RECENT IMPROVEMENTS IN CLOUD MOTION VECTOR DERIVATION FROM INSAT

R.R.Kelkar, A.V.R.K.Rao and R.C.Bhatia

India Meteorological Department
New Delhi 110 003 India

ABSTRACT

Cloud Motion Vectors were being derived since 1984 from INSAT, using visible imagery for cloud tracking and infra-red temperatures for height assignment. The derivation was made at 0600 UTC daily over the Arabian Sea, Bay of Bengal and a limited area of the western and central Indian Ocean. The method used was basically an automated procedure with a manual quality control.

INSAT-2A, the first of India's second generation operational satellites, was launched in July 1992. The INSAT-2A VHRR has an improved resolution of 2 km in the visible channel and 8 km in the infra-red channel. Coinciding with the launch of INSAT-2A, the ground data processing system was also upgraded. This has made it possible to derive CMVs at the standard synoptic hours of 0000 and 1200 UTC using infra-red channel data for cloud tracking as well. The system is capable of deriving up to 1000 wind vectors over the entire Indian Ocean from triplet images within about two hours. The CMV information is disseminated on the GTS.

This paper describes in detail the computational procedure currently used for extraction of INSAT CMVs, the techniques adopted for quality assurance, typical situations showing the usefulness of the INSAT CMVs, validation exercises and future plans for further improvements in the algorithms.

1. INTRODUCTION

In spite of their inherent errors and uncertainties, Cloud Motion Vectors (CMVs) derived from geostationary meteorological satellites have a significant use in operational synoptic analysis and numerical weather forecasting, as they represent the only source of upper wind data over the vast oceanic regions of the globe. Around the Indian peninsula, the only radiowind stations are those situated in the Lak-shadweep group of islands in the Arabian Sea and in the Andaman and Nicobar islands of the Bay of Bengal. Thus for the Indian Ocean region, CMVs are the best means of augmenting the meagre conventional data otherwise available.

In 1984, the India Meteorological Department commenced the use of the Indian geostationary satellite, INSAT-1B, for the purposes of extraction of CMVs, thus partially covering the data gap over the Indian Ocean. The computation procedure, which underwent many improvements over the years, has been described in several earlier papers (Kelkar et al 1986,1987, 1992, Kelkar 1993 and Yadav et al 1989). The basic approach was to make use of the INSAT visible imagery provided by the VHRR at a resolution of 2.75 km at the SSP, since the resolution of the infra-red channel was 11 km. This required that the CMV extraction be carried out around 0600 UTC when the INSAT disc would be fully illuminated. Further constraints were imposed by the lack of adequate computer resources, as a result of which the CMV extraction had to be performed in small sectors, of about 14 x 14 deg lat/long size, one at a time. The dissemination over the GTS was also done sector-wise and was spread over several hours. Even then, it was not possible to cover the entire Indian Ocean and the CMV coverage was restricted to the Arabian Sea, Bay of Bengal and parts of western and central Indian Ocean.

However, the INSAT CMVs have provided a wealth of information besides their use in day-to-day synoptic analysis particularly in relation to the southwest monsoon. They have been effectively utilised for studying various aspects like the formation of eddies, cross-equatorial flow, approach of the southwest monsoon towards the west coast of India, off-shore vortices and the extent of monsoon activity (Yadav and Kelkar 1990). The shift in the large-scale flow pattern after the onset of the monsoon and the establishment of low-level westerlies and upper-level easterlies is clearly brought out through the INSAT CMVs (Sant Prasad et al 1990).

2. INSAT-2 SATELLITE SERIES

The first spacecraft of the second-generation INSAT satellite series, INSAT-2A, was launched on 10 July 1992 and this has been followed by the successful launch of the INSAT-2B satellite on 23 July 1993. The INSAT-2 series while conforming to the basic multi-mission philosophy of the INSAT-1 series, have a Very High Resolution Radiometer (VHRR) which has an improved resolution of 2 km in the visible channel (0.55-0.75 microns) and 8 km in the infra-red channel (10.5-12.5 microns) as compared with 2.75 and 11 km respectively in the INSAT-1 satellites. The INSAT-1D satellite continues to be in operational service. India is thus at present in a fortunate position of having as many as three operational geostationary satellites viz. INSAT-1D, 2A and 2B stationed at longitudes 83, 74 and 93.5 deg E respectively.

3. NEW INSAT DATA PROCESSING FACILITY

Synchronising with the launch of the INSAT-2A satellite, IMD also established a new INSAT-2 Meteorological Data Processing System at New Delhi. A key feature of this new facility is its advanced and distributed computer architecture built around eight indigenous VAX 3400 computers. The system provides excellent built-in redundancy and high flexibility to allocate optimum computer power to various processing jobs. The eight computers are interconnected through an Ethernet local area network and they access a 4 Gb disk cluster via dual-ported disk controllers. Three of the eight nodes are assigned the ingest function in a redundant manner, and data streams from three satellites, INSAT-1D, INSAT-2A and polar-orbiting NOAA satellite, can be handled simultaneously, as also the GTS data from IMD's message switching computer. The other five computers are used for various output functions, such as hard-copy generation, tape archival, near-real time data dissemination to secondary users and applications like CMV extraction, SST and TOVS retrievals, etc. They also support four interactive image processing work stations. A part of the CMV computation job is passed on to two auxiliary array processors.

4. REVISED CMV ALGORITHM AND PROCEDURES

With the availability of improved resolution on the INSAT-2 VHRR and the required computer processing resources, a revised and improved algorithm for CMV computation was installed and the procedures modified with a view to meeting many long standing user demands. From 1 January 1993, INSAT-1D images are being used for deriving CMVs at 0600 UTC and INSAT-2A images for 0000 and 1200 UTC. The 0600 UTC CMVs are not sent over the GTS but used within IMD, whereas the 0000 and 1200 CMVs are disseminated regularly on the GTS. In each case, an image triplet is used. For example 0000 UTC CMVs are derived from INSAT-2A images of 2330, 0000 and 0030 UTC. The area of CMV derivation has now been extended to the entire Indian Ocean. The dissemination over the GTS is done in one batch within three hours.

The revised INSAT CMV algorithm performs cloud tracking by the cross-correlation method on cloud tracers in the central image with the previous and following images. This is followed by extensive quality assurance checks in an automated mode and the valid CMVs passing these tests are displayed on a video screen for manual editing before they qualify for GTS dissemination. The 0000 and 1200 UTC CMVs are derived at a grid interval of about lxl deg lat/long while the 0600 UTC CMVs are derived over a 2.5 x 2.5 deg grid. These grid locations are scanned for the presence of potential tracers. In the cloud tracking done on visible imagery, a tracer is considered acceptable if at least 10 % of the pixels in the pattern are cloudy, otherwise it is märked as clear. In the infra-red algorithm, the tracer is further categorised into low, middle or high level depending upon whether at least one-thirds of the cloudy pixels fall in that category.

The cross-correlation process involves normalisation of the reference window image chips, computation of the correlation matrix and normalisation of the search window sub-arrays. Two types of correlation peak quality tests are made to examine the sharpness of the peak and the likely presence of secondary peaks outside the peak edge. It is possible to compute a finer correlation subsequently by concentrating on the area around the peak. The correlation peak location can thereupon be updated to sub-pixel position by fitting a second order curve by the Newton-Raphson method.

After the complete CMV field data base is generated for both the image pairs, the CMVs are first subjected to a stability test. If colocated CMVs derived from the successive image pairs show a speed difference exceeding 20 knots, they are rejected. Also, direction differences must be confined to tolerance limits of 90, 60 and 40 deg respectively for winds of speeds < 10, 10-30 and > 30 knots to be accepted. The two CMV data sets are then averaged for subsequent tests. Absolute thresholds of minimum and maximum wind speeds are applied at this stage and CMVs with speeds less than or exceeding these extreme limits get rejected. The specified limits are 8 knots on the lower side and 50, 70 and 200 knots on the higher side for low, middle and high level winds respectively. If the forecast wind fields are available, the CMVs are compared with them. Matchups within 300 km should agree in speed by 30 knots and in direction by 60 deg to be considered acceptable. If the forecast wind field comparison cannot be carried out for any reason, the CMVs are tested against climatological values for the season. The last quality check to be applied is the gradient check to eliminate CMVs which do not fit in with the overall flow pattern. Here, individual CMVs must not be at variance with their mean value over a 300 km square area by more than 30 knots and 60 deg in speed and direction. After all the above automated quality assurance tests have been performed, the accepted CMVs are viewed interactively by the analyst and he may decide to reject a few of them or he can reclassify some to a different height level. The final product data set is then coded as per the WMO SAT0B code and routed through the IMD message switching computer on to the GTS.

5. RESULTS AND DISCUSSION

The revised CMV algorithm is being used for the derivation of Cloud Motion Vectors over the entire Indian Ocean on an operational basis at 0000 and 1200 UTC from INSAT-2A and at 0600 UTC from INSAT-1D. The CMV data has been extremely useful for augmenting the data on which the synoptic analyses for these hours is based.

In recent months (November and December 1993), two tropical cyclones developed over the Arabian Sea and the Bay of Bengal and crossed the Indian coastline. The CMV fields over the oceanic regions were found to be of great help in the demarcation of the large-scale flow and hence in the prediction of the movement of the storms. Both the INSAT-ID and INSAT-2A CMV data during the days of these tropical cyclones have brought out the lower level as well as upper level flow patterns very clearly.

The CMV data derived from INSAT-2A at 0000 and 1200 UTC from infra-red image data was initially found to exhibit a rather high frequency of purely zonal winds (090 or 270 deg), while this feature was not noticed in the INSAT-1D CMVs derived with visible imagery. The basic reason for the large number of zonally aligned CMVs is the 8 km resolution of the INSAT-2A radiometer, which reduces the number of directions along which a tracer can be tracked.This is particularly so in the case of light winds which generate a tracer movement of only one or two i-r pixels. This anomaly has been removed through a software change introduced very recently, which performs a finer correlation computation in the area around the coarse peak, thus enabling accurate positioning of the wind vector in sub-pixel fashion instead of using discrete pixel locations for computing the vector direction.

A validation exercise has been carried out in which INSAT-2A CMVs were compared with upper wind data contained in AIREPs (aircraft reports). The comparison was made over the north Arabian Sea and adjoining land areas and southern parts of the Bay of Bengal from where AIREP reports are generally available in good number. For the period April - June 1993, wind data recorded at flight levels 370, 350 and 330 was compared with CMVs available for these heights within 2 deg of lat/long and 6 hours of observation time. The number of such colocated pairs was about 140. The results of the study showed that there is a good agreement between the CMVs and colocated AIREP data. Particularly, the AIREP data set also exhibited a higher incidence of upper winds with directions of 240-280 deg, just as in the case of the CMVs.

In another inter-comparison study, INSAT CMVs falling within the region of the overlapping coverage of the Japanese GMS satellite, were compared with GMS CMVs for the period January-September 1993. The study was restricted to upper levels of 200/250 mb. The search for colocated pairs was confined to a neighbourhood of 2 deg lat/long and the number of such pairs found was about 150 for 0000 UTC and 220 for 1200 UTC. The agreement between the INSAT and GMS data sets was found to be quite good, the speed differences being within 10 kts and the directions agreeing within 20 deg in 60 per cent of the cases studied.

6. REFERENCES

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.

Kelkar R.R. and Rao A.V.R.K. (1992) "Extraction of Quantitative Meteorological Information from INSAT Imagery", *J. Met.Soc. Japan,* 70, pp 551-561.

Kelkar R.R. (1993) "INSAT Meteorological Applications", *Advances in Tropical Meteorology,* Tata McGraw-Hill, pp 179-190.

Sant Prasad, Khanna P.N., Rao A.V.R.K, and Kelkar R.R.(1990) "Satellite-derived Monthly Averaged Wind Fields over the Indian Ocean in April-July 1988", *Mausam,* 41, pp 445-450.

Yadav B.R. and Kelkar R.R. (1989) "Lower Level Wind Flow over the Indian Ocean during the Onset of Monsoon-1987", *Mausam,* 40, pp 323-328.