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Lower level wind flow over the Indian Ocean during the onset of Monsoon-1987

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सार — 28 मई से 7 जून 1987 की अवधि के दौरान हिन्द महासागर के कुछ भागों पर प्रतिदिन प्राप्त इनसेट–1बी निम्न स्तरी मेघ गति सदिश (CMVs) को एक नई प्रकार की गुणता नियंत्रण तकनीक का विषय बनाया गया। केरल पर दक्षिण-पश्चिमी मानसून के आरम्भ होने से पूर्व और उसके एकदम बाद के पवन प्रवाह को समझने के लिए इनसेट मेघ चित्रों की जानकारी के साथ उचित पवन आंकड़ों का विश्लेषण किया गया। यह देखा गया है कि मानसून के प्रारंभ होने की तारीख से 2–3 दिन पूर्व, दक्षिण-पूर्वी अरब सागर में तथा सोमाली तट पर पवन की गति तीव्र हो गई तथा विषुवत रेखा को पार करने वाले प्रवाह भी प्रबल हुए। इसके आरम्भ होने के दिन से लगभग चार दिन पूर्व, दक्षिणी अरब सागर में अंत: स्थापित भ्रमिल सहित एक पूर्व-पश्चिमी द्रोणी क्रमानुसार उत्तर की ओर गतिशील होती है, इससे केरल में दक्षिण-पश्चिमी मानसून तरंग स्थापित होती है। मानसून के स्थापित हो जाने के बाद समुद्र पर मेघ गति सदिश के आंकड़े अत्यंत स्पष्टरूप से प्रबल मानसून प्रवाह दर्शाते हैं।

ABSTRACT. INSAT-1B low level cloud motion vectors (CMVs) extracted daily over some part of the Indian Ocean during the period 28 May to 7 June 1987 were subjected to a new quality control technique. The accepted winds were analysed in conjunction with INSAT imagery to understand the wind flow prior to and just after the onset of the southwest monsoon over Kerala. It was observed that 2-3 days before the actual date of onset there was strong cross-equatorial flow and strengthening of the winds in southeast Arabian Sea as well as off the Somali coast. An east-west trough with embedded vortices moved northward in south Arabian Sea systematically for about 4 days prior to the day of onset, thereby establishing the southwest monsoon current over and off Kerala coast. After the setting in of the monsoon the CMV clusters very clearly showed the strong monsoon current over the ocean.

1. Introduction

The arrival of the southwest monsoon over India is an eagerly-awaited meteorological event each year. Because of the far-reaching economic consequences of an untimely monsoon, the need to predict the date of onset well in advance has already been recognised. Until the beginning of the satellite era in the 1960s, the vast expanse of the Indian Ocean to the south of the Indian Peninsula was characterised by almost a total absence of meteorological observations. From satellite pictures, Ananthakrishnan *et al.* (1968) and Jambunathan (1974) have shown that cloudiness near Trivandrum latitude in the Arabian Sea persists for a week covering 1/3 of the sky prior to the date of the onset of monsoon over Kerala. The European geostationary satellite, METEOSAT, giving a view of west Indian Ocean up to about 65°E provided the first opportunity (Findlater 1969, Cadet and Debois 1979) to study the Somali jet during the Indian summer monsoon.

After the launch of INSAT-1B in 1983, the complete coverage of the Indian Ocean through 3-hourly and even half-hourly satellite imageries became available to the meteorologists. Consequently, the extraction of cloud motion vectors (CMVs) over the Arabian Sea, the Bay of Bengal and the north Indian Ocean was also started and afterwards extended to a large contiguous area of the Indian Ocean. The CMVs extracted from the INSAT cloud imageries, and the images themselves, together constitute virtually the only source of information over the Indian Ocean.

In the present study, the INSAT data set comprising the low level wind vectors and the imagery have been used to examine the flow pattern associated with the onset of monsoon 1987 over Kerala. The period considered is from 28 May to 7 June 1987, chosen so as to cover the 5 days each prior to and following the actual date of onset, which was 2 June 1987. The INSAT data for the 11-day period was supplemented by the conventional observations from ships, island and coastal stations and also by a small number of available CMVs of METEOSAT satellite. The data was analysed and interpreted to understand some of the important aspects of monsoon like, (*i*) cross-equatorial flow, (*ii*) monsoon wind during the onset phase, (*iii*) strengthening or weakening of monsoon current and (*iv*) formation of the Somali jet etc.

2. INSAT cloud motion vectors

2.1. *CMV-sector coverage of Indian Ocean*

Fig.1 shows the six sectors of the INSAT-1B full disc image over which cloud motion vectors are extracted, *viz.*, (1) BB (Bay of Bengal), (2) AS (Arabian Sea),

TABLE 1

Quality control statistics for INSAT CMVs for 28 May to 7 June 1987

Date (1987)	Low-level CMVs extracted (total of all sectors)	CMVs rejected (total number) for scrutiny check				CMVs accepted (%)
		I	II	III	IV	
28 May	189	5	21	0	15	78
29 ,,	165	3	24	1	11	76
30 ,,	158	7	19	2	11	75
31 ,,	63	6	4	2	2	78
1 Jun	131	14	21	0	3	71
2 ,,	90	16	9	0	1	71
3 ,,	69	8	7	1	2	72
4 ,,	59	8	10	0	1	69
5 ,,	192	12	26	1	4	78
6 ,,	161	11	17	0	5	78
7 ,,	213	8	24	1	5	82

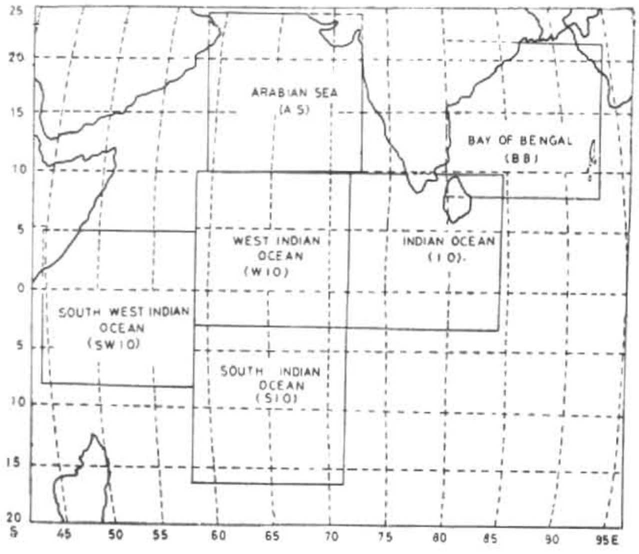


Fig. 1. Six CMV sectors

(3) IO (Indian Ocean), (4) WIO (West Indian Ocean), (5) SWIO (Southwest Indian Ocean) and (6) SIO (South Indian Ocean). CMVs from all the six sectors were used in the present study.

2.2. *CMV extraction procedure*

At the INSAT Meteorological Data Utilization Centre (MDUC), New Delhi, two successive visible imageries of 0530 and 0600, or 0600 and 0630 GMT, and an IR image taken for the time of the first visible image are used for the extraction of CMVs. The automated extraction technique (Kelkar & Khanna 1986 and Kelkar *et al.* 1987) is based on a pattern matching procedure adopted to arrive at a minimum absolute difference of grey shade between corresponding picture elements of the same cloud pattern of size 40 km × 40 km over a half-hour interval. The wind speed and direction are obtained from the relative shifts of the centre of the pattern. The height is calculated from the infrared brightness temperature using the value of the sea surface temperature (SST) and a standard lapse rate of 6.5° C/km. Wylie and Hinton (1981) examined cloud motion winds over Indian Ocean and concluded that for defining the synoptic scale wind fields the CMVs derived from FGGE data set could be directly used without extensive smoothening or editing. Some workers have also examined as to how close the satellite derived winds are to the true winds at the different levels (Hubert and Thomsell 1979).

2.3. *Scrutiny of CMV data*

The CMV data were classified as per the height for three broad layers of the atmosphere, *viz.*, (*i*) <3 km representing (say) 850 mb, (*ii*) 3 to 8 km representing (say) 500 mb and (*iii*) >8 km representing (say) 200 mb. Only the first category of CMVs was made use of in the present study. The data set was subjected to a systematic scrutiny before utilising it for further analysis. The following were the steps (I to IV) in the quality control procedure :

I : Preliminary check

CMVs derived over peripheral land areas in any of the six sectors were ignored for the purpose of the present study. In addition, certain oceanic CMVs which could be obviously regarded as *grossly in error* in respect of height, direction, or speed were weeded out at this stage.

II : Gradient check

The winds passing through the preliminary check were subjected to a gradient check :

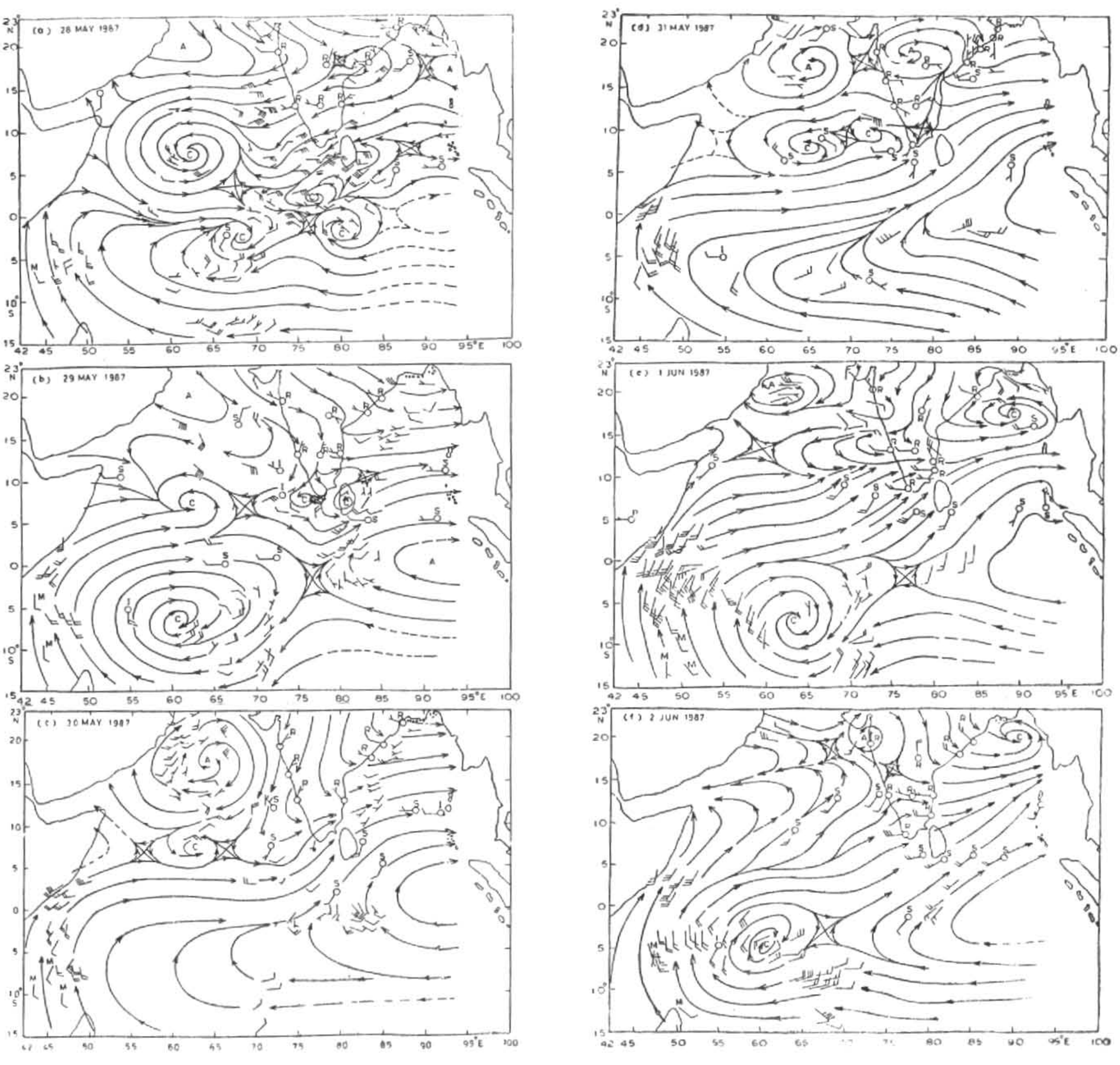
(*a*) Any abrupt change in the direction within a cluster of CMV points, when there is likelihood of a simple uni-directional flow, was disregarded.

(*b*) Similarly, any abrupt change in the speed, with respect to other closely knitted points reported in a simple uni-directional airflow, was rejected.

The "gradient check" was not applied in other types of situations like the Somali jet, strengthening/weakening of winds or veering/backing of winds etc.

III : Inter-comparison check

The INSAT wind data set was augmented with conventional winds and other satellite derived winds in the



Figs. 2 (a-f). Sequence of low level winds in the Indian Ocean from 28 May to 2 June 1987

region. A few winds had to be omitted due to inconsistencies found during the intercomparison amongst the wind data from the different sources like (*a*) METEOSAT, (*b*) Ships observations and (*c*) Radiosonde/Rawin/Pibal observations.

IV : Synoptic check

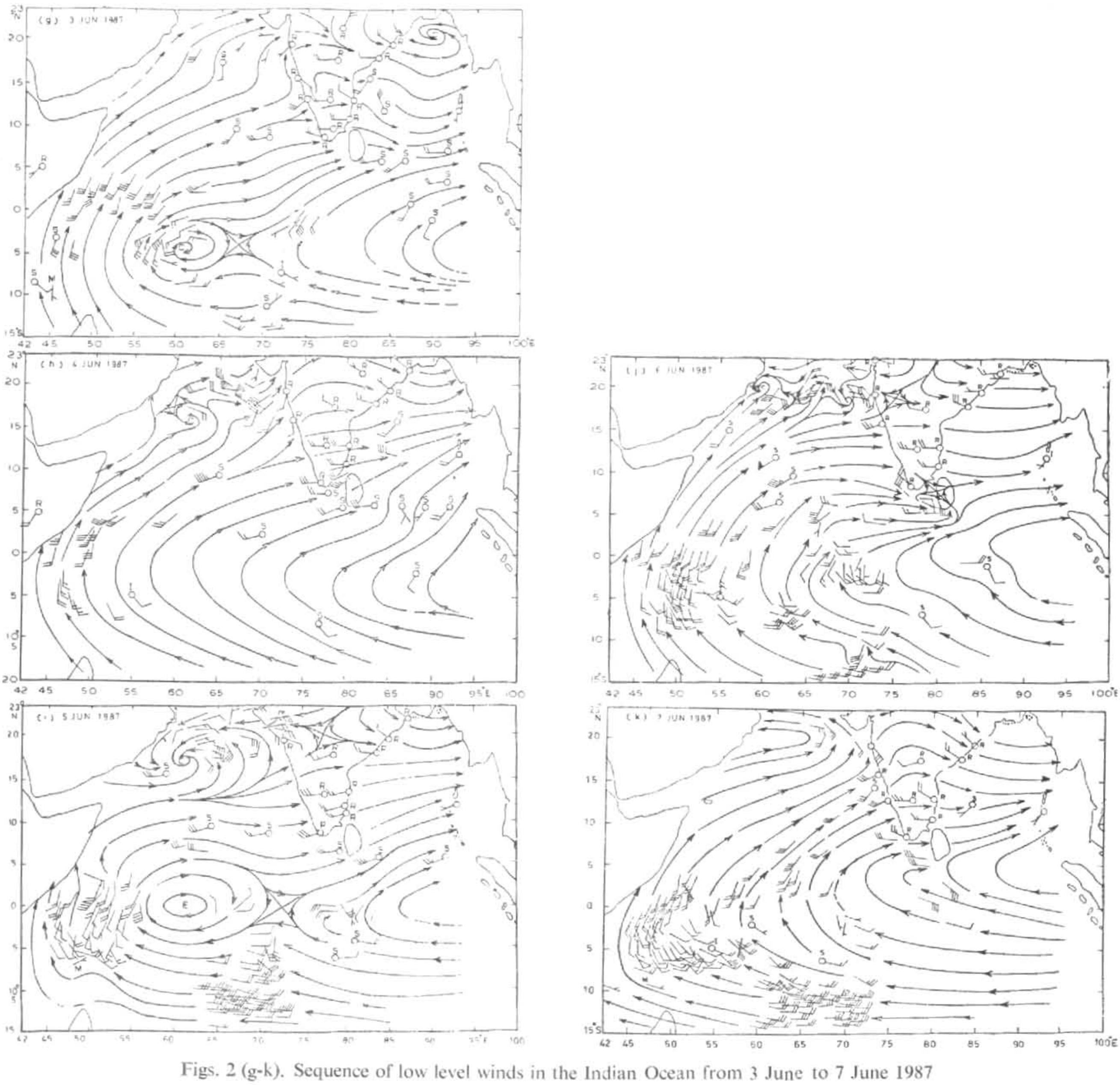
The CMVs that did not support the prevailing synoptic features over any area and the CMVs that were not justified by the cloud configurations seen in the satellite imagery were edited suitably. This check is to finalise the data set coherent with the characteristic features of the current weather systems. However, for examining any meso-scale features this check is to be applied judiciously.

The four checks described above result in the elimination of spurious CMVs, the rejection of CMVs not representing the general wind flow and finally the creation of a cohesive CMV data set.

Table 1 shows the number of INSAT CMVs rejected at each stage of the 4-step 'decision tree', starting from the raw data set. It may be seen that during the 11-day period considered here, the percentage of acceptable CMVs was 70-80% on any given day. The largest rejection occurred at stage II, *viz.*, gradient check.

3. Analysis and interpretation of data

Figs. 2 (a-f) show the plot of low level CMVs just before and on the day of the onset of monsoon over Kerala and Figs. 3 (A-F) show the corresponding INSAT



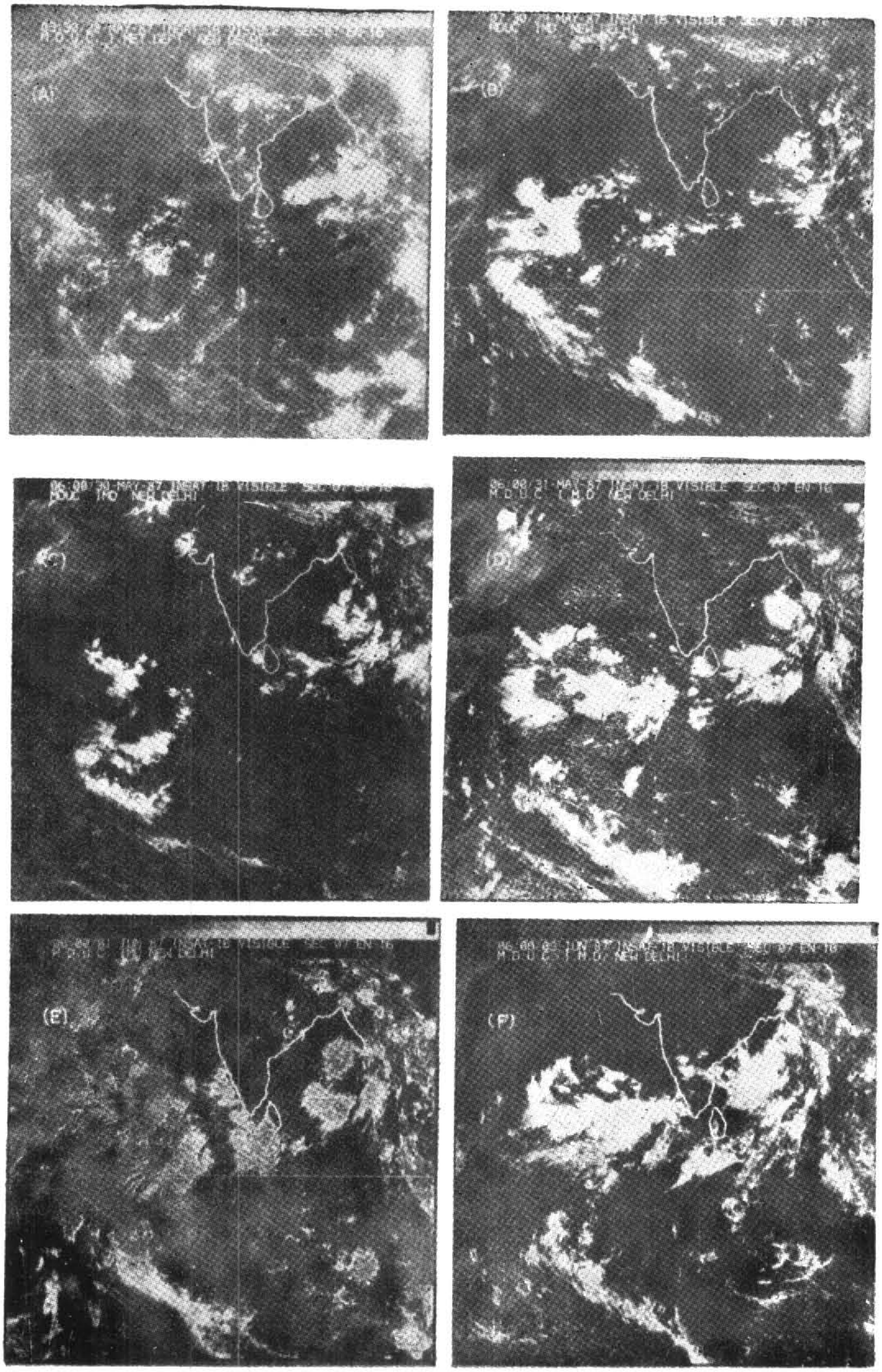
Figs. 2 (g-k). Sequence of low level winds in the Indian Ocean from 3 June to 7 June 1987

cloud imageries. Similarly, Figs. 2 (g-k) and Figs. 3 (G-K) show the plot of low level CMVs and the corresponding INSAT cloud imageries respectively just after the onset of monsoon. The INSAT images are mostly for 0600 GMT. Figs. 2 (a-k) have plot of all the accepted INSAT CMVs and also the plot of winds (obtained by conventional methods for the observation time ± 6 hours of 06 GMT) which are plotted as R, I, M and S where R denotes Radiosonde/Rawin/Pibal wind over the continents, I denotes Radiosonde/Rawin/Pibal wind over the Islands, M denotes the CMVs derived from METEOSAT images and S denotes Ships' wind observations. The results of the streamline analysis of CMV data are discussed below.

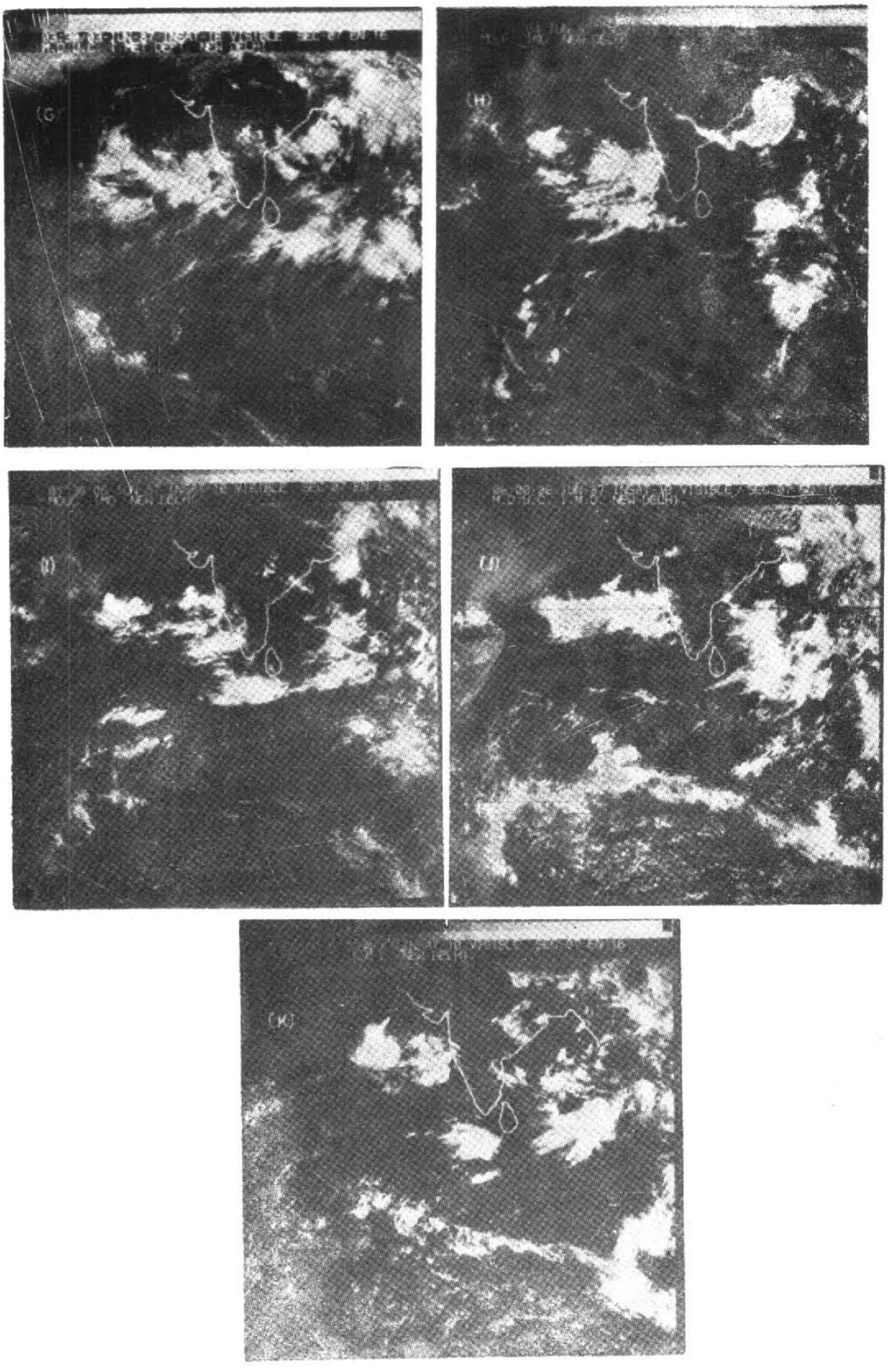
3.1. *Pre-onset phase* (28 *May*-1 *June* 1987)

The CMVs in the Indian Ocean (IO) sector were having mostly northerly or easterly component on 28 May but changed into southerly or westerly component on 29 May. Later, they became southwesterly or west-southwesterly CMVs.

On 28 May, the air flow was strong northeasterly in the southeast Arabian Sea off Kerala coast and CMVs did not indicate any cross-equatorial flow between 55° E and 80° E. But on 29 May the air current crossed over the equator into northern hemisphere. At Somali coast the equatorial flow (Fig. 2b) from the southern hemisphere was evident from the INSAT-CMVs reported as southerly/20 kt off Somali coast and also from the METEOSAT-CMVs reported as southerly/10 kt off the adjoining east coast of Africa. On 30 and 31 May 1987 the cross-equatorial flow was also clearly noticed with speed of CMVs increasing up to 35 kt especially off Somali coast.



Figs. 3 (A-F). Sequence of visible pictures showing clouds over the Indian Ocean from 28 May to 2 June 1987



Figs. 3 (G-K). Sequence of visible pictures showing clouds over the Indian Ocean from 3 June to 7 June 1987

The circulation to the southwest of Sri Lanka on 28 May moved into southeast Arabian Sea on 29 May. The changes in the wind field in the south Arabian Sea (from easterlies to southwesterlies) were under the influence of the progressive northward movement of this circulation/vortex and it brought the monsoon to Kerala on 2 June. During this period an anticyclonic circulation persisted over north Arabian Sea while the cyclonic circulation or the off-shore vortex also persisted over south Arabian Sea. The anticyclone got obliterated and the cyclonic circulation moved northward in such a way that on 1 June the equatorial trough (E-W oriented) was located along 14° N with full sway of 20-25 kt SW/WSW winds striking the Kerala coast. Thus the southwest monsoon current approaching the Kerala coast was well established on 1 June 1987 as also supported by the ships' observations (Fig. 2e) in the southeast Arabian Sea.

3.2. *Onset day* (2 *June* 1987)

Figs. 2 (d-f) show that the coastal winds over Kerala changed from southeasterly (on 31 May 1987) to westerly (on 1 June 1987) then to southwesterly (on 2 June 1987). Fig. 2 (f) shows that Trivandrum reported WSW/30 kt. This was all under the influence of the vortex which moved from the southwest of Sri Lanka to southeast Arabian Sea as an off-shore vortex. The CMVs over the southwest Indian Ocean and Indian Ocean sectors showed a strong sustained current from southern hemisphere crossing into northern hemisphere. This air flow not only swept the extreme southern Indian Peninsula but also emerged out into the Bay of Bengal where the Bay branch of monsoon was quite active. On this day the onset of monsoon over south Kerala was declared and there was widespread rainfall recorded in Kerala (Kozhikode 7 cm, Cunnanore 6 cm, Trivandrum city 5 cm, Allepy 3 cm, Punnalore 2 cm and Palghat 2 cm). The other synoptic feature noted in the upper air was that the cyclonic circulation located around 8°N, 63° E embedded in E-W trough along 8° N on 29 May moved north and merged with the trough located roughly along 14° N on 1 June.

The Bay branch of monsoon was also active with 15-20 kt southsouthwesterly winds crossing the equator between 75° E and 90° E and then feeding a monsoon depression centred in the Bay of Bengal at 1130 IST about 17° N and 88.5° E. The INSAT imagery (Fig. 3F) revealed the significant cloud features associated distinctly with (1) the onset of monsoon over Kerala, (2) the monsoon depression in the Bay of Bengal and (3) the two separate cross-equatorial currents, one active as the Arabian Sea branch and the other active as the Bay of Bengal branch of monsoon.

3.3. *Post-onset phase* (3-7 *June* 1987)

After the onset of monsoon over Kerala, the Arabian Sea branch continued to be active and smoothly progressed northward. This advance in the northern limit of monsoon (NLM) was well supported by the systematic movement in the cloud cover over the west coastline and consequently the CMVs of southwesterly flow also had systematic northward march in the Arabian Sea. The large coverage with CMVs over the Indian Ocean in this post-onset phase revealed the following significant information :

(*i*) The cross-equatorial flow was well established in terms of wind direction and speed.

(*ii*) The winds off Somali coast were not only sustained but also strengthening day-by-day from 20 kt to 40 kt.

(*iii*) The winds in south Arabian Sea had strengthened as southwesterly 30 to 40 kt and on 6 June 1987 a ship reported SW/50 kt (Fig. 2 j).

(*iv*) In the south Indian Ocean sector, the easterly winds having 5-15 kt speed on 3 June (Fig. 2 g) strengthened to 15-35 kt on 5 June 1987 (Fig. 2 i) and persisted thereafter.

(*v*) The cluster of CMVs from 5 to 7 June 1987 (Figs. 2 i-k) indicates clearly the full route of the airflow from south Indian Ocean and southwest Indian Ocean in the southern hemisphere crossing the equator and then emerging out into northern hemisphere, as a well established monsoon current. On 5 June an intense vortex formed in northwest Arabian Sea roughly around 17°N, 63° E and it later moved northnorthwest and became unimportant. It did detract the monsoon current away from the west coast of India keeping the sea area more prone to rain clouds than the Indian coast line. It was also observed that these vortices/troughs in the upper air can be distinctly traced over the sea area with the help of anaylsis of CMV data.

4. Concluding remarks

(*i*) The CMVs provide a wealth of wind data over the oceanic region hitherto not available for studies connected with the Indian summer monsoon. In this study the INSAT-CMVs proved to be very useful for understanding the low level air flow at the time of the onset of monsoon.

(*ii*) The CMV data are the main source of vital information like, (a) the formation of eddies, (b) the cross-equatorial flow, (c) the distinct approach of southwest monsoon winds towards the west coast of India, (d) the off-shore vortices and (e) the activity of the two branches of monsoon, *viz.*, Arabian Sea branch and the Bay of Bengal branch, etc.

(*iii*) A quality control technique has been developed in this paper to scrutinize the raw CMV data, and it is found that the deployment of this technique leads to the generation of a consistent data set.

(*iv*) It is felt that there is considerable scope for the use of the scrutinized CMV data in conjunction with the conventional wind data in our day-to-day synoptic analysis and forecasting.

(*v*) The normal air-flow pattern over the oceanic region could be worked out after collecting sufficient wind data over the Indian Ocean particularly for the monsoon period (June to September).

References

Ananthakrishnan R., Srinivasan, V., Ramakrishnan, A.R. and Jambunathan, R., 1968, "Synoptic features associated with the onset of the southwest monsoon over Kerala", *India met. Dep. Forecasting Manual*, IV, 18.2.

Cadet, D. and Debois, M., 1979, "Low level airflow over the western Indian Ocean as seen from Meteosat", *Nature*, **278**, 538-539.

Findlater, J., 1969, "A major low-level air current near the Indian Ocean during the northern summer", *Quart. J. R. met. Soc.*, **95**, 362-380.

Hubert, L.F. and Thomsell Jr. A., 1979, "Error characteristics of satellite-derived winds", NOAA Tech. Rep. NESS 79.

Jambunathan, R., 1974, "Satellite cloud picture data for prediction of onset of southwest monsoon over Kerala", *Vayu Mandal*, **4**, pp. 34-35.

Kelkar, R.R. and Khanna, P.N., 1986, "Automated extraction of cloud motion vectors from INSAT-1B imagery", *Mausam*, **37**, pp. 495-500.

Kelkar, R.R., Sant Prasad and Mani Gandeswaran, S., 1987, "Spatial and temporal homogeneity in a half-hourly sequence of satellite-derived upper winds", *Mausam*, **38**, pp. 197-202.

Wylie, D.P. and Hinton, B.B., 1981, "Some statistical characteristics of cloud motion winds measured over the Indian Ocean during the summer monsoon", *Mon. Weath. Rev.*, **109**, 1810-1812.