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Satellite-derived monthly average wind fields over the Indian Ocean in April-July 1988

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सार — यह शोध-पत्र, हिन्द महासागर के भागों पर, भारतीय उपग्रह से व्युत्पन्न मेघ गति सदिश पर आधारित अप्रैल 1988 से जुलाई 1988 तक की अवधि के लिए औसत मासिक पवन प्रवाह का वर्णन करता है। मोनेक्स-79 के दौरान GOES आंकड़ों से पहले से प्राप्त प्रतिमानों से IIOE एटलस में दिए गए माध्य मासिक जलवायु विज्ञान से तुलना की गई। औसत पवन क्षेत्र से व्युत्पन्न भ्रमिलता और सृति क्षेत्र की भी चर्चा की गई। मानसून पूर्व से मानसून प्रतिमान तक के संक्रमण को इस विश्लेषण में स्पष्ट रूप से प्रस्तुत किया गया है। जून में, सोमाली तट की तरफ पूर्व से पश्चिम पवन गति की वृद्धि 2° उत्तर के आसपास प्रबलत्तम है और निम्न स्तर प्रवाह में पवन अधो-प्रवाह को आगे बढ़ाती हुई निम्न स्तर जेट के निर्माण को दर्शाती है।

ABSTRACT. This paper describes the average monthly wind flow for the period from April 1988 to July 1988 based on the INSAT-derived cloud motion vectors over parts of the Indian Ocean. Comparison of these patterns has been made with those obtained earlier during MONEX 1979 with GOES data and with the mean monthly climatology given in the IIOE atlas. The vorticity and vergence fields derived from the average wind fields have also been discussed. The transition from the pre-monsoon to the monsoon pattern is clearly brought out in the analysis. In June, the east-to-west increase of the wind speed towards Somali coast is strongest along 2°N and further strengthening of the wind down-stream in low level flow reflects the formation of the low level jet.

1. Introduction

Observations of the wind flow over the oceanic areas are an important pre-requisite to weather prediction by numerical models and to synoptic scale forecasting. Prior to the utilisation of the geostationary meteorological satellite INSAT-1B, the Indian Ocean had remained a perennial data gap region in this respect. The derivation of cloud motion vectors (CMVs) from INSAT imagery commenced in November 1984 at the Meteorological Data Utilisation Centre, using an automated procedure (Kelkar and Khanna 1986). Subsequently, the areal coverage was extended and interactive quality control procedures were introduced. From January 1988, high-quality CMV data sets on magnetic tapes are available. The data are also being disseminated on Global Telecommunication System (GTS).

Many studies have been conducted with the CMV data generated from the GOES satellite which was temporarily brought over the Indian Ocean during MONEX 1979. Joshi *et al.* (1987) assessed the impact of the GOES-derived winds in monsoon forecasting using a general circulation model. Mahajan *et al.* (1986) studied the onset of the 1979 monsoon with respect to the wind pattern and its changes in the lower levels over west Indian Ocean using satellite winds derived from GOES data during MONEX 1979. They related the abrupt changes in the flow pattern with the onset of monsoon and concluded that the satellite-derived wind data are of potential use to forecast the onset of monsoon rainfall along the west coast of India. The onset of the monsoon in 1987 over India was examined by Yadav and Kelkar (1989) with reference to INSAT-derived cloud motion vectors.

The areas over which INSAT CMVs are derived as a routine are shown in Fig. 1. The CMVs derived at 06 UTC are transmitted over the GTS. For the study of the monsoon activity in all the phases, namely, onset, advance and withdrawal, the deviation of the flow pattern from climatological fields is of interest. Such fields over the oceanic areas in the monsoon region were in the past, derived with the data obtained in specially organised experiments such as IIOE of 1963-64 (Ramage and Raman 1972). These fields were derived with the observed winds through radiowind ascents over the oceanic area which are sparse in space and time scales. However, the GOES derived satellite winds were used for the first time in calculating the average fields over the monsoon area during May to June 1979 by Young *et al.* (1980) who used objective analysis on a grid. In view of the encouraging agreements of the daily INSAT satellite-derived wind patterns with the wind analysis from synoptic charts, an attempt has been made in the present paper to construct the average wind fields over the oceanic areas over which the INSAT CMVs are derived. Unlike over land, CMVs and winds may be regarded as synonymous over oceanic areas. The average monthly wind patterns were derived for the period from April 1988 to July 1988 in order to observe the changes in the wind flow during the pre-monsoon to monsoon periods. The authors have also presented the average monthly vergence and vorticity patterns for the above period.

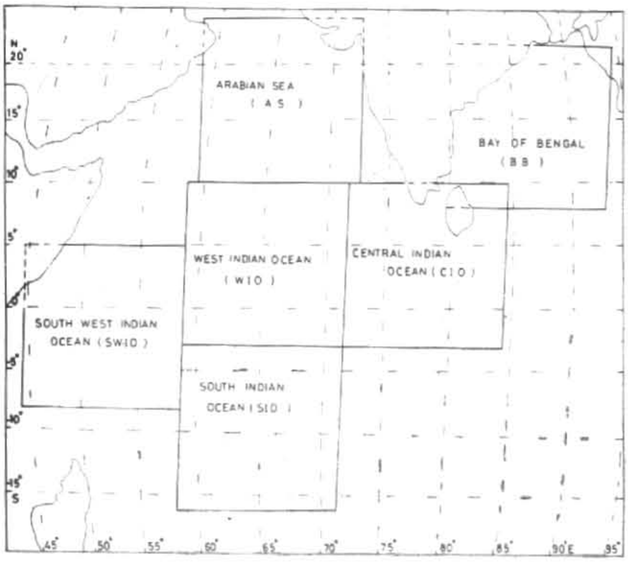

Fig. 1. Areas of Indian Ocean over which INSAT CMVs are derived at 06 UTC. CMVs for Arabian Sea, Bay of Bengal and central Indian Ocean are also derived at 03 UTC.

2. Data used

The INSAT cloud motion vectors are basically derived through an automated procedure (Kelkar and Khanna 1986) and they show a good degree of spatial and temporal consistency (Kelkar *et al.* 1987). The CMVs are computed for every 1-deg. latitude/longitude box subject to availability of suitable cloud tracers. These CMVs are then subjected to quality control by interactive editing procedures which are described by Yadav and Kelkar (1989). Those CMVs, which are not supported by synoptic features as indicated by the cloud configuration, are deleted. For editing 06 UTC, CMVs, synoptic upper air charts of 00 UTC which are the latest available, are used for reference. Those CMVs which indicate isolated strong gradients are also eliminated. The CMVs which are not consistent internally, and CMVs in disagreement with known climatological features are deleted.

For the analysis of the present paper CMVs of 03 and 06 UTC (daily) for the period April-July 1988 were used.

3. Methodology

In the MDUC CMV derivation technique the CMVs are assigned a height corresponding to the modal cloud top temperature of the reference pattern. In the present study, the CMVs are categorised in two levels. Those CMVs whose heights are less than 3 km are taken as low level CMVs and those whose heights are greater than 8 km are taken as high level CMVs. The CMVs are resolved into their east (U) and north (V) components. Since the CMVs can be derived only in the region where cloud tracers are available, it is obvious that their density is not uniform. Therefore, CMVs are averaged over 2.5 deg. latitude/longitude boxes. Although occasional instances of strong vertical wind shears may exist, they can be ignored in view of the spatial and time averaging done for this study. The monthly averages of these CMVs for each box were computed subject to the condition that there should be at least five CMVs in a box during the month. However 85% of the boxes had more than 10 CMVs. These CMVs were plotted and streamlines were drawn. Isotachs were drawn at the intervals of 10 kt.

Using the average U and V components in each box, the divergence and vorticity fields were also derived as monthly mean pattern as per the following formulae :

$$\text{Divergence} = \frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y}, \qquad \text{Vorticity} = \frac{\partial V}{\partial X} - \frac{\partial U}{\partial Y}$$

Since the grid size is only 2.5° Lat./Long. equal weightage was given to all CMVs for averaging within a box. The central finite difference method has been employed to calculate the divergence and vorticity as follows :

$$\text{Div}\,(i,j) = \frac{U_{(i+1,\,j)} - U_{(i-1,\,j)}}{2\,d\cos\phi} + \frac{V_{(i,\,j+1)} - V_{(i,\,j-1)}}{2\,d}$$

$$\text{Vor}\,(i,j) = \frac{V_{(i+1,\,j)} - V_{(i-1,\,j)}}{2\,d\cos\phi} - \frac{U_{(i,\,j+1)} - U_{(i,\,j-1)}}{2\,d}$$

where, (i, j) is the grid point, ϕ is the latitude in degrees and d is the grid distance.

The formulae cannot be applied at the edges of the sectors.

Isolines are drawn on the average monthly values at the interval of 1×10^{-6} sec^{-1}. Though the vorticity and vergence patterns have been computed for all the four months, we are presenting the patterns of April and July 1988 only to bring out the contrast between pre-monsoon and monsoon situations.

4. Results and discussion

4.1. *Mean low level wind flow*

The mean wind patterns for low level winds for April, May, June & July 1988 are shown in Fig. 2. These patterns are compared with those presented by Young *et al.* (1980) and Ramage & Raman (1972).

In the month of April, the ridge line runs along 15° N with circulation centres lying over Arabian Sea & Bay of Bengal and is more or less in the normal position. The winds are light up to 10° S. In the northern hemisphere, the winds east of 75° E have a southerly component while the winds west of 75° E have predominantly northerly components.

In the month of May, a ridge is located along 67° E over Arabian Sea while the anticyclone over Bay of Bengal has moved eastwards. A trough is located along the east coast. A convergence zone is located in the southern hemisphere roughly along 5°S. The south-easterlies, south of this convergence zone are stronger. North of this convergence zone, the winds are light except over the north Arabian Sea. The west to east increase of wind speeds along 5°S in May is in agreement with the mean pattern of May (Ramage & Raman 1972).

In the month of June, the cross-equatorial flow has set in and both the branches of the monsoon, *i.e.*, Arabian Sea and Bay of Bengal branches are well established. The winds over the Bay of Bengal are convergent towards the head Bay. Near the latitude of recurvature (SE becoming SW'ly), *i.e.*, about 2° N, the winds are light over the longitudinal belt between 60° E & 85° E becoming stronger west of 60° E. The stronger winds of the

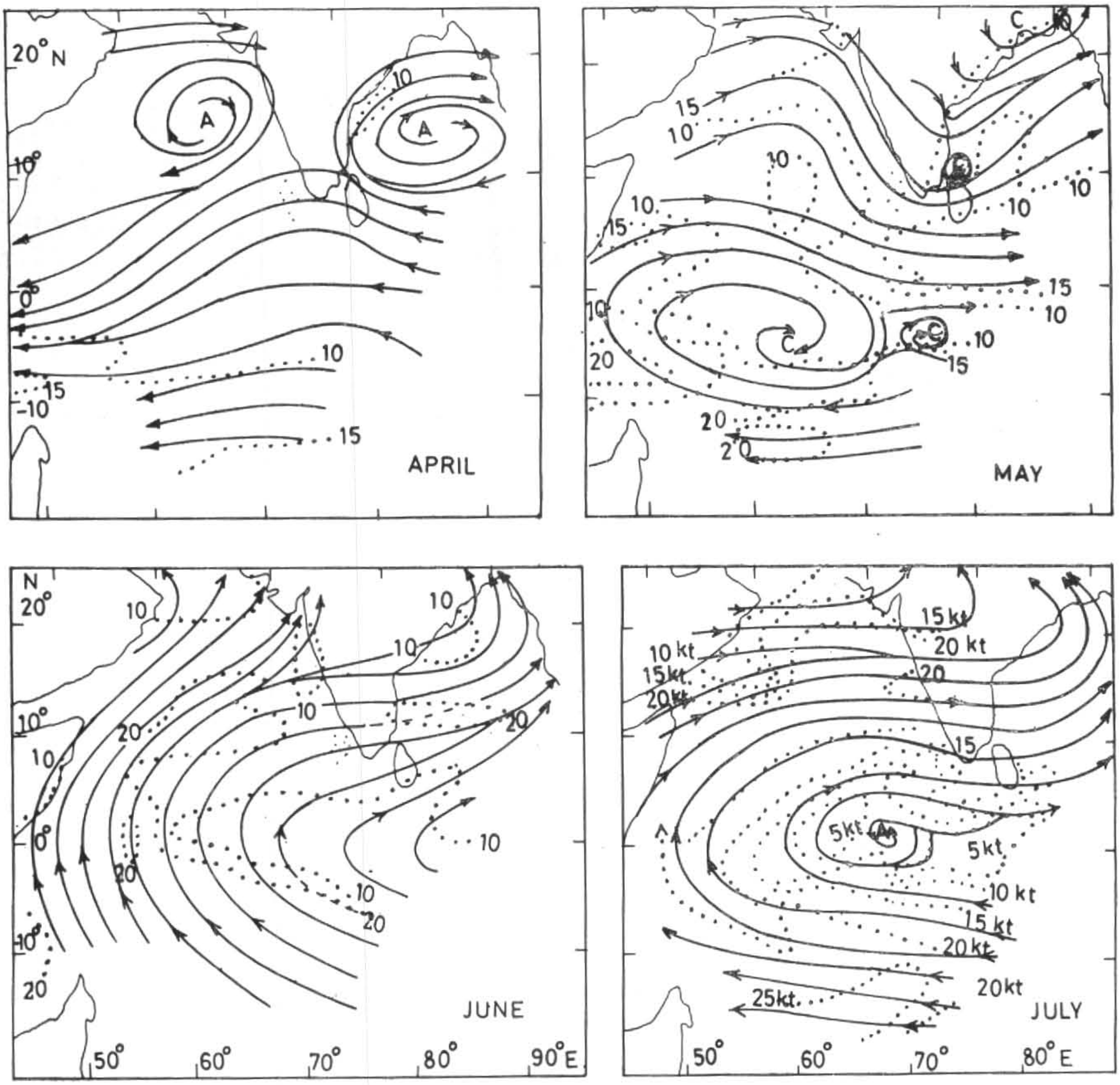

Fig. 2. Average monthly flow patterns and isotachs (in knots) for April, May, June and July 1988 derived from low level CMVs

order of 25 to 30 kt off the coast of Somalia continuing further downstream up to Peninsular India, suggest the presence of low level jet. On comparison of this pattern with that presented by Young *et al.* (1980) the southeasterly flow in the southern hemisphere is comparatively stronger in June 1988, a normal monsoon year, than the winds in the month of June 1979 (Young *et al.* 1980) which was a bad monsoon year.

In the month of July, the wind pattern continues to exhibit similar features with increase in convergence over head Bay. The monsoon trough is well-established. Anticyclonic vortices are seen roughly along the equator east of 70° E. A comparison of these charts (April to July) with those of IIOE atlas (Ramage & Raman 1972) shows close agreement.

4.2. *High level wind flow*

The high level wind patterns for the corresponding months are given in Fig. 3.

The ridge line in the northern hemisphere in April lies approximately along 10° N which is very near to the normal position as expected in a normal monsoon year, like 1988. The position of the ridge line in the southern hemisphere also closely agrees with the normal position which is located around 10° S. Winds of the order of 20 kt are seen over the southeastern Arabian Sea and adjoining central Arabian Sea. In May, the ridge line is located somewhat north of the normal position in the northern hemisphere while its position in the southern hemisphere agrees with the normal. Easterlies, characteristics of

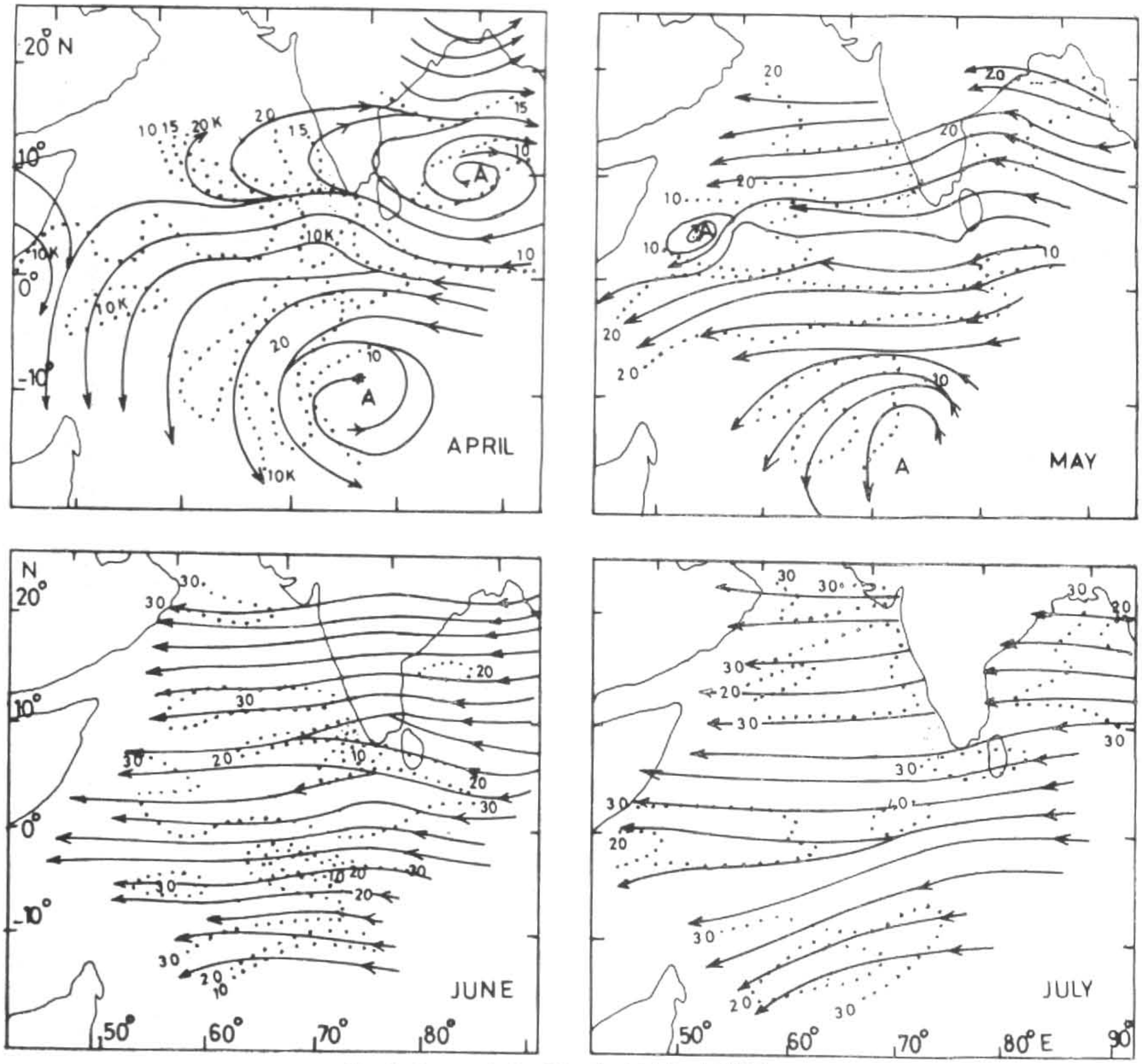

Fig. 3. Same as in fig. 2 but for high level CMVs

monsoon season, are well brought out in the charts of June and July over the Arabian Sea, Bay of Bengal and central Indian Ocean.

4.3. *Vorticity fields*

4.3.1. *Low level pattern* — The vorticity patterns are shown in Fig. 4 for April and July, the representative months for pre-monsoon and monsoon season. The low level vorticity pattern in the month of April indicates two negative vorticity centres in the central Bay of Bengal and Arabian Sea which coincide with the anticyclonic centres located over the same areas in the low level flow pattern. Positive vorticity is seen along the equatorial regions between 60° E and 80° E.

As the season changes from pre-monsoon to monsoon months, the vorticity fields become weak. The anticyclonic vorticity moves northwards and cyclonic vorticity prevails over northern portions of Arabian Sea as well as the Bay of Bengal in conformity with the progress of the monsoon season.

4.3.2. *High level pattern* — In the pre-monsoon season particularly in the month of May (not shown), cyclonic vorticity prevails over the Bay of Bengal in the high levels. This relates to the fact that no storm formed in the Bay of Bengal during the month May 1988 although cyclonic vorticity prevailed in the low levels. This pattern changed in the monsoon season with the prevalence of anticylonic vorticity both in the Arabian Sea and Bay of Bengal north of 10°N latitude. Over this region, being north of the mean position of easterly jet, anticyclonic vorticity is a normal feature.

The belt of anticyclonic vorticity along 2° N during pre-monsoon season changes to cyclonic vorticity in the monsoon season.

4.4. *Vergence fields*

4.4.1. *Low level patterns* — The vergence patterns for the months of April and July are shown in Fig. 5. A broad zone of convergence prevails over equatorial region during the pre-monsoon season. A small area of

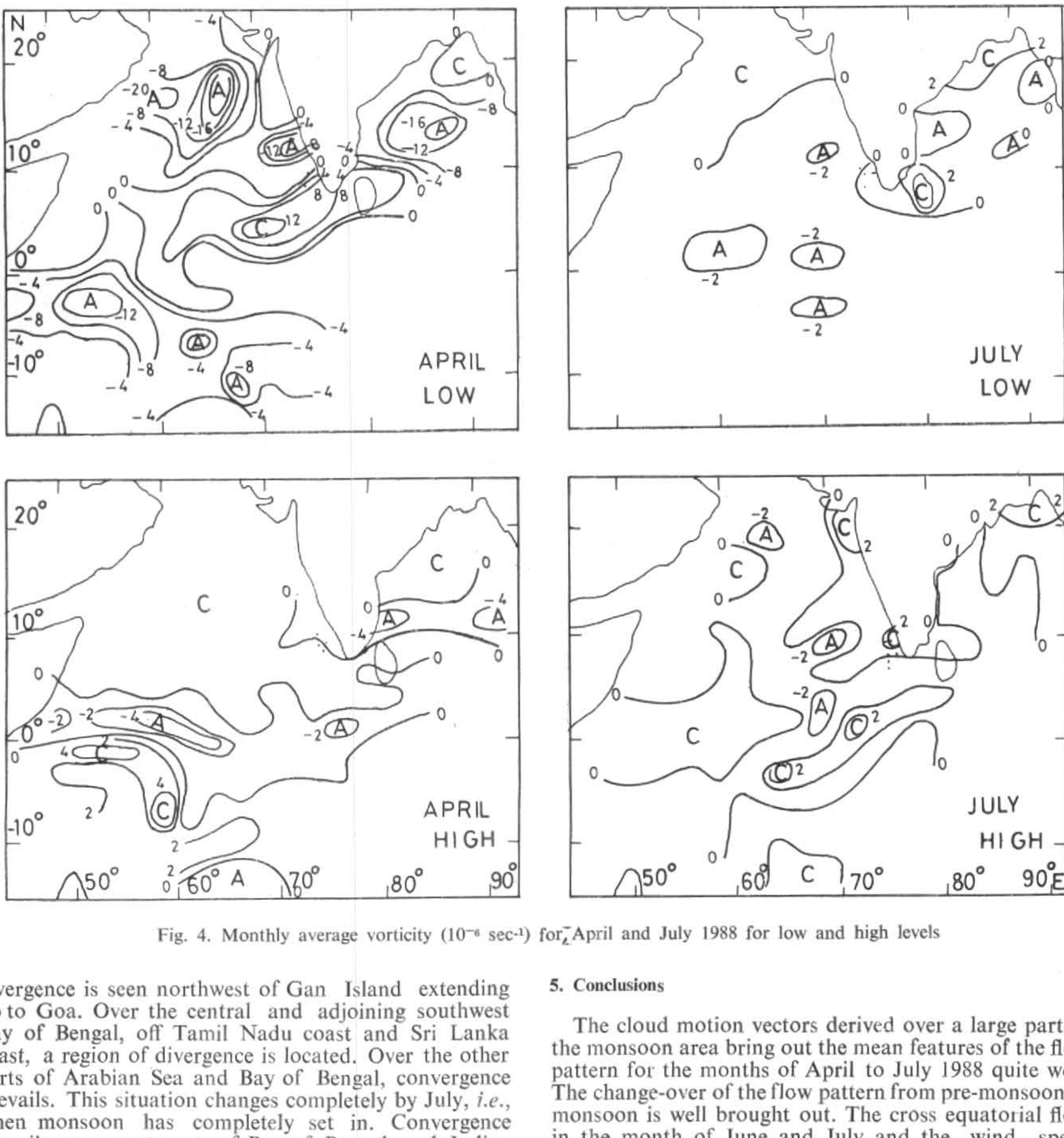

Fig. 4. Monthly average vorticity (10^{-6} sec^{-1}) for April and July 1988 for low and high levels

divergence is seen northwest of Gan Island extending up to Goa. Over the central and adjoining southwest Bay of Bengal, off Tamil Nadu coast and Sri Lanka coast, a region of divergence is located. Over the other parts of Arabian Sea and Bay of Bengal, convergence prevails. This situation changes completely by July, *i.e.*, when monsoon has completely set in. Convergence prevails over most parts of Bay of Bengal and Indian Ocean and eastern parts of Arabian Sea except over the region northwest of Gan Island and over southwest Bay of Bengal off Tamil Nadu and Sri Lanka coasts where weak divergence prevails.

4.4.2. *High level pattern* — In the pre-monsoon season in higher levels, a broad belt of divergence occurs, in the equatorial regions. A tongue of this belt extends up to Kerala coast and further eastwards to the southwest Bay of Bengal. This upper air divergence and the low level convergence zone may, perhaps, be associated with the widespread thunderstorm activity over Kerala and off Kerala coast during this season. As the monsoon establishes over the country, convergence prevails in most parts of the Bay of Bengal. A broad zone of divergence prevails north of equator over Indian Ocean.

5. Conclusions

The cloud motion vectors derived over a large part of the monsoon area bring out the mean features of the flow pattern for the months of April to July 1988 quite well. The change-over of the flow pattern from pre-monsoon to monsoon is well brought out. The cross equatorial flow in the month of June and July and the wind speed gradients from east to west are in conformity with the charts presented by Young *et al.* (1980). The low level vorticity and vergence fields also agree to a large extent with the mean patterns given by Hastenrath and Lamb (1979) for the surface patterns. The northward progression of the convergence field from April to June is in good agreement with the onset phase of the monsoon current.

The analyses based upon the INSAT cloud motion vectors, support the existing concepts of the arrival of the monsoon current from the southern hemisphere. The present study, though preliminary, has well depicted the changes in the flow pattern from pre-monsoon season to monsoon season.

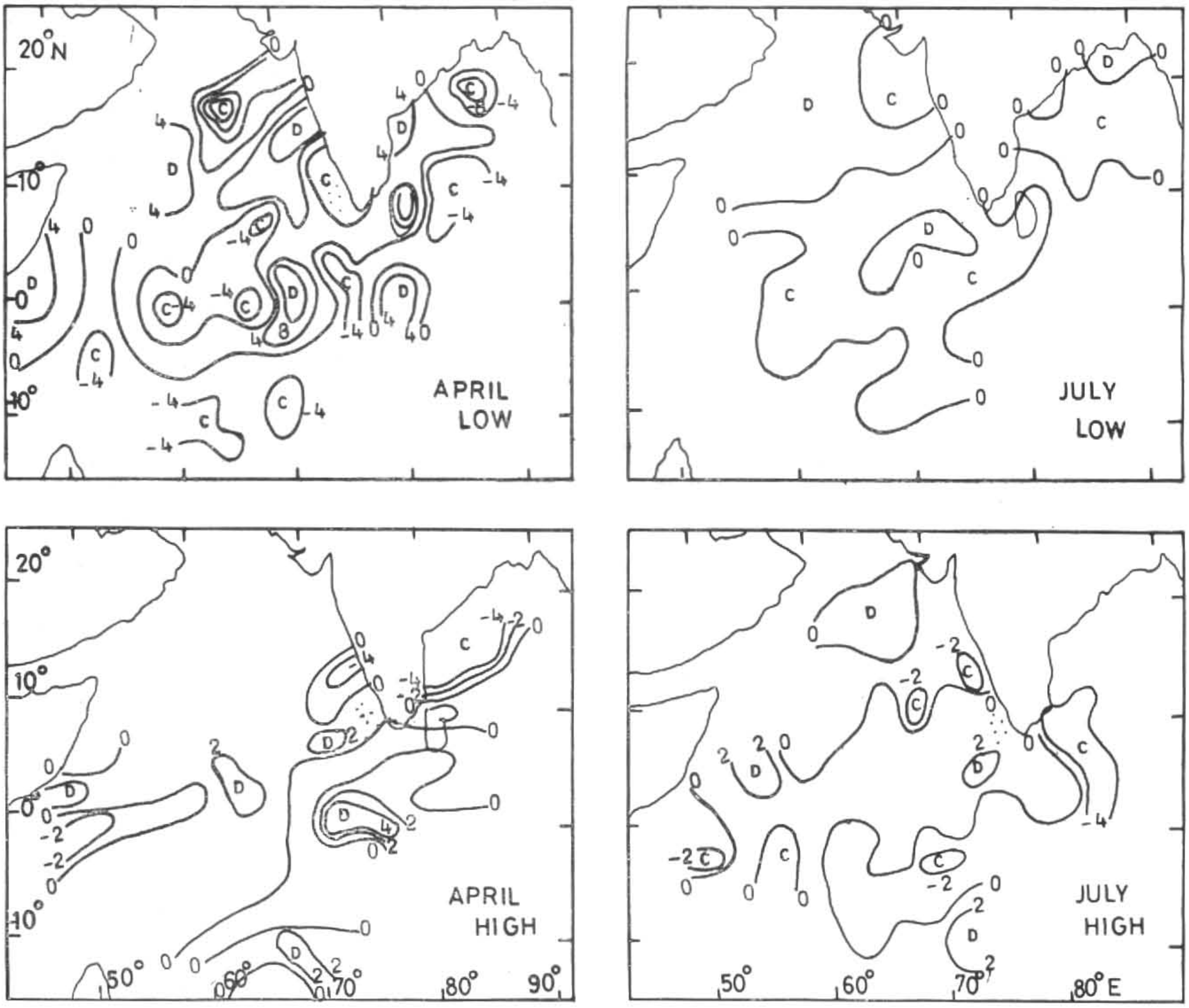

Fig. 5. Same as in Fig. 4 but for divergence (10^{-6} sec^{-1})

It is proposed to expand the scope of the work to cover all the months (subject to availability of tracers), using a larger CMV data base, as it gets built up over the coming years.

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