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A study of sea surface pressure (SSP), sea surface temperature (SST) and cloudiness patterns over Indian Ocean region in some years of contrasting southwest monsoon rainfall in India : Part II

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सार — सन् 1961, 1964, 1965 और 1966 वर्ष के समुद्री वार्षिक सार में दिए गए आंकड़ों की सहायता से हिन्द महासागर (15° द० के उत्तर और 40° पू० एवं 100° पू०) पर विभिन्न महीनों में समुद्री सतह दाब (स० स० दा०), समुद्री सतह तापमान (स० स० ता०) के स्वरूप और मेघाच्छन्नता के बंटन का अध्ययन किया गया है। अप्रैल और मई में मेघाच्छन्नता के प्रमुख क्षेत्र तापीय रिज अक्ष क दक्षिण में और कोष्ण समुद्र पर 65° पू० देशान्तर के पूर्व में होते हैं। अच्छे मानसून वाले वर्षों में जून, जुलाई और अगस्त के महीनों में प्रमुख मेघाच्छन्नता की एक पट्टी बंगाल की खाड़ी और 65° पू० के पूर्व में अरब सागर में प्रबल रहती है लेकिन खराब मानसून वाले वर्षों में दो अलग-अलग पट्टियां एक उत्तरी अक्षांशों में और दूसरी भूमध्यसागर की ओर जाती हुई कम मेघाच्छन्नता को दर्शाती प्रतीत होती है। खराब मानसून वाले वर्षों में जब केवल एक ही पट्टी होती है तब सितम्बर मास में स्थिति ठीक इसकी उल्टी हो जाती है।

ABSTRACT. A study is made of the sea surface pressure (SSP) and sea su face temperature (SST) patterns and distribution of cloudiness for different months over Indian Ocean (north of 15° S and between 40° E and 100° E) with the help of *Marine annual summary data* for the years 1961, 1964, 1965 and 1966. In April and May the area of major cloudiness lies to the south of the thermal ridge exis and east of 65° E longitude over warm sea. In the months of June, July and August of good monsoon years, only one belt of major cloudiness lying over Bay of Bengal and Arabian Sea east of 65° E is prominent, whereas in bad monsoon years two distinct belts, one lying in the nothern latitudes and the other running along equatorial ocean with interlying region of lesser cloudiness are observed. The reverse happens in the month of September when only one belt is observed in bad monsoon years.

1. Introduction

Ranjit Singh (1980) studied the sea surface temperature and pressure patterns for different months over Indian Ocean (north of 15° S and between 40°E and 100°E) with the help of *Marine annual summary data* for 17 areas (as given in the Fig. 1 of that paper) published by India Meteorological Department for the years 1961, 1964, 1965 and 1966 (that paper hereafter referred to as Part I). It was shown that (1) The zone of warmest sea surface waters during the months of April and May was observed to be located northward in the years 1961 and 1964 (the years of good monsoon over India) as compared to 1965 and 1966 (the years of bad monsoon over India). The values of SST were also higher for most of the oceanic areas in the years 1961 and 1964 as compared to 1965 and 1966 during these months. (2) Well defined pressure patterns with isobars 1008 and 1009 mb encircling and pressure gradient directed towards the Indian Peninsula were observed during the month of April in 1961 and 1964 but in 1965 these features in pressure patterns were absent. The pressure values were also generally found to be lower in most of oceanic areas during the monsoon months in 1961 and 1964 as compared to those of 1965 and 1966. They were in particular lower over Arabian Sea during the month of April. (3) A general fall of SST values ranging from 1° to 3°C was observed after May during the monsoon months in most of the oceanic areas and this was ascribed due to evaporative cooling.

In the present paper the study is continued with the cloudiness distribution patterns for the months April to September for the groups of years of contrasting monsoon rainfall over India with a view to identify the difference in the oraganisation of their mean patterns and whether such difference in pattern could be helpful for a better understanding of the southwest monsoon and for an advance prediction of good and bad monsoon rainfall over India. Cloudiness patterns for October

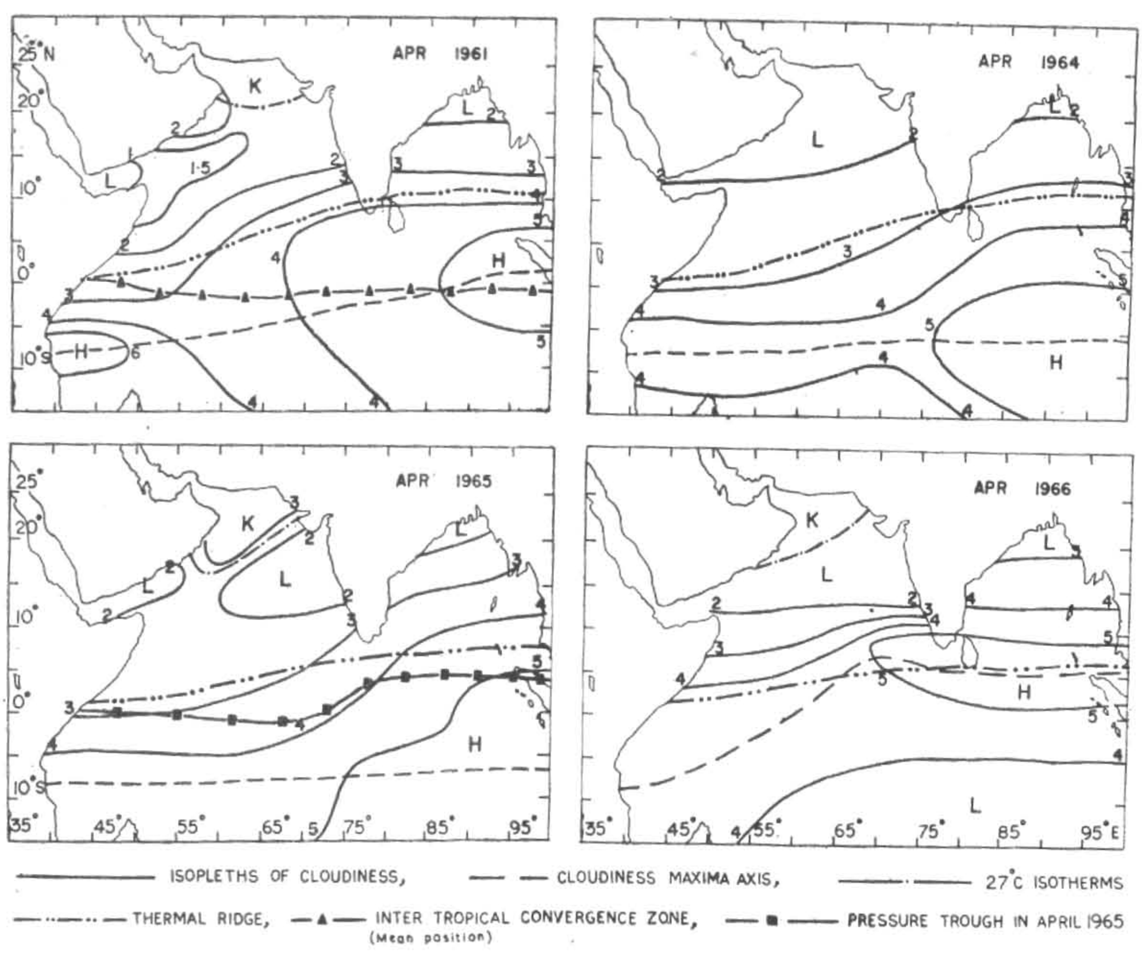

Fig. 1 (a). Distribution of cloudiness for the contrasting years of 1961, 1964 and 1965, 1966 in April

and November are also presented for the year 1961.

2. Monthwise distribution of cloudiness

Cloudiness may not be the simple result of one single physical condition but product of the various conditions working together. Out of these the sea surface temperature (SST) (for that reason thermal ridge axis), low pressure belt (low pressure trough axis) and the intertropical convergence zone (ITCZ) may be the factors of major importance. As the information on mean monthly wind value is not included in the wind frequency tables the mean position of ITCZ at 0.5 km were extracted from '*Climatological charts of the Indian Monsoon Area* 1945'—an IMD publication.

2.1. *April and May*—In the study No. 1 of SSP and SST patterns over Indian Ocean regions for the years 1961, 1964, and 1965 and 1966 it was found that the axes of thermal ridge were located over Arabian Sea and Bay of Bengal in the months of April and May and they were located northward in the years 1961 and 1964, the years of good monsoon rainfall over India as compared to 1965 and 1966, the years of bad monsoon rainfall. It was again shown that in the month of April 1965 (unlike the years 1961 and 1964) the pressure trough axis still lay over the Indian Ocean though north of the equator. It was located north of the mean climatological position of ITCZ at 0.5 km but to the south of the thermal axis for the year 1965. This suggests that some machanism superposed over the simple northward passage of the sun with season, does play a part in determining the good and bad monsoon years and that its effect may be witnessed in the month of April sufficiently in advance before the onset of monsoon. It is noticed in the form of delay in the northward displacement of subtropical anticyclone over the Indian Ocean and consequent lagging in the northward movement of pressure trough. Similar observations were made by Banerjee *et al.* (1978) in their study of the latitudinal position of subtropical ridge on the mean circulation chart of April at 500 mb level. They noticed that years when the subtropical ridge at 500 mb in April is poleward of the normal position are followed by good rainfall distribution while years when the ridge axis is equatorward of the normal position are followed by poor southwest monsoon rainfall.

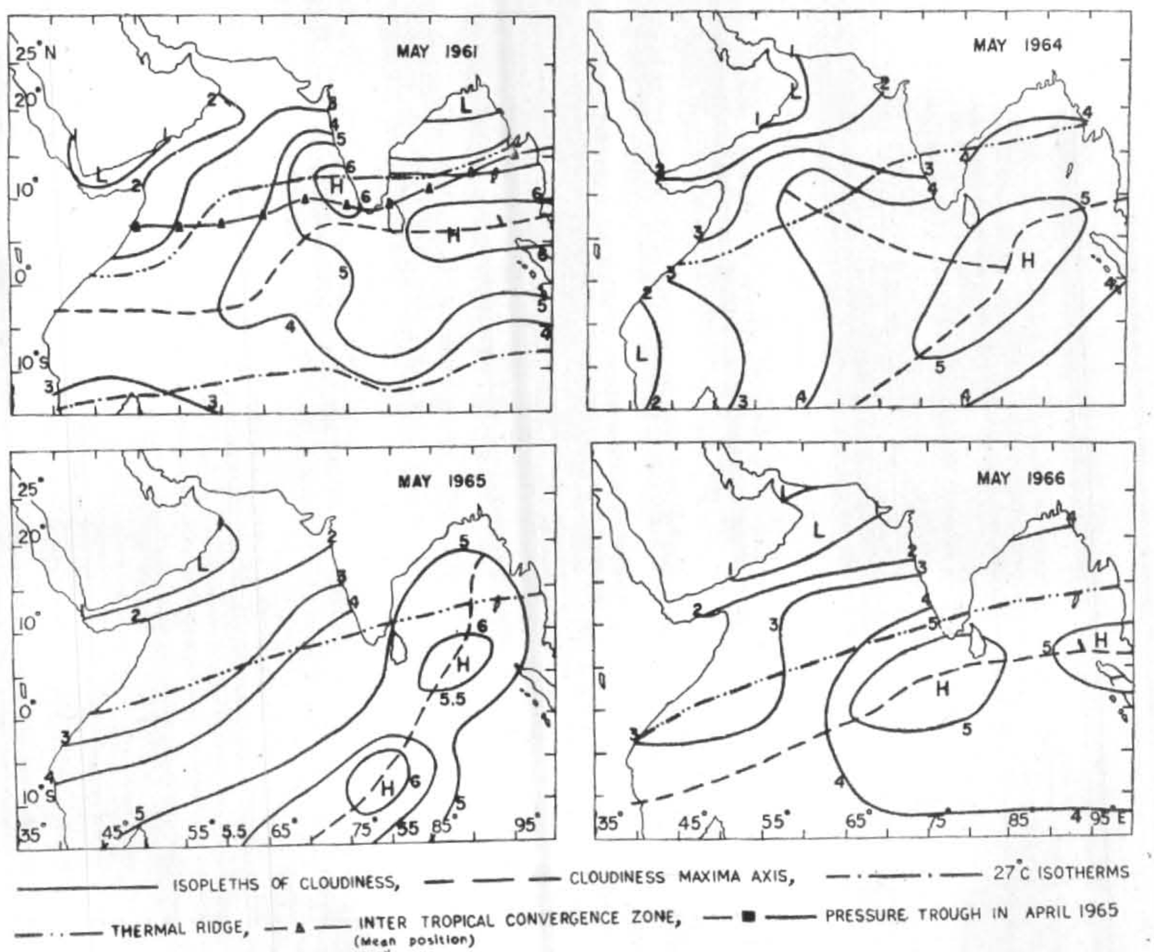

Fig. 1 (b). Distribution of cloudiness for the contrasting years of 1961, 1964 and 1965, 1966 in May

The southward intrusion of subtropical westerlies of upper troposphere into the Arabian Sea and adjoining Peninsular India (southward displacement of subtropical anticyclones) during the years when monsoon fails (Joseph 1976, 1978) or the shifting eastward and equatorwards of the Tibetan high (Kanamitau and Krishnamurti 1978) may be the different forms in which this mechanism is manifested.

In April the axis of maximum cloudiness more or less coincides with the mean position of ITCZ both lying to the south of the equator (Fig. 1). The area of major cloudiness (>4 octas) lies south of the thermal ridge in 1961, 1964 and 1965 which is located in northern hemisphere. In 1966, however, the axis of maximum cloudiness shifts to the north of equator and area lies 5° on either side of the thermal ridge, east of 70°E. This was due to the formation of severe cyclonic storm in the Bay of Bengal close to the Area 17, which had also affected the mean pressure pattern. A second area of major cloudiness is located around Area 15 near east Africa coast.

In the month of May the pressure trough axis moves over the continental landmass of north India with pressure gradient directed from south to north over seas. The thermal axis is still located over sea displaced northwards from its April position over Arabian Sea and Bay of Bengal. Temperature rises 1-2 degrees everywhere and vary from 28° to 30°C. The major cloudiness (>4 octas) area and its axis begin to move northward from April onward. In May it stretches 10 degrees to the north and south of the equator, east of 70°E. The north Arabian Sea, the east Arabia, Somali coast and the head Bay of Bengal are the areas of low cloudiness during this month. The common features of cloudiness in different years were that the area of maximum cloudiness always lay to the south of thermal axis. It generally coincides with the mean position of ITCZ. ITCZ is the zone, where the trade winds of the southern and of the northern hemisphere meet. It is located in northern hemisphere from May till November and slopes southward (2-4 degrees) with height at 3 km towards colder waters. ITCZ in May lies close to the thermal axis though slightly to its south. Whereas

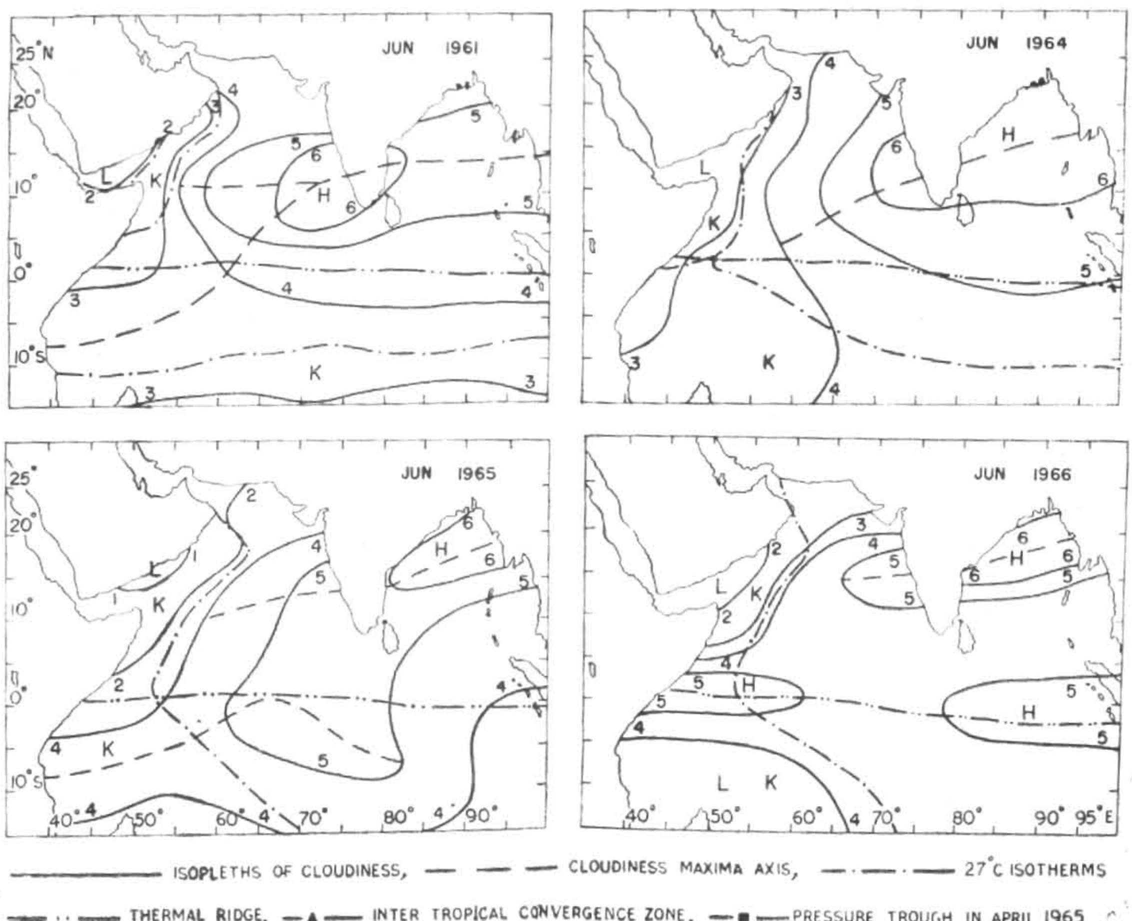

Fig. 2 (a). Distribution of cloudiness for the contrasting years of 1961, 1964 and 1965, 1966 in June

the cloudiness distribution in Bay of Bengal does not distinguish much between the years of good and bad monsoon years it seems to do so over the Arabian Sea. There is more cloudiness over most of the areas in Arabian Sea in 1961 and 1964 than in 1965 and 1966. The area of major cloudiness extends more to the north in 1961 & 1964 than in 1965 & 1966. In 1961 it appears as a distinct area of maximum cloudiness off west coast of India extending upto 15°N.

2.3. *June, July, August and September* — From June to September pressure trough, ITCZ and thermal ridge axes all the three lie over the continental landmass of northern India and extend on either side to the east and west. The ITCZ and pressure trough slope southward with height towards colder region over sea upto 500 mb. A general fall of SST values ranging from 1° to 3°C is observed in Arabian Sea and Bay of Bengal during the monsoon months. The fall is maximum in the month of August. The thermal ridge axis is not discernible over Bay and Arabian Sea during the months of June, July and August. However, a secondary thermal ridge with temperature gradient directed north and south is observed running parallel to the equator over Indian Ocean. The belt of maximum cloudiness over Bay of Bengal and Arabian Sea shows a northward displacement from June to August. In 1961 and 1964, the years of good rainfall distribution over India, this belt appears very prominently with cloudiness gradually decreasing southward whereas in June and August of 1965 and 1966 the years of bad monsoon two major cloudiness belts appear, one in the northern latitudes over Bay of Bengal and Arabian Sea but less prominent and the other running along equator which is also the location of secondary thermal ridge (Fig. 2). The double cloudiness maxima, however, may not be found in the month of July.

In the good monsoon years the second belt appears as an extension of the primary, the more prominent belt with cloudiness 6 to 8 octas, lying to the north (15-20°N) where as in years of bad monsoon the second belt appears as a distinctly separate secondary belt of cloudiness maxima in addition to the northern primary belt with lesser cloudiness in the inter-lying region. The primary

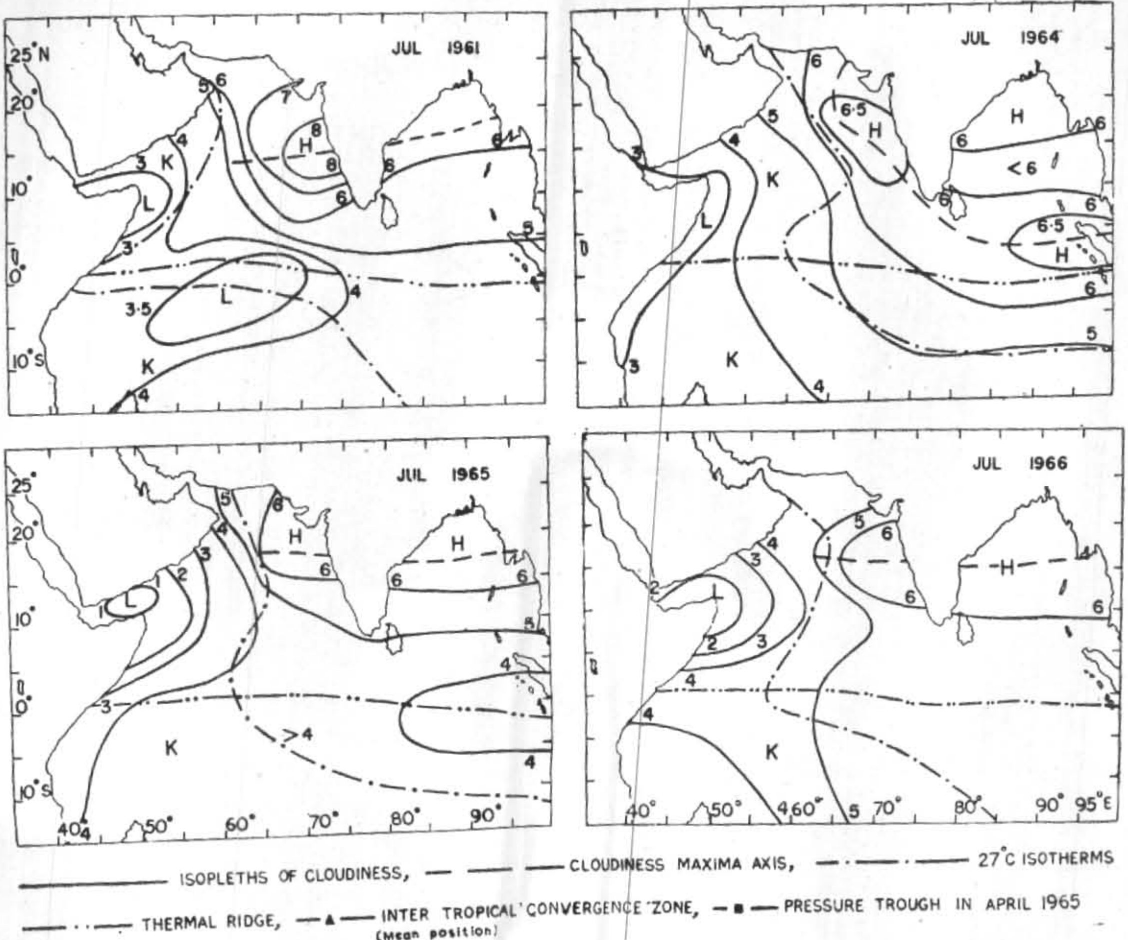

Fig. 2 (b). Distribution of cloudiness for the contrasting years of 1961, 1964 and 1965, 1966 in July

belt of major cloudiness lies to the south of primary thermal ridge axis and the ITCZ over land, whereas the secondary belt more or less coincides with the secondary thermal ridge axis. It is here that a secondary ITCZ is observed to be located over ocean as a trough system with embedded cyclonic vortices in the lower and middle troposphere. This ITCZ over ocean slopes but little with height and more or less coincides with the thermal ridge. Studies of Saha (1971), Rao and Raghavendra (1967) and Raman (1965) also held similar views.

In September the monsoon activity weakens. The axis of warmest water is again discernible over Arabian Sea and Bay of Bengal. The northern belt of major cloudiness shows a southward displacement merging with the equatorial belt. However in 1961, the year of good rainfall and also the year of maximum number of depressions tracking through the northern India (3 in number) we get two cloudiness maxima belts, one lying in the northern latitudes, over Bay of Bengal and Arabian Sea (18°N) and the other lying over the equatorial ocean.

A general evaporative cooling is observed in Arabian Sea and Bay of Bengal during monsoon months. The excessive cooling off north Somali and east Arabia coast may be attributed to the additional factor of upwelling ocean current under the influence of strong cross equatorial southerly and southwesterlies (Part I). The low cloudiness is observed parallel to the Somali and east Arabia coast over the cold sea water area which gradually stretches eastward at places upto 70° E from June to August and September (Part I). The position of 27°C isotherm for different months of the year 1961 and for the months of April to September for the year 1964, 1965 and 1966 are shown in their corresponding charts. No significant difference is observed regarding the mean picture on eastward stretching of the cold water for the two different groups of year.

2.3. *October and November* — The axis of warmest waters moves southward in October and remains more or less at the same position in the month of November. The belt of major cloudiness (⩾5 octas) shows a southward displacement and lies between equator and 10° to 15°N mostly south

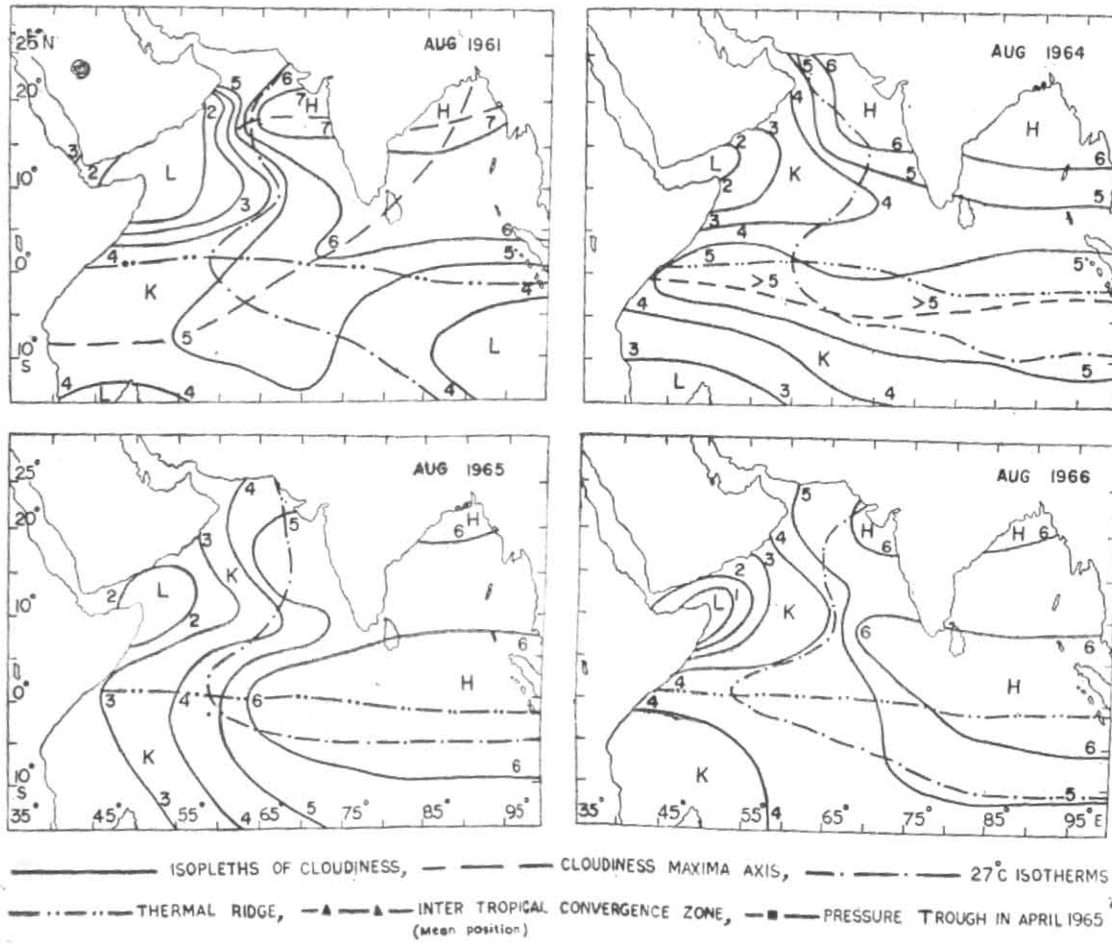

Fig. 2 (c). Distribution of cloudiness for the contrasting years of 1961, 1964 and 1965, 1966 in August

of the primary thermal ridge axis (Fig. 3). A second belt of major cloudiness makes appearance south of 8°S in November. The low cloudiness areas mainly exists over north Arabian Sea, east Arabia and Somali coasts. The area 8 gets more cloudiness during the month of November with the rise of temperature.

3. Discussion

(1) The latitudinal and longitudinal displacement of the major subtropical anticyclonic cells do exhibit some kind of oscillation on an yearly scale (may be under the influence of westerlies or *vice versa*). The subsiding atmospheric motions and the clear skies associated with it affect the sea surface temperature and pressure fields. Thus the relatively southward location of thermal ridges in the months of April and May in 1965 and 1966 or the lag observed in the northward displacement of pressure trough in the year 1965 (both poor monsoon years) may be explained due to a lag in the northward displacement of subtropical anticyclone as observed by the relatively high pressure field over Arabian Sea and Bay of Bengal during these years.

(2) The present study made with the distribution of mean monthly cloudiness throws light on the seasonal migration of the major cloudiness belt across the equator to summer hemisphere. It does not give any idea about the formation and migration of cloudiness belt over Arabian Sea during an active monsoon spell. However, the mean picture brought out in this study resembles mostly the one depicted in the '*Global Atlas of Relative Cloud Cover* 1967-70 *based on data from meteorological satellites*', a U.S.A. publication or in the studies made with the satellite observed cloudiness by various Indian authors (Sikka 1971 etc).

(3) In the above discussion, the pressure trough, the thermal ridge and the ITCZ are found to differ significantly in their positions particularly in the months of April and May. The pressure trough is located much to the north of thermal ridge and ITCZ (see May charts). Also the thermal ridge is located to the north of ITCZ (*see* April charts). The former is obviously due to the differential heating of sea and land masses. The Indian Peninsula in the month of April and the north Indian

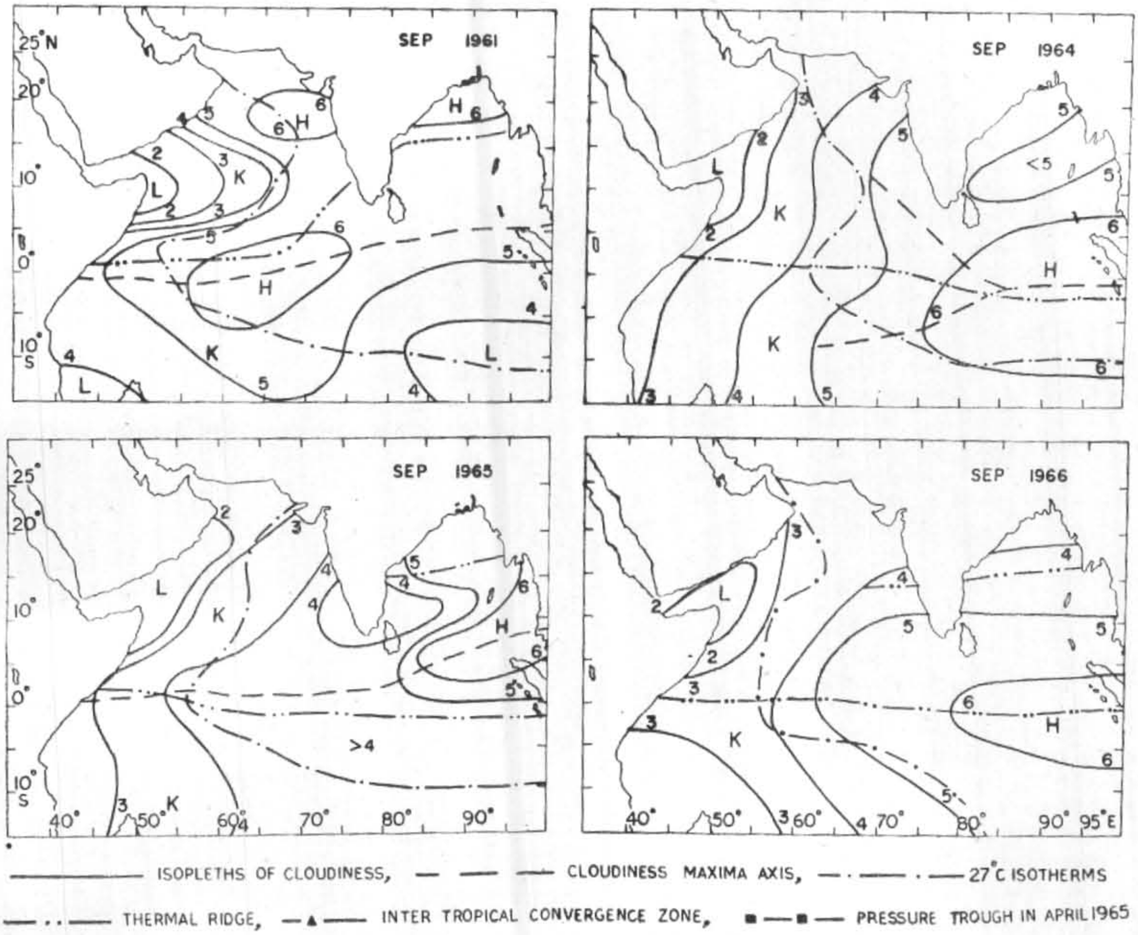

Fig. 2 (d). Distribution of cloudiness for the contrasting years of 1961, 1964 and 1965, 1966 in September

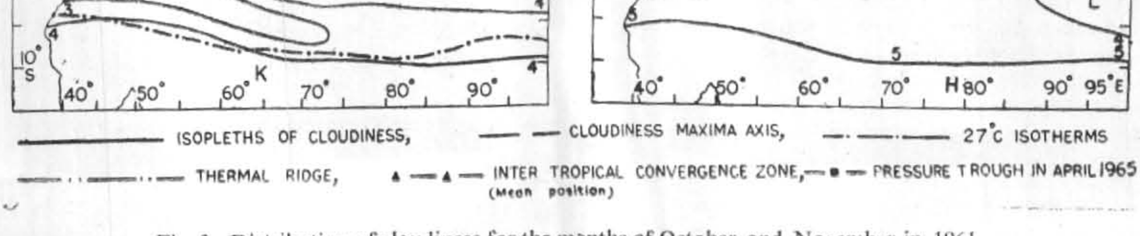

Fig. 3. Distribution of cloudiness for the months of October and November in 1961

and the adjacent landmass in the month of May are much warmer than the sea waters. The fall of pressure there further modifies the pressure field over the sea such that pressure gradient is directed in their directions. The latter is due to the lag in the response of wind field to changes in temperature field. A lag in the response of pressure field over to the change of temperature by one to two months is also observed by consulting the Fig. 4 of Part-I of this study; though it may not be easy to get an exact correlation between the two because of the evaporative cooling of sea waters during monsoon.

(4) The pressure trough is located much to the north of ITCZ on the surface and both slope southward with height to the colder region and come closer at 3 km and above. During monsoon months the secondary ITCZ and pressure trough do not exhibit any significant slope with height and are found to coincide with the secondary thermal ridge near the equator. The cloudiness maxima are observed to be located closer to and to the south of ITCZ position at surface. This is obviously due to the favourable conditions of wind convergence and conditional instability and moisture supply along and to the south of ITCZ.

(5) Prolonged or frequent breaks in monsoon may be one of the reasons for a poor monsoon year over India. In the break period weather shifts to the northern latitudes near foot hills of Himalayas thus making the northern belt of cloudiness over sea less prominent. On the other hand low pressure area associated with weather have been observed to migrate from east to west near equatorial regions both in Bay of Bengal and Arabian Sea (Koteswaram 1950, Mukherjee 1968, Pant 1980) thus making the equatorial belt of cloudiness relatively more prominent. This may explain why two distinct cloudiness maxima are observed in the months of June and August of the bad monsoon years as compared to only one but more prominently displayed in the good monsoon year. July gets lesser breaks comparatively.

5. Conclusion

The major findings of this study are :

(1) We may get an advance indication about the ensuing good or bad monsoon rainfall over India from the distribution of mean sea surface pressure (SSP), sea surface temperature (SST) and cloudiness field for the month of April over Indian Ocean, Bay of Bengal and Arabian Sea.

(2) In April and May the area of major cloudiness ($\geqslant$5 octas) mostly lies to the south of thermal ridge over sea. There is more cloudiness over most of the areas in Arabian Sea extending to more northern latitudes in the months of April and May in good monsoon years than in bad monsoon years.

(3) In the months of June, July and August of monsoon season the secondary thermal ridge and ITCZ are located along the equator over Indian Ocean. In the good monsoon years only one belt of maximum cloudiness lying over the Bay of Bengal and Arabian Sea east of 65°E appears very prominently. Whereas, in bad monsoon years two distinct belts of major cloudiness one lying over Bay of Bengal and Arabian Sea and the other located along the equator appear prominent particularly in the months of June and August.

(4) In September, in the year 1961 of good rainfall, there appear two major cloudiness belts one lying over the Bay of Bengal and Arabian Sea east of 65°E and the other lying over the equatorial ocean. In bad monsoon years only one belt of mean monthly cloudiness merged with the equatorial cloudiness appears permanently over the south Bay and Arabian Sea.

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References

Banerjee, A.K., Sen, P.N. and Raman, C.R.V., 1978, *Indian J. Met. Hydrol. Geophys.*, **29**, 1 & 2, pp. 425-431.

Jambunathan, R. and Ramamurthy, K., 1975, *Indian, J. Met. Hydrol. Geophys.*, **26**, 4, pp. 465-478.

Joseph, P.V., 1976, Proc. Symp. Tropical Monsoon, Indian Institute of Tropical Meteorology, Pune-5, India, pp. 494-504.

Joseph, P.V., 1978, *Indian J. Met. Hydrol. Geophys.*, **29**, 1 & 2, pp. 412-418.

Kanamitou Masao, and Krishnamurthi, T.N., 1978, *Mon. Weath. Rev.*, **106**, 331-347.

Koteswaram, P., 1950, *Indian J. Met. Geophys.*, **1**, pp. 162-164.

Mukherjee, A.K. and Natarajan, G., 1968, *Indian J. Met. Hydrol. Geophys.*, **19**, 3, pp. 285-288.

Pant, P.S., 1980, *Mausam*, **31**, 2, pp. 215-221.

Raman, C.R.V., 1965, Met. results of IIOE, pp. 155-163.

Ranjit Singh, 1980, *Mausam*, **31**, 4, pp. 601-608.

Rao, Y.P. and Raghavendra, 1967, Proc. symp. Indian Ocean, New Delhi Part-II, pp. 1011-1014.

Saha, K.R., 1967, *Tellus*, **23**, 2, 183-195.

Sikka, D.R. 1971, *Indian J. Met. Geophys.*, **22**, pp. 405-412.

India Met. Dep., 1945, *Climatological Charts of the Indian Monsoon Area.*

USA, NOAA (NESS) and USAF publication, *Global Atlas of Relative cloud cover*, 1967-70.

USA, National Science Foundation, *Meteorological Atlas of the International, Indian Ocean Expedition*, **I**, The Surface Climate of 1963 and 1964, **II**, Upper Air.