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Some aspects of southwest monsoon as seen in satellite cloud imagery

D. K. MISHRA*, G.R. GUPTA, ONKARI PRASAD and TRIBHUWAN NATH

Meteorological Office, New Delhi

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सार — 1978-79 तथा 1984-88 के वर्षों के उपग्रह मेघ बिम्बों का अध्ययन किया गया है। दक्षिण-पश्चिम मानसून के कुछ पहलुओं को प्रलेखित किया गया है। यह दर्शाया गया है कि क्रास (पार) भूमध्य रेखीय बहाव तथा उसकी स्थिति और तीव्रता दक्षिण-पश्चिम मानसून के प्रारम्भ में और ऋतु के दौरान महत्वपूर्ण भूमिका निभाती है। दक्षिण गोलार्ध भूमध्य रेखीय द्रोणी क्रास भूमध्य रेखीय बहाव का नियमन करने में भूमिका अदा करता है और इस प्रकार दक्षिण-पश्चिम मानसून के विकास की विभिन्न प्रावस्थाओं की ओर ले जाता है। दक्षिण गोलार्ध भूमध्य रेखीय द्रोणी की प्रगाढ़ता और मानसून गतिविधि के मध्य के व्युत्क्रम संबंध का शुष्क तथा नम अवधियों के पूर्वाभास में साधन के रूप में प्रयोग किया जा सकता है। इस शोधपत्र में प्रस्तुत किए गए परिणाम मानसूनी वायुमंडल में हो रही भौतिक प्रक्रियाओं को समझने में सहायक हैं।

ABSTRACT. Satellite cloud imagery for the years 1978-79 and 1984-88 have been studied. Some aspects of southwest monsoon have been documented. It has been shown that the cross-equatorial flow, its location and intensity, play an important role in the onset of southwest monsoon and its activity during the season. The southern hemispheric equatorial trough plays the role of regulating the cross-equatorial flow and thus leads to the development of different phases of southwest monsoon. The inverse relationship between the intensity of southern hemispheric equatorial trough and the monsoon activity can be used as a tool in foreshadowing dry and wet spells. The results presented in the paper are helpful in understanding the physical processes taking place in the monsoonal atmosphere.

Key words — Cross-equatorial flow, onset vortex, southern hemispheric equatorial trough, spells of increased cloudiness, spells of decreased cloudiness.

1. Introduction

Early investigations of the southwest monsoon were handicapped due to near absence of data over the Indian Ocean. Most of the studies on the large scale aspects of monsoon have made use of the limited observations collected during the International Indian Ocean Expedition (1962-64) and the monsoon experiments carried out during the years 1973, 1977 and 1979. During the monsoon experiment 1979, U.S. geostationary satellite GOES-IO (GOES-Indian Ocean) provided round the clock imagery over the monsoon region and thus enabled the first total view of the monsoon activity from space. Thereafter, since 1983 the Indian geostationary satellite, INSAT-1B, has been providing the cloud imagery over this region in the visible channel (0.55-0.75 μm) in daytime and in thermal channel (10.5-12.5μm) round the clock. The satellite imagery is the only continuous meteorological data base to be available over the Indian Ocean and has enabled the continuous monitoring of southwest monsoon activity. The satellite data utilized in this study include visible and infrared pictures received from INSAT, GOES and NOAA satellites and the wind vectors derived from the half hourly cloud imageries of the geostationary satellites GOES-IO, METEOSAT and INSAT. The synoptic charts have also been consulted wherever found necessary. These data afford an insight into the processes taking place within the monsoonal atmosphere, some of which are discussed in the following paragraphs.

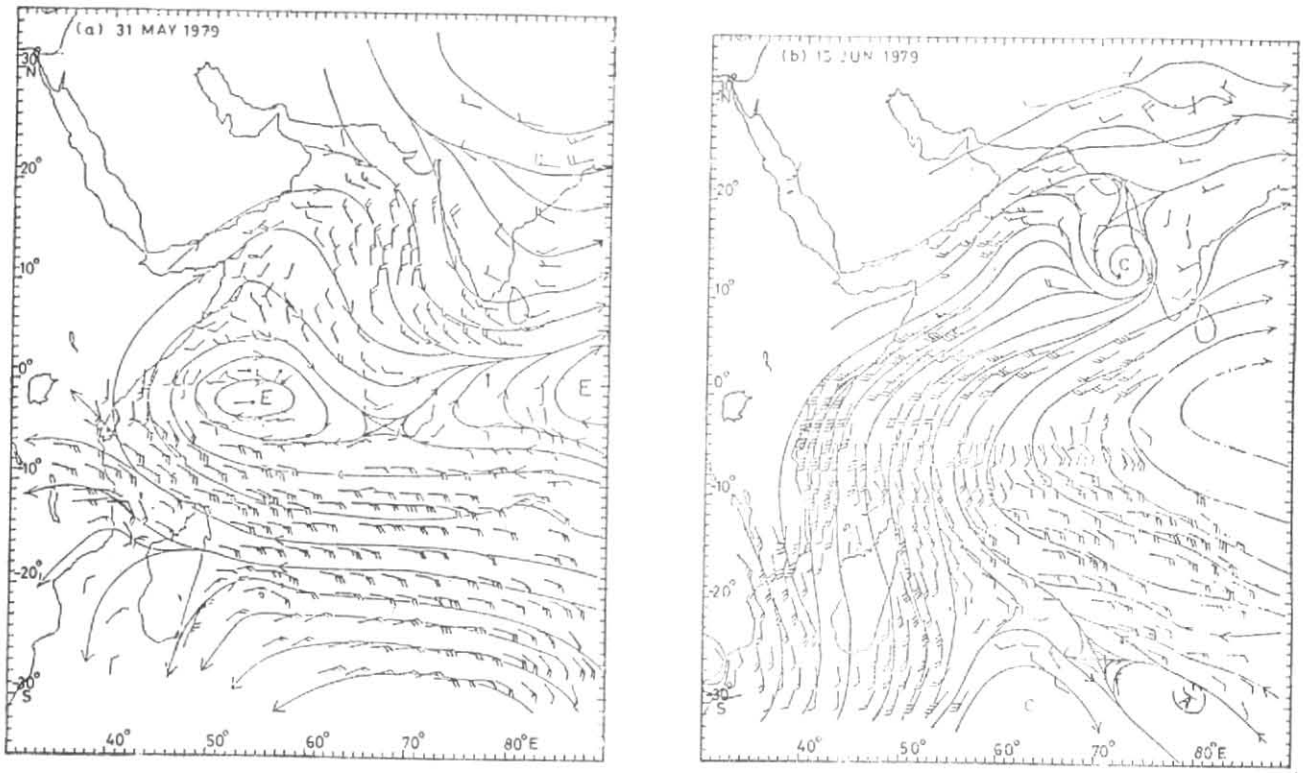
2. Onset of monsoon

2.1. Recent studies have indicated that during the onset phase the meridional cross-equatorial pressure differential and the passage of the baroclinic waves in the southern hemisphere lead to a surge in the southeast trades equatorward. This in turn results in the strengthening of the deflected equatorial southwesterlies in the lower levels, surge in the Cross-Equatorial Flow (CEF) and formation of an onset vortex, on some occasions, on the northern flank of the southwesterly current. The onset vortex may form either in the Bay of Bengal or in the Arabian Sea. It moves northward bringing the monsoon over India. Satellite data provide a further insight into these aspects. These have been discussed below taking three examples of the onset of monsoon during the years 1984, 1979 and 1978.

2.2. *Onset in the year 1984*

The INSAT-1B pictures show that a surge in southeast trades began in southeast Indian Ocean by 26 May 1984. The CEF of low level southwesterlies got organised east of longitude 70° E by 27 May 1984. A cloud band with embedded intense convection formed with its axis running from 20° S/105°E to Andaman Sea through

*Present Address : 1129, Kovanda Way, Milpitas, CA 95035, U.S.A.



Figs. 1 (a&b). Low level wind flow 600-1000 hPa derived from GOES-IO data over the Indian Ocean (Crozet *et al.* 1979) and from land Rawin observations, (a) 0930 UTC of 31 May 1979 and (b) 0930 UTC of 15 June 1979

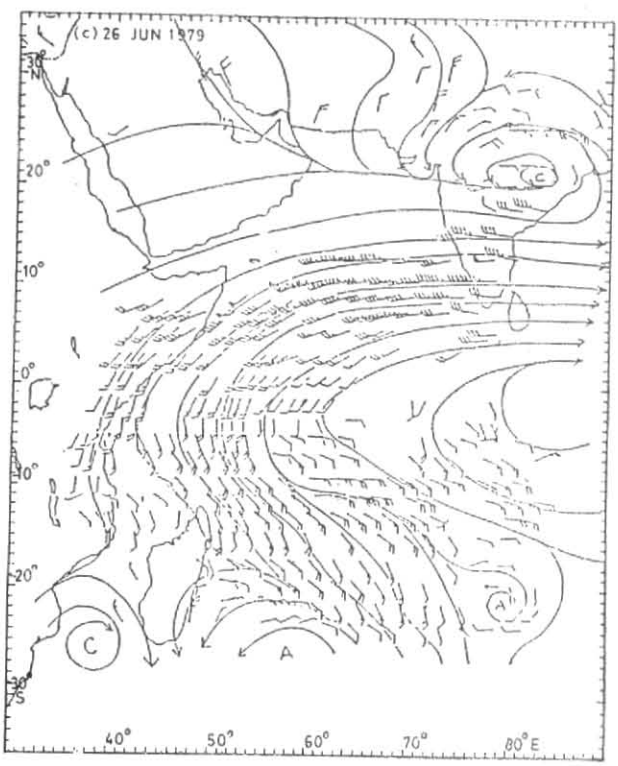


Fig. 1 (c). Low level wind flow 600-1000 hPa derived from GOES-IO data over the Indian Ocean (Crozet *et al.* 1979) and from land Rawin observation. 1000 UTC of 26 June 1979

8°S/85°E. By 29th the southern part of the band weakened and moved west while the northern part strengthened. The satellite picture of 29 May shows the cold surge as cumulus lines indicating southeasterly flow east of 75°E and south of 13°S. Further north the convective band extended northeastward into the Bay of Bengal. On the head of the band an onset vortex developed over the southwest Bay and west central Bay of Bengal as indicated by curved cumulus lines. The onset vortex concentrated further and moved northward. During this process the CEF got further organised across the western Indian Ocean leading to the onset of monsoon over the west coast of India. The INSAT-1B picture of 1 June 1984 (Fig. 2) shows the well organised cloud band extending from west Indian Ocean across south Arabian Sea to the head of Bay of Bengal where the onset vortex was located. The southwesterly flow across the equator is clearly seen in the cloud organisation over the whole of the Indian Ocean during this period. The development of the monsoon convective clusters within low level westerly flow over the Arabian Sea south of latitude 15°N and their eastward propagation up to the Kerala-Karnataka coast marked the onset of monsoon over Kerala.

2.3. *Onset in the year 1979*

Figs. 1(a-c) show the low level wind vectors derived over the Indian Ocean from GOES-IO imageries of 0700-0900 UTC in the visible channel by Crozet *et al.* (1979). The authors have composited these data with ground based 850 hPa wind data for 1200 UTC over the Indian sub-continent and have carried out streamline analysis. These charts show a weak deflected southwesterly current over the west Arabian Sea and a relatively

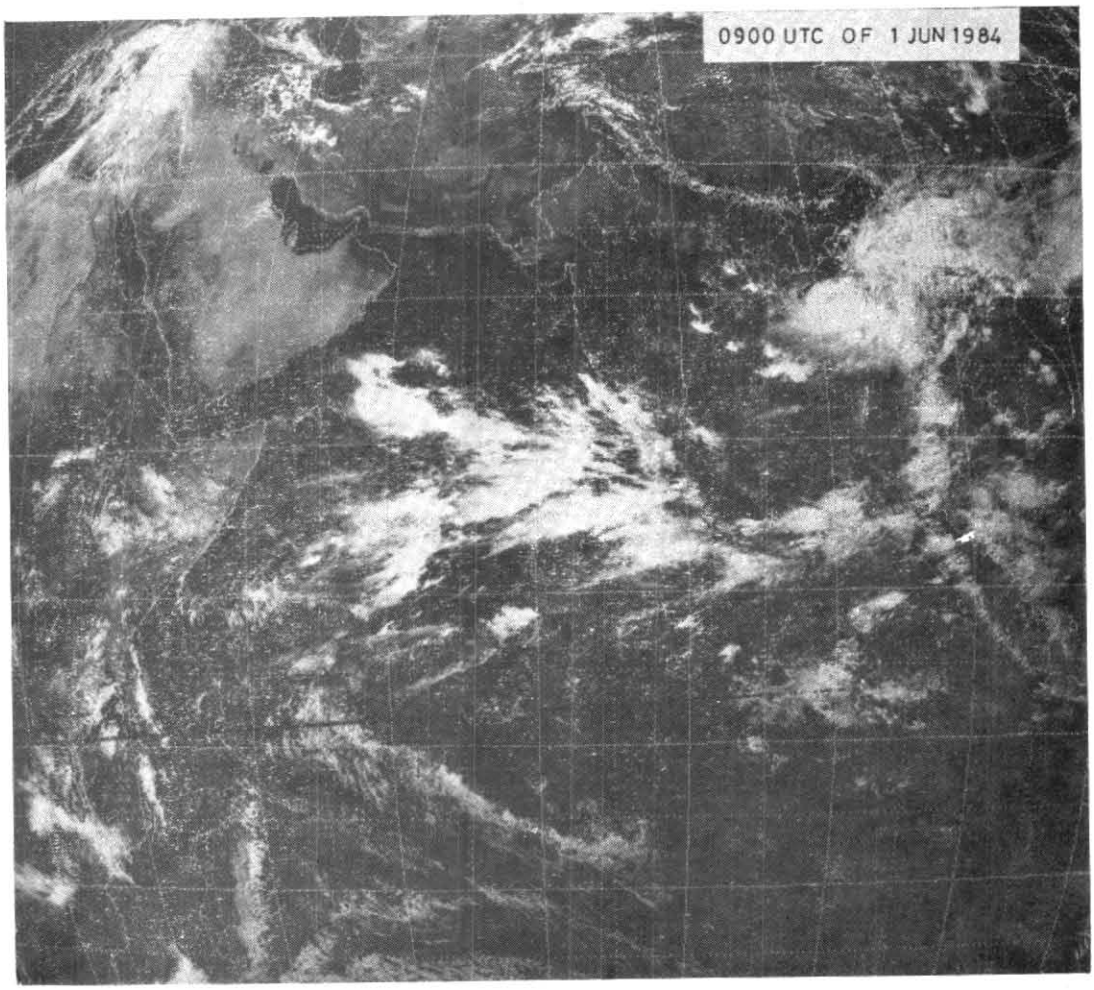


Fig. 2. INSAT-1B visible channel pictures showing the surge in cross-equatorial flow and the formation of onset vortex during the onset phase of southwest monsoon in the year 1984

stronger northerly flow over the east Arabian Sea up to 31 May 1979, i.e., around the normal date of onset of monsoon over Kerala (Fig. 1a). These features persisted till 12 June and appear to have been responsible for the delayed onset of monsoon. The low level circulation started changing thereafter, leading to the strengthening of cross-equatorial southwesterly flow, change of low level flow over the Arabian Sea from northwesterlies to southwesterlies and the formation of an onset vortex in southeast Arabian Sea. On 15 June the low level jet with maximum wind speed of 55 kt formed within the southwesterly flow, as also the onset vortex had intensified (Fig. 1b). By 26 June (Fig. 1c) strong westerlies (30-50 kt) had established over south Arabian Sea and the Peninsular India. The formation of a large monsoon convective cluster within the low level southwesterlies in south Arabian Sea by 12 June and its propagation eastward onto the Kerala coast marked the onset of monsoon. These features are also seen in the Summer Monex (1979) satellite data presented by Young *et al.* (1980).

2.4. *Onset in the year 1978*

The low level wind field derived from Meteosat cloud imagery over the west Indian Ocean showed that weak equatorial westerlies and very little CEF up to 10 May 1978 (Cadet and Desbois 1980). Between 10 and 16 May the cross-equatorial southerly jet got organised off Somali coast and southwesterlies over the south Arabian Sea strengthened markedly to the maximum speeds of 40 kt (Mishra and Gupta 1984). The CEF was established on 12 May 1978 and increased progressively thereafter. In association with this the southwest monsoon advanced over SE Andaman Sea and the extreme southern parts of Bay between 14 and 16 May. These changes over the Indian Ocean preceded the onset of monsoon over Kerala that took place on 28 May 1978.

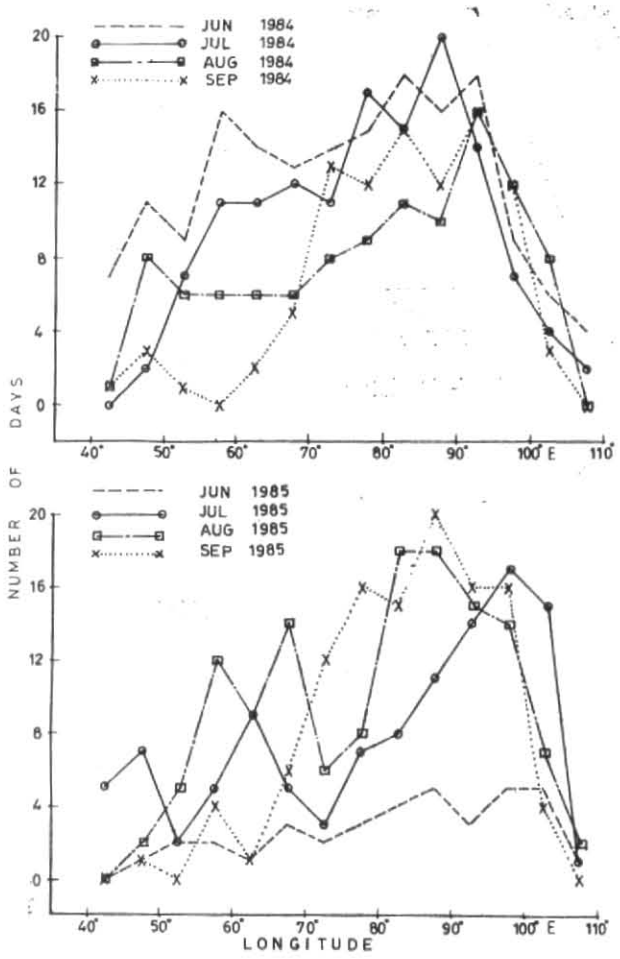
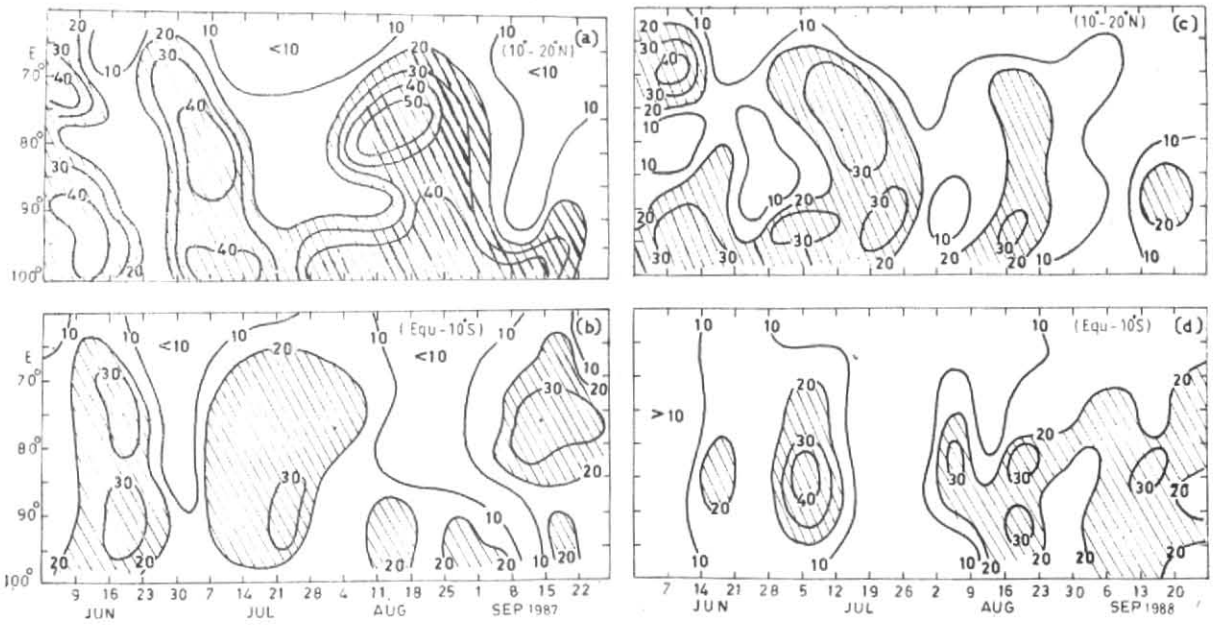


Fig. 3. Monthly frequency of cross-equatorial flow at 5-degree intervals along the equator between longitudes 40°E and 110°E



Figs. 4 (a-d). Time latitude cross-section of weekly mean cloudiness during southwest monsoon 1987-88 (a) 10°-20°N, (b) Equ-10°S, (c) 10°-20°N and (d) Equ-10°S

2.5. On a few occassions the onset vortex may intensify further and may even develop into a severe cyclonic storm with a core of hurricane winds. In June 1982, a cyclonic storm developed over the east central Bay of Bengal on 1 June during the onset phase. It intensified as it moved northwestward and crossed Orissa coast close to Paradip on the night of 3 June 1982. The Bhavnagar cyclone of 1976 developed over southeast Arabian Sea on 30 May 1976 during the onset phase, moved northward and crossed Gujarat coast near Mahuva on the morning of 3 June 1976.

3. Cross-equatorial flow

The INSAT-1B pictures appear to indicate that the Cross-Equatorial Flow (CEF) over the Indian Ocean in the lower levels has a predominant influence over the southwest monsoon activity over south Asia. Some of these aspects are discussed below.

3.1. *Position of CEF*

3.1.1. In satellite imagery the CEF is indicated by the orientation of the individual cumulus cloud elements as also by their large scale organisation. Usually strong CEF is associated with intense convection so that a large convective band is formed within the tropical belts on both sides of the equator. Such a band shows a SE-NW orientation within the southwest trades and turns toward northeast within the deflected southwesterlies south of equator. Further north the band is oriented along the monsoon flow.

3.1.2. As mentioned above the CEF can be qualitatively inferred from the orientation of cumulus cloud elements along the equator, for those areas where such cloud elements could be identified. Employing this approach the monthly frequency of CEF for every 5 deg. longitude interval between 40°E and 110°E is shown in Fig. 3. On a cursory look the CEF would appear to increase from west to east, but this may not be true. Here, the detection of flow depends upon the cumulus elements whose frequency increases from west to east. Hence in the cloud field the flow is better detected eastward. However, the figure does indicate that a significant amount of CEF takes place east of 70°E, *i.e.*, in the Bay of Bengal.

4. Weekly mean satellite cloudiness

Analysis of satellite observed cloudiness data over the Indian Ocean for three characteristic monsoon seasons, namely, (a) a drought year—1979, (b) an year of normal to excess rainfall over most of the meteorological subdivisions—1983 and (c) an year of near normal rainfall—1984 by Prasad *et al.* (1988) and that of a severe drought year (1987) by Johri and Prasad (1990) has further confirmed that the SHET serves to regulate the CEF of southeast trades into north Indian Ocean and thus leads to the development of different phases of the summer monsoon. The role of SHET is further examined in this paper using INSAT-1B cloudiness data of 1987 and 1988.

Weekly mean cloudiness in the belts equator-10°S and 10°-20°N during the monsoon seasons of 1987 and 1988 is shown in Figs. 4 (a-d). The latitude belt equator-10°S witnessed three spells of increased cloudiness (SICs) : (*i*) from the week ending on 9 June till the week ending on 23rd, (*ii*) from the week ending on 7 July till the week ending on 4 August and (*iii*) from the week ending on 8 September till the end of the season. Prolonged spells of increased cloudiness in this belt as seen in the year 1979 (Prasad *et al.* 1988) were also seen in 1987. Out of the three SICs, the second SIC was most prominent which caused almost non-monsoonal weather over a large number of meteorological sub-divisions of India in the month of July 1987. It is interesting to note that these three SICs had corresponding spells of decreased cloudiness (SDCs) in the belt 10°-20°N. The third SIC in the belt equator-10°S resulted in rapid withdrawal of monsoon from northwest India. Figs. 4(c-d) present same data for the year 1988. In the year 1988 the SICs were short lived in the zone of SHET. The inverse relationship between cloudiness in the zone of SHET and southwest monsoon activity over India holds good in the year 1988 too.

Thus the cloudiness data of the southwest monsoon 1987-88 further confirms the dominating role of SHET in the development of the monsoon and its different phases.

5. Conclusions

(1) Onset of summer monsoon over Kerala is preceded by a surge in the low level CEF which sometimes results in the formation of an onset vortex. In some years the surges is seen in the formation of a convective band extending from south Indian Ocean northeastwards into the Arabian Sea or Bay of Bengal.

(2) The CEF takes place all along the equatorial Indian Ocean. Its strength varies considerably both with longitude and time.

(3) SHET plays the role of regulating the cross-equatorial flow into the north Indian Ocean and thereby leads to the development of different phases of southwest monsoon.

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