percentage distribution of all clouds and of heavy cumulus and cumulonimbus clouds for the 1973 monsoon season. Significant features observed in these cloud distributions over the Indian Ocean during the monsoon seasons of 1973 and 1974 are summarized below:

(*i*) During the monsoon months, total cloud amount as well as the amount of heavy convective cloudiness (including *Cb*) increase from west to east on both sides of the equator. The heavy convective cloudiness is generally confined to ocean area north of latitude 10 S.

(*ii*) Little or no cloudiness was observed over the ocean area west of 60E throughout the monsoon seasons of 1973 and 1974, except in July 1974 when heavy convective clouds extended westward upto 50 E between equator and 5 S.

(*iii*) There is marked increase in cloudiness over the Arabian Sea north of latitude of 15 N after the onset of monsoon. These clouds contain very little of deep convective clouds west of 70 E. The clouds in this area predominantly consist of closed cellular patterns or stratocumulus, indicating inhibited convection in the lower levels and subsidence aloft. At times the closed cells changed into open cell or into small cloud lines. The overall cloudiness over this area was much less in the year 1974 as compared to 1973, but the above pattern was observed in both the years.

(*iv*) The total and the heavy convective cloudiness over the ocean area increase from June to July, decrease from July to August and again increase in September. The peak of convective activity occurs in July.

(*v*) South of equator, a prominent convective cloud maximum oriented in east-west direction occurs between 2 S and 9 S east of longitude 60 E, with an average position along 4 S, in association with SHET. Generally the western end of the axis of the cloud

TABLE 1

Frequency distribution of convective cloud clusters (size 12.5 degree² or greater) over the ocean area from Lats. 15°N-15° S, Longs. 40° E-100° E

Belt	No. of cloud cluster of shape: Amor-phous	Elong-ated (Band structure)	Quasi-circular	Vorti-cal	Total	Percent-age
(a) June-September 1973						
15°N-10°N	92	25	6	0	123	17.4
10°N-5°N	63	15	5	0	83	11.8
5°N-Eq.	89	20	8	1	118	16.7
Eq.-5°S	145	18	4	0	167	23.7
5°S-10°S	118	13	5	7	143	20.3
10°S-15°S	64	5	3	0	72	10.2
Total	571	96	31	8	706	100
Percentage	80.9	13.6	4.4	1.1	100	
(b) June-September 1974						
15°N-10°N	106	18	7	0	131	15.0
10°N-5°N	62	12	1	0	75	8.6
5°N-Eq.	85	18	0	0	103	11.8
Eq.-5°S	224	31	2	0	257	29.5
5°S-10°S	173	19	7	0	199	22.8
10°S-15°S	95	8	3	0	106	12.2
Total	745	106	20	0	871	100
Percentage	85.5	12.2	2.3	0	100	

maximum is tilted equatorward, and the eastern end dips southwards. This is observed prominently in September 1973 and July 1974. The ocean area west of 60 E is generally cloud free, hence the position of the trough in that area cannot be derived from the cloud field. Large day-to-day fluctuations occur in the position and the intensity of SHET.

(*vi*) In July 1974, the heavy convective clouds south of equator showed a marked increase as compared to the previous month. They also extended westward upto latitude 50 E along the western end of the axis of the cloud maximum. Both these features indicate a more vigorous convective activity in association with an active Southern Hemispheric Equatorial Trough (Mishra & Singh 1980).

(*vii*) A secondary cloud maximum is seen north of equator between 2 N and 5 N, east of longitude 60 E. Another cloud maximum exists over the north and adjoining central Bay of Bengal. In between these two cloud maxima north of equator there lies a cloud minimum around Lat. 10 N. The cloud minimum around 10 N and the maximum over the north Bay of Bengal have earlier been reported by Nene (1971).

4. Cloud system distribution

4.1. A pattern of cloud distribution over Indian Ocean during the southwest monsoon based on satellite imagery of the two monsoon seasons is presented in Fig. 2. The extreme western part of the ocean close to the coasts of Arabia and Africa between Lats. 25 N and 13 S is usually cloud-free. The rest of the ocean exhibits varied cloud systems with large day-to-day variations in their areal extent and locations, related to various intensities of convection. The characteristics and distributions of the main cloud systems are discussed below.

4.2. *Convective cloud clusters*

Heavy convective clouds, *viz.*, cumulonimbus, large cumulus and their combinations, occur in the monsoon season over the Indian Ocean north of Lat. 13 S. Convective cloud clusters characterized by deep layer convection during some part of their lives, occur around the SHET and over the ocean area towards its north except for the north and west Arabian Sea. Both convective cloud clusters and cumulus cloud lines occur in the zonal belt between SHET and 13 S. A transition from cellular pattern to cumulus lines takes place at the southern boundary of this zonal belt, and from cumulus lines to convective clusters at its northern boundary. Just north of 13 S the convective clouds appear as cumulus lines generally aligned along with southeast trade winds, the individual cloud elements having larger size and more intense convection towards the SHET. The cumulus lines are generally oriented from southeast towards northwest, turning towards north or northeast near the SHET.

These cloud clusters, being associated with enhanced convection, play an important role in the transport of sensible and latent heat from ocean to the atmosphere. A frequency distribution of the cloud clusters having area equal to one-half of a 5-degree latitude square or greater, for 5-degree latitude belts in the ocean area bounded by Lats. 15 N-15 S, Longs. 40-100 E is presented in Table 1 (a & b) for the two monsoon seasons. The minimum area chosen here approximates to the area of the smallest synoptic scale disturbances. The clusters have been divided into 4 broad types after Barret (1971), depending upon their shape and organization, *viz.*, (*i*) amorphous, (*ii*) elongated or band type, (*iii*) quasi-circular clusters associated with weak cyclonic circulation and (*iv*) vortical clusters distinctly indicating a cyclonic circulation. The amorphous and elongated clusters do not have any closed circulation associated with them.

In both the years more than 80 per cent clusters were of amorphous type alone, indicating that both to the north and south of equator weak tropical disturbances are predominant in this season. Elongated convective clusters with band-type structures come next with 12-14 per cent occurrence. Well-organised vortices and tropical cyclonic storms are almost rare. The zonal distribution of convective clusters shows a maximum in the latitude belt equator to 5 S, which corresponds to the Southern Hemispheric Equatorial Trough (SHET). This cloud distribution agrees with the location of the near equatorial ridge in the sea surface temperature (SST) distribution. An examination of the SST normals for the Indian Ocean (Hasternath & Lamb 1979) shows that during the monsoon

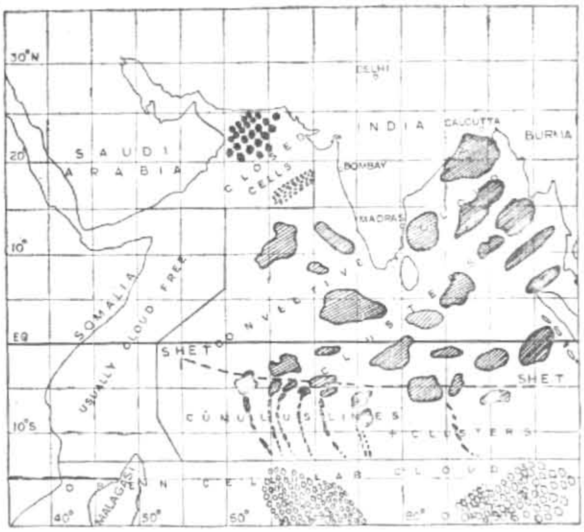

Fig. 2. Cloud systems distribution during southwest monsoon seasons for the years 1973 and 1974

TABLE 2

Comparison between areal coverages of convective cloud clusters over the south Indian Ocean (Lats. 0°-10° S, Longs. 40°-100°E) during periods of active monsoon (1-20 July 1973) and weak monsoon (16-27 July 1974) in units of 1° Lat. × 1° Long. squares

Coverage of cloud clusters (deg²)	During active monsoon (1-20 July 1973)	During weak monsoon (16-27 July 1974)
Average area	25.3	155.7
Range	12-42	75-210

TABLE 3

Daily variation of areal coverage of convective cloud clusters in SHET with the daily rainfall over five stations at the west coast of India for the period 9-30 July 1974

Date (July 1974)	Areal coverage*	Rainfall (mm)				
		Bombay	Ratnagiri	Panjim	Honavar	Manglore
9	46	39	77	181	118	163
10	47	84	37	49	56	31
11	33	49	33	17	23	8
12	128	107	24	7	25	8
13	113	34	tr	2	tr	9
14	80	1	5	8	0	6
15	115	5	13	4	69	11
16	150	1	1	8	13	23
17	167	tr	4	8	21	4
18	160	1	9	1	4	4
19	175	1	0	5	0	3
20	184	6	0	1	0	2
21	197	0	1	1	8	2
22	129	1	17	3	19	90
23	170	4	0	25	130	49
24	179	tr	61	40	14	12
25	210	2	0	55	52	93
26	155	tr	1	0	60	29
27	93	0	6	29	139	61
28	53	7	33	18	26	52
29	48	4	5	84	—	37
30	35	41	47	23	46	90

*Of convective clusters in deg² (Unit 1° Lat. × 1° Long.)

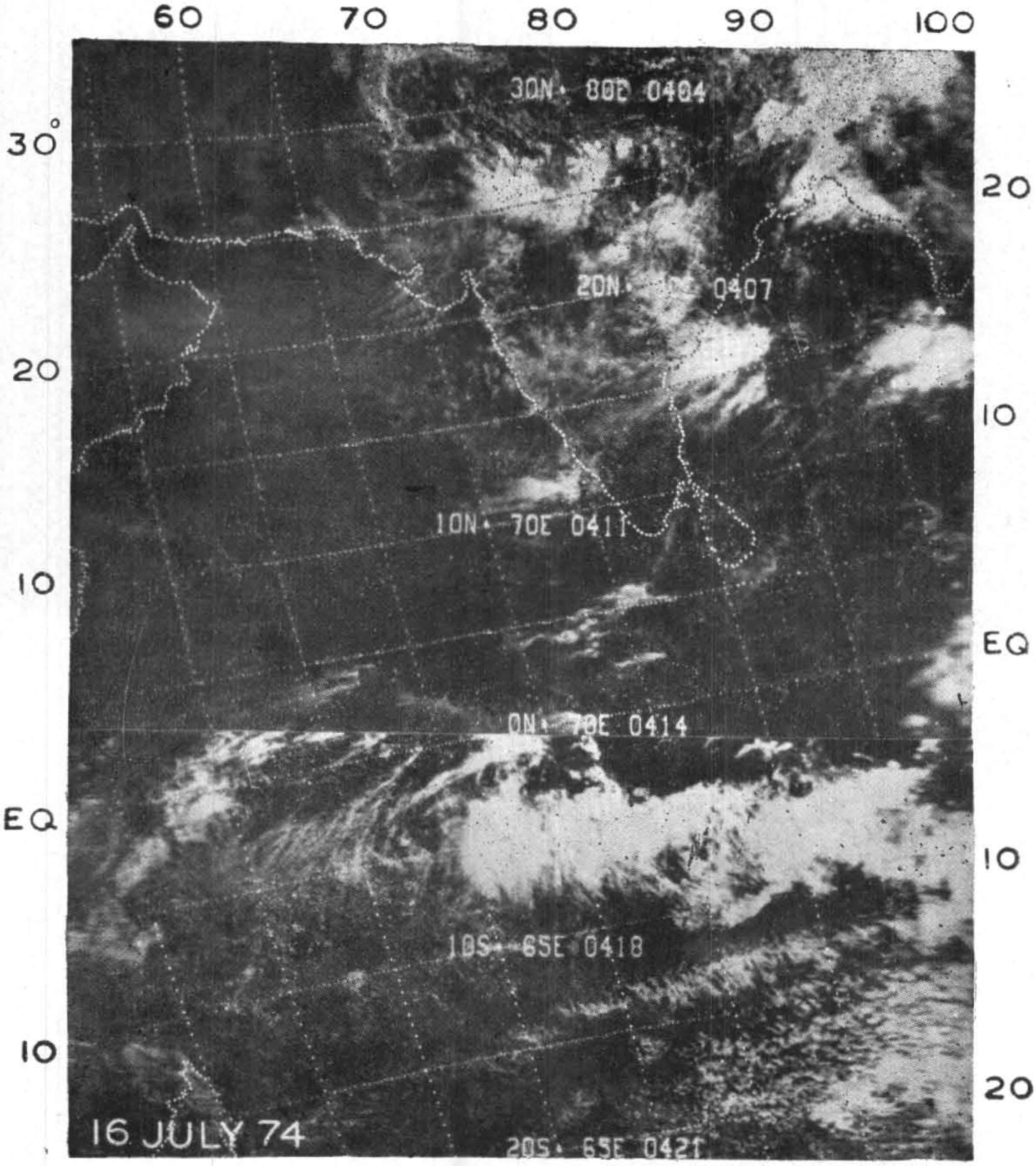

Fig. 3. NOAA-2 daytime visible channel imagery of 16 July 1974 during the period of break monsoon showing the closed cellular clouds over the north Arabian Sea extending upto the west coast of India

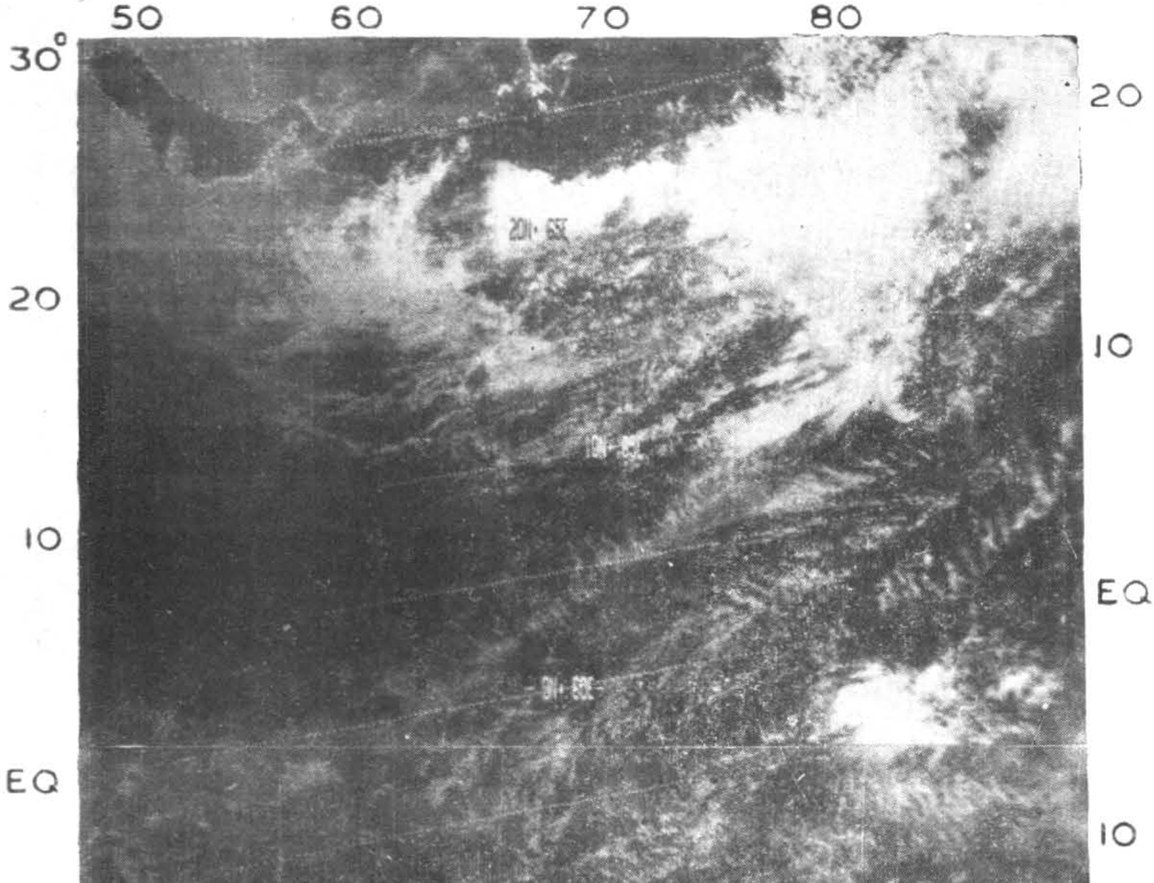

Fig. 4. NOAA-2 daytime visible channel imagery of 8 July 1973 showing active monsoon over India and weak convection south of the equator

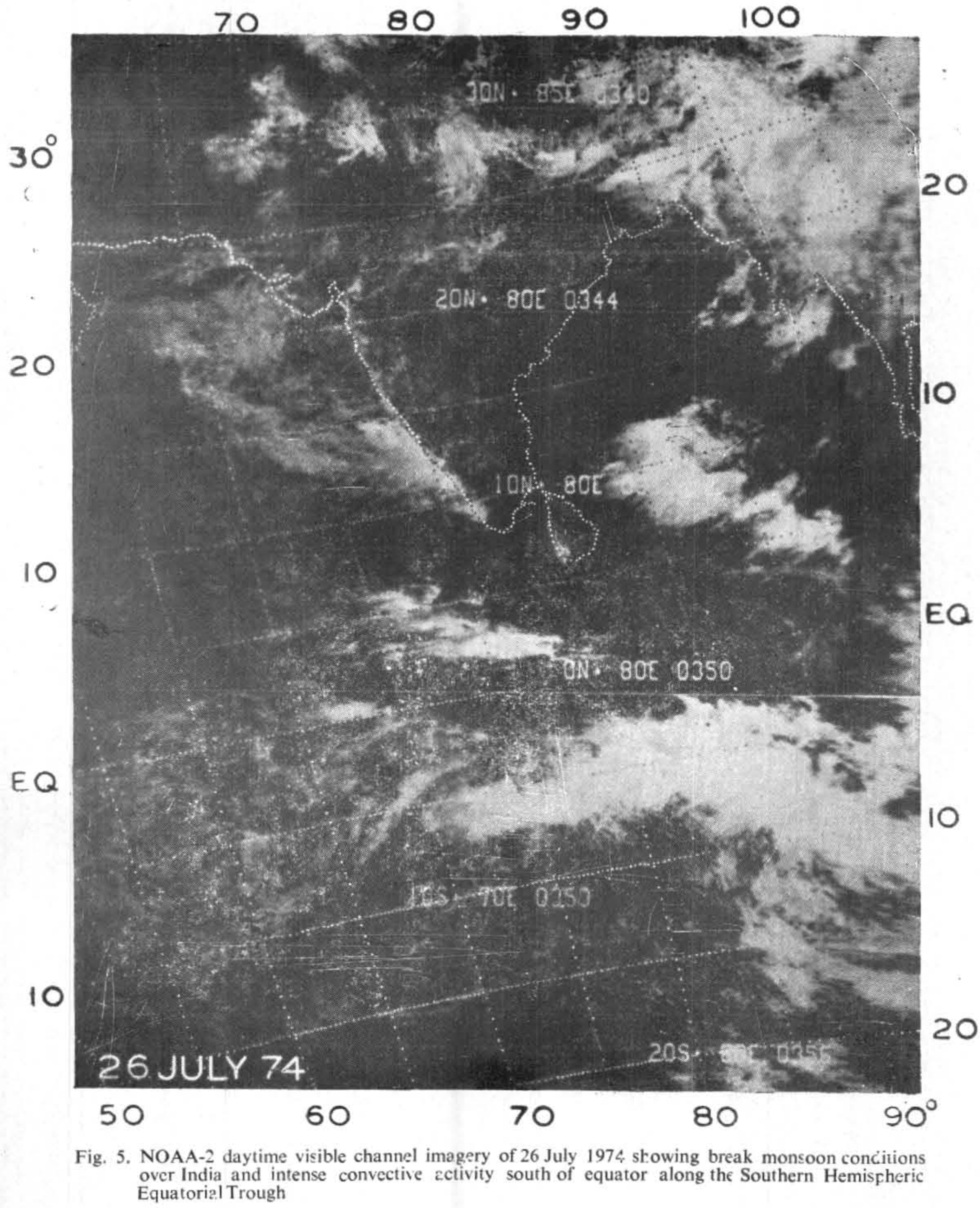

Fig. 5. NOAA-2 daytime visible channel imagery of 26 July 1974 showing break monsoon conditions over India and intense convective activity south of equator along the Southern Hemispheric Equatorial Trough

months (July to September) the SST ridge lies around the equator with warm waters having temperatures greater than 28 deg. C lying east of Long. 60 E in the region of the convective cloud maximum. This warm ocean surface causes increased evaporation and enhanced convection so that heavy convective clouds occur generally to the east of 60 E (para 3 above).

4.3. *Open cellular clouds*

Open cellular patterns were predominant over the ocean area south of Lat. 13 S during the northern summer monsoon season. These open cells were more pronounced in the wake of cold frontal bands associated with mid-latitude disturbances in the south Indian Ocean. They result from the outbreak of cold air behind an eastward moving frontal zone due to the advance of this cold air over the relatively warmer ocean surface below. They were generally aligned in the SE-NW direction.

4.4. *Closed cellular clouds*

Closed cellular patterns were predominant over the Arabian Sea north of Lat. 16 N west of Long. 70 E, during the southwest monsoon season. Mostly the closed cells are aligned in a SW-NE direction with individual cloud cells increasing in size and intensity eastward, indicating a southwesterly flow in the planetary boundary layer. The closed cellular pattern extends upto the west coast of India during periods of a week or break monsoon, as seen in the NOAA-2 visible channel imagery of 16 July 1974 (Fig. 3). Closed cells represent a weak air-sea temperature contrast and a pronounced and persistent inversion (Agee & Chen 1973). The appearance of closed cells over the Arabian Sea are, therefore, the result of the existence of the inversions over west Arabian Sea during the monsoon season.

5. Relationship between oceanic cloud distribution asd monsoon activity over India

5.1. The inter-annual differences in the extent and frequency of the total and heavy convective cloudiness in the near equatorial Indian Ocean during 1973 and 1974 can be related to variations in the activity of southwest monsoon over India. The year 1973 had a good monsoon season, and whole of India except coastal Andhra Pradesh received normal or excess rainfall. As against this, the year 1974 had a poor monsoon season and nearly half of the country including most of the central and northwest India received deficient or scanty rainfall. A comparison of the monsoon rainfall distributions during these years with the respective cloud distributions shows that in the year 1973 when the monsoon was good, the heavy convective cloudiness south of equator was much less and the SHET was less marked as compared to that in the poor monsoon year 1974. Also Table 1 shows that in the year 1974 the convective cloud clusters decreased in the ocean areas north of equator and increased to the south of the equator, as compared to the year 1973. The heavy convective cloudiness increased significantly in the latitude belt Equator-10 S during the months of June and July 1974 when the monsoon activity over India was poor. During these months, the onset of southwest monsoon was delayed by 10-15 days over several parts of India and the entire country could come under the monsoon only by 16 July 1974. Also, weak monsoon conditions prevailed over the Peninsula in the first half of June 1974 and over most of the country in the second half of July. This suggests an inverse relationship between the convective cloudiness in the SHET and the southwest monsoon activity over India.

5.2. A comparison of daily areal coverages of convective cloud clusters in the region of SHET (*i.e.,* the ocean area covered by Lats. 0-15 S and Longs. 40-100 E) during the periods of active monsoon and weak monsoon over India brings out a sharp contrast in the convective activity in SHET associated with these two conditions. For this purpose, a period of active monsoon over most of the country from 1 to 20 July 1973 is compared with a weak monsoon period from 16 to 27 July 1974 (Table 2). The average area of convective cloud clusters in SHET was only 4 per cent of the total area during the active monsoon period, as compared to about 26 per cent during the weak monsoon. The intense convection in SHET thus increased more than 6 times during the weak monsoon period, as compared to good monsoon period over India. The NOAA-2 visible channel cloud imagery of 8 July 1973 (Fig. 4) shows typical cloud distribution during active monsoon over India, with dense convective and multilayer clouds over the Peninsula and Bay of Bengal, and generally weak convection south of equator. The cloud picture of 26 July 1974 (Fig. 5) during break monsoon period shows large convective cloud clusters within the active SHET aligned into long broken bands in west-east direction, and very little intense convection north of equator.

5.3. Changes in the areal coverage of convective clusters in SHET also appear to be inversely related to the rainfall over the west coast of India. For the weak monsoon period, 16-29 July 1974, the abrupt increase in the area of the cloud clusters in SHET on

12th corresponds to sharp decrease in rainfall over the west coast between 11 and 14 July (Table 3), which was followed by the setting in of weak monsoon conditions over the major parts of the country by 16 July. Similarly the large decrease in area of convective clusters around 27 July corresponds to increase in the coastal rainfall during 22-30 July, and the revival of monsoon activity at the end of the last week of July 1974. This again supports the negative association between the monsoon activity over India and the intensity of SHET.

5.4. During the period of weak monsoon over India as the dense convective cloudiness decreased north of the equator, the closed cellular patterns covered a larger area over the Arabian Sea. At times these closed cells extended over the central Arabian Sea and upto the west coast of the Peninsula, replacing the convective clusters.

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