RETRIEVAL AND VALIDATION OF CLOUD MOTION VECTORS USING INFRARED DATA FROM KALPANA-1 SATELLITE

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ABSTRACT

A new dedicated meteorological satellite KALPANA-1 was successfully launched on 12th September 2002 with an imager having three channels i.e. Visible, Infrared and Water vapour. The ground resolution of data are 2 km for visible and 8 km for Infrared and Water vapour. The derivation of Cloud Motion Vectors (CMVs) using infrared data has been started from April 2003. In the quality check procedure of the derivation technique, the output of the Limited Area Model (LAM) forecast, produced operationally in IMD, has been preferred over climatology. During the last one year, the derived CMV's were utilized for day to day operational forecast as well as input in the IMD's Limited Area Forecast System (LAFS).

Along with the salient points of derivation technique, the paper describes the validation of CMVs with the available LAM forecast and Meteosat-5 CMVs. The comparison shows that the quality of Kalpana-1 CMVs compares well with the Meteosat-5 CMVs. However, the density of Kalpana-1 CMVs is less. The error-statistics of these observations and its utility in operational forecast and also the impact of the data in the LAM analysis and forecast system is presented.

1. INTRODUCTION

Ever since the non-availability of data from INSAT-1D, India was looking forward for a suitable substitute to give continuity to its space observations related to weather. India took a leap when it could place 950 kg. weighing exclusive meteorological satellite in space by using its own launch vehicle namely Polar Satellite Launch Vehicle (PSLV) in the month of September 2002. This Satellite namely Kalpana-1 named after the Indian born US Astronaut Kalpana Chawala who lost her life during the return flight of Space Shuttle as a tribute to her. This satellite has a payload called Very High Resolution Radiometer (VHRR) with three channels viz. Visible (0.55µ-0.75µ), Infrared (10.5µ-12.5µ) and Water Vapour (5.7µ-7.1µ) with a ground resolution of 2 km, 8 km and 8 km respectively. After Kalpana-1 satellite became operational in the month of October 2002, IMD began deriving Cloud Motion Vectors (CMV) from the Infrared data, twice a day from the triplets at 23:30 , 00:00 and 00:30 UTC and 07:00, 07:30 and 08:00 UTC. The history of CMV derivation in IMD from INSAT data started with *Kelkar et.al (1986)* using pattern matching by searching equality in pixel to pixel between tracer and target images. With the inception of IMDPS, cross correlation technique is being used for pattern matching. Several improvements have been carried out by various scientists (*Bhatia et.al 1996, Khanna et.al 1998, Khanna et.al 2000)* with better results and reduced rms errors and biases.

In this paper, the CMV's derived from the infrared data of Kalpana-1 satellite have been presented. The derived CMV's have been extensively utilized to study ONSET of Southwest Monsoon of 2003 and 2004. Rapid Scan winds derivation capability has been demonstrated by production of winds for monsoon studies. Kalpana-1 derived CMV's have been compared with those derived from Meteosat-5 as a part of validation. Statistics of comparison between Kalpana-1 CMV's and the LAM forecast winds has been presented.

2. METHODOLOGY OF CMV DERIVATION

Like any other method for derivation of cloud motion vectors, the technique being used in IMDPS includes Registration of triplet imagery, Cloud Tracers selection and Tracking of Cloud Tracers, CMV computation, Height Assignment and Quality control of Cloud Motion Vectors.

2.1 Registration

In INSAT Meteorological Data Processing System (IMDPS), every reception is navigated automatically as a part of near real time processing. If required, the capabilities (NAV-SHIFT) are applied which exercise the North-South or East-West transnational shifts or rotation to achieve the accuracy of Navigation. It is presumed that frame-to-frame registration is achieved as a result of accurate navigation and the computation of vector displacement uses latitude/longitude of the initial and final points of the Vector.

2.2 Cloud tracers selection and tracking of cloud tracers

The process of identification of potential tracers is fairly simple process. The steps of cloud tracer selection includes (a) Tracer Location List Generation (b) Tracer Threshold Calculation (c) Tracer Histogram Generation (d) Tracer Selection . Initially a list of potential tracer is generated from each subset of 16 x16 pixels from the tracer image. The output of 18-layer cloud analysis model (Fig.1) has been used to get the range of pressure levels for low medium and high clouds. Using the Thermal Infrared calibration and the available vertical temperature profile data from NOAA, the corresponding gray shade values for the range of pressure levels are obtained. Cloud motion vector are derived from the triplet of images such as 23:30, 00:00 and 00:30 UTC and 07:00, 07:30 and 08:00 UTC of imagery. The central image i.e. the image of 00:00 UTC or 07:30 UTC is taken as tracer image. The other two images are taken as target images. In tracer image each subset of 16 x 16 pixels is used for identification of a cloud tracer. A four-bin histogram of the Infrared data delineating clear low, medium and high clouds is prepared (Fig.2). The tracer is identified corresponding to highest frequency of the bin. The identified tracer at each location is tracked in search windows of the target images using cross-correlation method (Fig.3). From the displacement in the direction of maximum correlation, the cloud motion vector is computed from the triplet of images for each location.

2.2.1 Masking option

Cloud tracking becomes difficult if multilayer clouds are present in the scene. To overcome this difficulty, IMDPS has a provision of ‘Masking Option’. All pixels in the reference and the Search window, which were not identified as part of a specific cluster, are masked out. Masking option exists for all 0’s, 200’s or random numbers. Many trials were made in IMDPS with various masking options. None of the trials has produced better results than ‘No Mask Option ’.

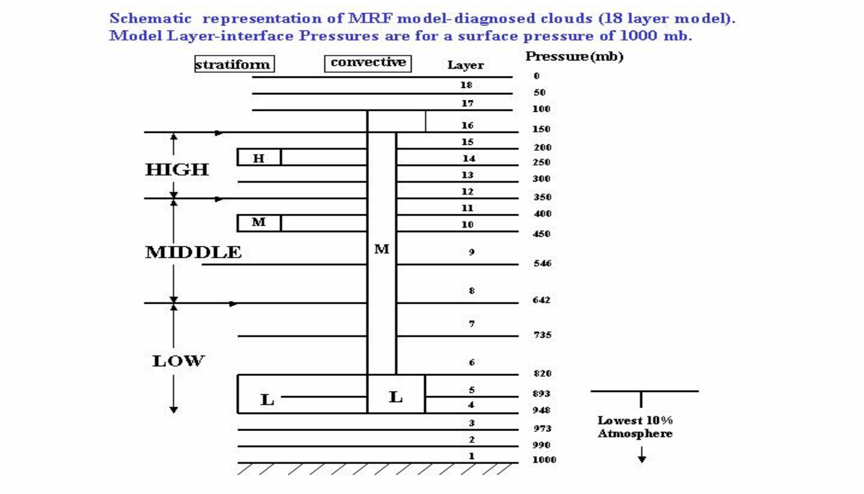


Figure 1.

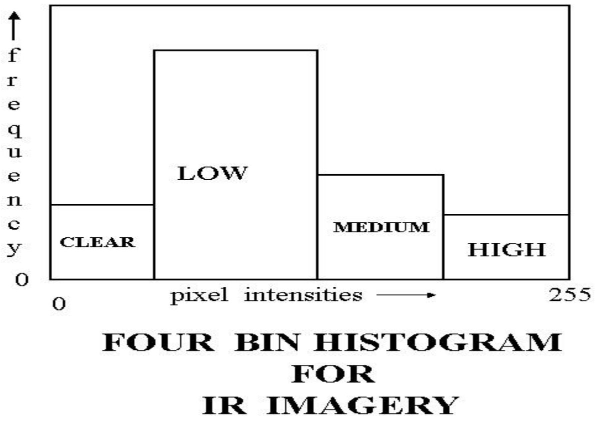


Figure 2.

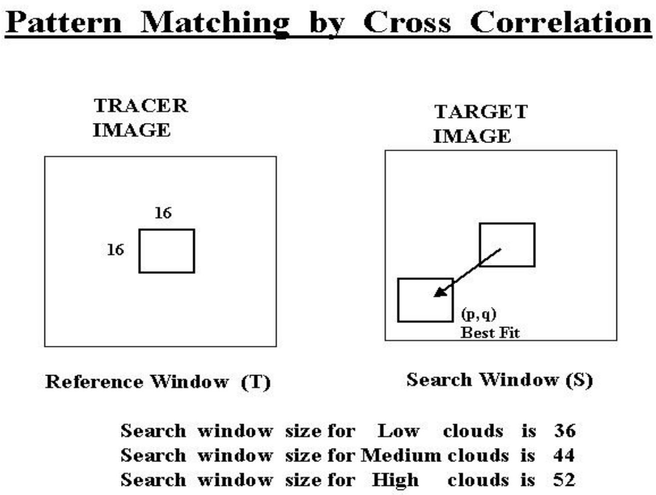


Figure 3.

2.3 CMV calculation

Before the computation of Cloud Motion Vector, the classification of the tracked sub-set is performed. This is basically a validation step so as to ensure that the same cloud pattern was tracked. For each of the tracked cloud target, the four-bin histogram is generated as was done for the cloud tracer and the same classification criteria is applied. The cloud target is rejected if it is not of the type of cloud tracer. The centre of the reference/search window is the initial point of the vector and the location for which absolute maximum peak is obtained as the final position of the vector. From these positions, CMV is calculated. If correlation returns multiple locations with the same maximum value, the first one is accepted.

2.4 Height assignment of CMV

Height assignment of the CMV's is being done using Infrared Window (IRW) technique at present.

Mean temperature of the 25% coldest IR pixels (John LeMarshal et al. 1993, Merrill R 1989, Nieman S. J et al. 1997) is considered for assigning the height of the CMV. The software of the system is being upgraded and the H_2O- IRW Intercept Method will also be tried shortly.

2.5 Quality control of derived CMV’s

Quality control of the generated cloud motion vectors includes reasonable minimum and maximum limits of CMV, testing the spatial and temporal consistencies of the vectors, comparison of the vectors with forecast field vectors or comparison with climatology in the event of non-availability of forecast field. The quality control is performed in two stages : (i) Objective (ii) Interactive. The objective tests include: (1) Absolute Threshold Speed Test (2) Speed Test (3) Direction Stability Test (4) Gradient Test (5) Forecast Field Test and (6) Climatology Test.

In the Forecast Field Test the CMV’s are being checked against LAM or NMC or ECMWF forecast fields as per the availability.

The CMV’s which have passed objective tests are available for interactive editing by the analyst at the work station. The CMV’s can be displayed on the monitor and the analyst can flag all those vectors which are inconsistent with the general field of motion. However, any deviant CMVs can be retained if the cloud pattern suggest the likely existence of some new or rapidly changing circulation system. It is also possible to change the level of CMV’s.

3. ONSET OF SOUTHWEST MONSOON

The Southwest Monsoon is the rainy period for the Indian Sub-continent. In this season, 80% of the annual rainfall occurs. The spatial and temporal distribution of summer monsoon rainfall over the country and its variability affects the agricultural output significantly. The delay in the onset of monsoon by a few weeks adversely affects the crop output while the early onset might not be utilized to advantage without an advance forecast. Thus, the monitoring and forecasting of the summer monsoon onset over Indian-Subcontinent is very much important for the economy of India. Fig. 4, Fig. 5 and Fig. 6 display the cloud motion vectors pertaining to Low, Medium and High-level CMV’s. The Low level CMV’s clearly show a well established cross equatorial southwesterly flow over West-coast of India indicating establishment of Southwest monsoon over southern peninsula.

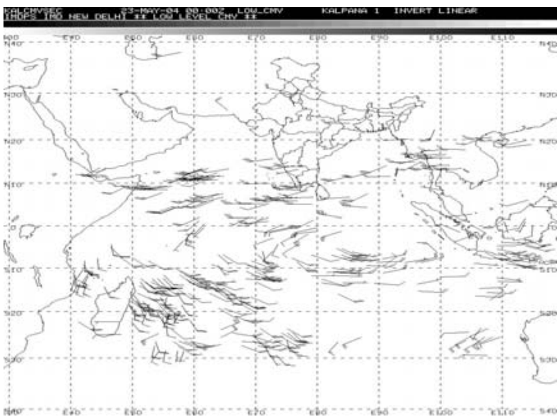


Figure 4. Low level CMV.

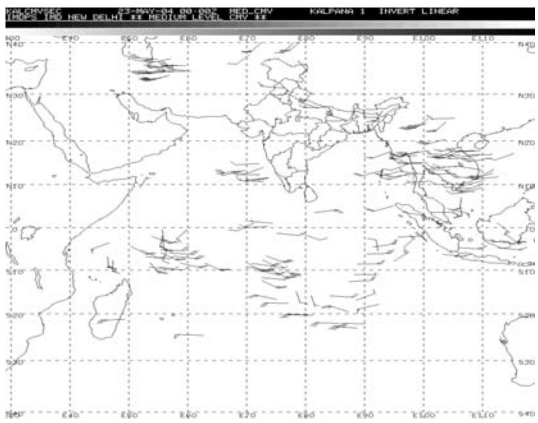


Figure 5. Medium level CMV.

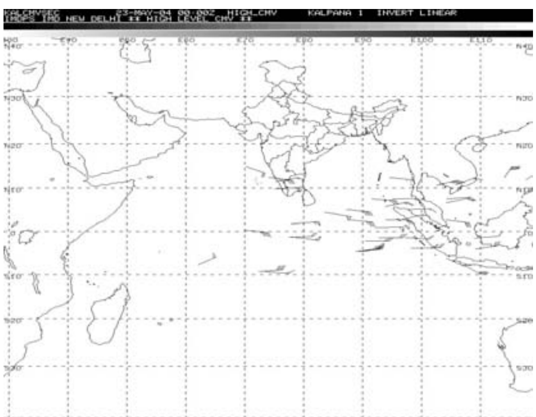


Figure 6. High level CMV.

4. RAPID SCAN WINDS

INSAT satellites have the capability of the rapid scan. It can cover an area of about 25° North-South in 351 number of scans (solid angle 4.5°). Cloud motion vectors from Infrared data of Kalpana were derived for rapid scan and are displayed in Figs. 7, 8 and 9 for Low, Medium and High clouds respectively. The cross equatorial flow can easily be seen in the Low Level CMV's.

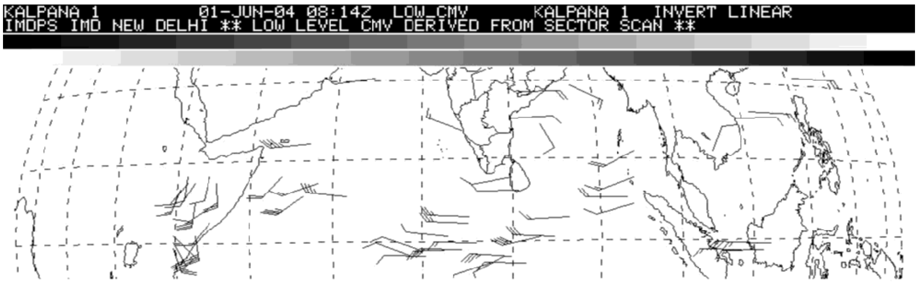


Figure 7. Low Level CMV from Kalpana-1 IR Image 01-June-2004.

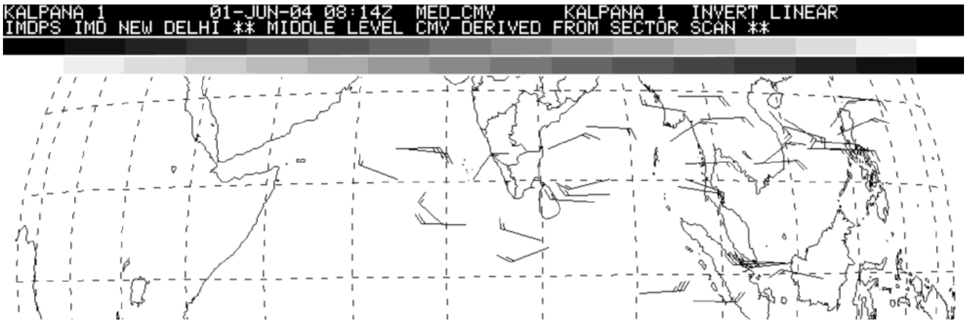


Figure 8. Medium Level CMV from Kalpana-1 IR Image 01-June-2004.

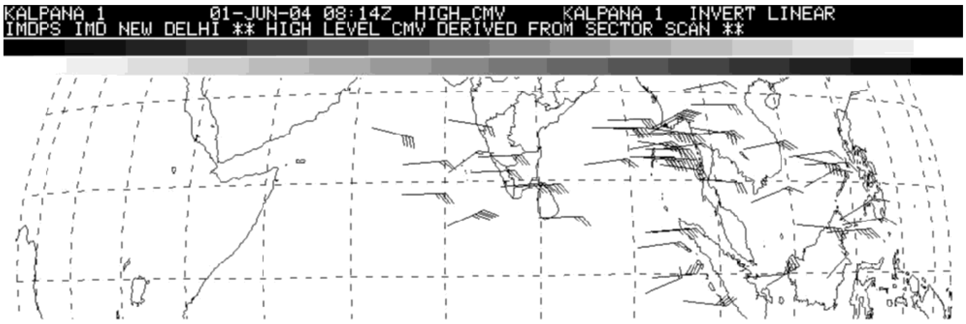


Figure 9. High Level CMV from Kalpana-1 IR Image 01-June-2004.

5. IMPACT OF CMV's ON MODEL ANALYSIS AND FORECAST

5.1 IMD's operational NWP system

IMD operational NWP is based on a limited area analysis and forecasting system (LAFS) that consists of real time processing of data received on Global Telecommunication System (GTS), objective analysis by 3-D multivariate optimum interpolation (OI) scheme and limited area forecast model.

5.2 Input data

The grid point fields for running the model are prepared from the conventional and non-conventional data received through GTS. The data consists of the surface SYNOP/SHIP, upper air TEMP/PILOT, SATEM, SATOB, AIREP, DRIBU and AMDAR, which are extracted and decoded from the raw GTS data sets. The synthetic observations such as cyclone bogusing data also included as per requirement.

5.3 Analysis procedure

The objective analysis is carried out by three dimensional multivariate optimum interpolation (OI) procedures. The variables analysed are the geopotential, u and v components of wind and specific humidity. Temperature fields are derived from the geopotential fields hydrostatically. Analysis is carried out on 12 sigma surfaces from 1.0 to 0.05 in the vertical and 1°x1° horizontal lat/long. grid for limited area horizontal domain of 30°S to 70°N ; 0° to 150°E.

5.4 Forecast model

The IMD limited area forecast model is a semi-implicit semi-Lagrangian multilayer primitive equation model based on sigma co-ordinate system and Arakawa C-grid in the horizontal. The present version of the model has a horizontal resolution of 0.75° x 0.75° lat/long (domain 30°S to 50°N and 25°E to 130°E) and 16 sigma levels (1.0 to 0.05) in vertical. The detailed description of model formulation, horizontal and vertical descretization and time integration scheme used in the experiment is given in Prasad et al (1997), Krishnamurti et al (1990). The lateral boundary conditions are obtained from the global forecasts of the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi.

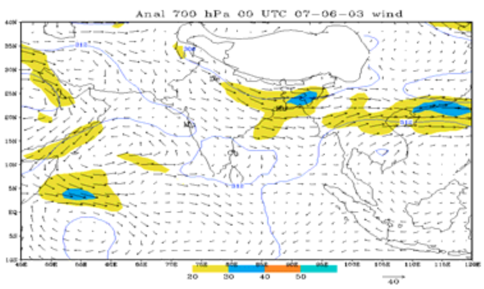
5.5 Results and discussion

In this study the onset of Monsoon over Kerala for the years 2003 and 2004 were considered. Numerical experiments were conducted with additional CMV data (experiment) and the results are compared with the operational products without these additional data (control).

5.5.1 Case 1: 05-09 June 2003

Southwest monsoon advanced into Kerala (extreme southern part of India) and adjoining parts of Tamil Nadu on 8th June with a delay of about a week. It advanced into parts of coastal and south interior Karnataka and some more parts of Tamil Nadu on 10th. In the present study the performance of the limited area model for the onset phase of the monsoon was investigated. The 700 hPa analysis for 6, 7, 8, and 9 of June, 2003 are given in Fig.10 (a-d) In this case the impact of Cloud Motion Vector (CMV) data was exmined in the operational NWP model during the onset phase of Summer Monsoon over Kerala. The model forecasts are produced with the additional CMV data and compared with the operational real-time forecasts produced without this data. The 24 hours forecast 700 hPa shows improvement in strength of wind speed 3-4 knots over Arabian Sea in experiment (Fig.10 (e-f). However wind strength over northern India shown more reliable compared with control run. The 24 hours forecast rainfall based on the experiment for 8th June shows the rainfall belt extending northwards over Kerala and Tamil Nadu. The 24 hours forecast rainfall based on the experiment for 8th June shown slight northward propagation in the rainfall belt compared to the control run (Fig.10-h) that agrees better with the observations. Verification analysis and forecast fields with this additional data has shown substantial improvements in the analysis and model predicted rainfall.

a



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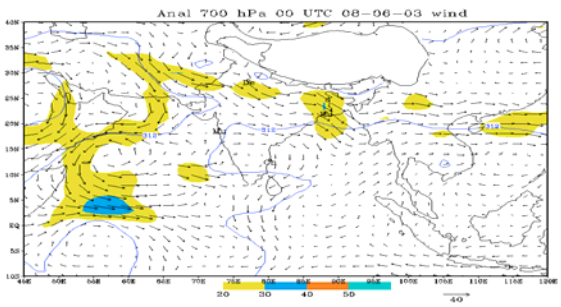

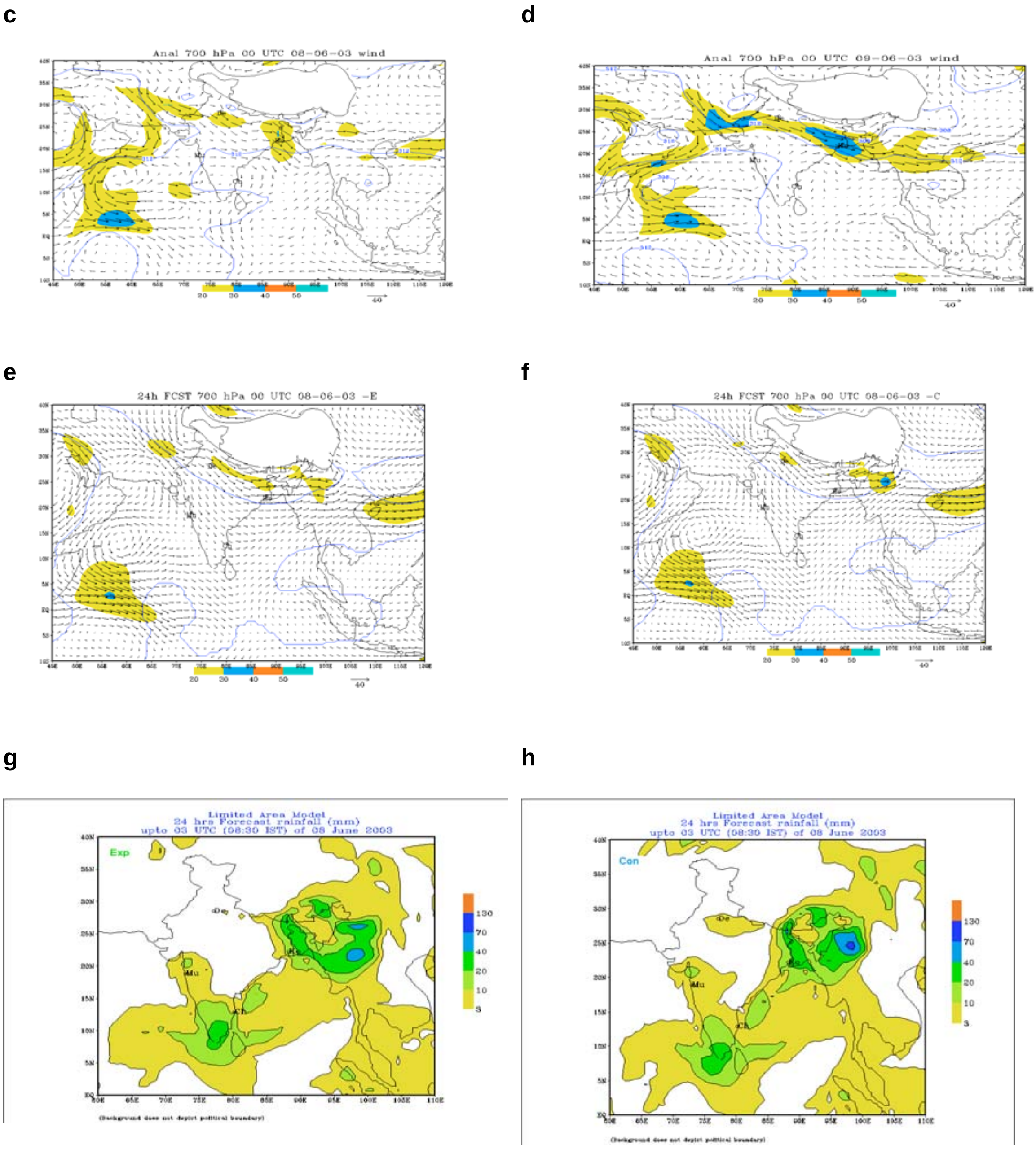

Figure 10. LAM analysis for 6– 9 June 2003 and Day-1 forecast wind and rainfall (mm) experiment (e, g) and control (f, h).

5.5.2 Case 2 18 May 2004

The onset of Monsoon of the year 2004 was also studied. The onset took place on 18th May, 2004 about two weeks earlier than the normal onset date of 1st June over Kerala. The limited area analysis for 12 UTC of 18th May and 24 hours forecasts for 19th May 2004 were given in Fig.11 (I-m). The 700 hpa wind analysis field shows the Southwesterly flow with wind strength of 20-30 Kts. Over Southern parts of India and at 200 hPa the easterlies extending upto 15° N along the Southern peninsular India. The 24 hours forecast for 19th June shows the further strengthening of wind along the Bay of Bengal and north east parts of India. The model predicted rainfall along the west coast and north-eastern parts of India was more realistic.

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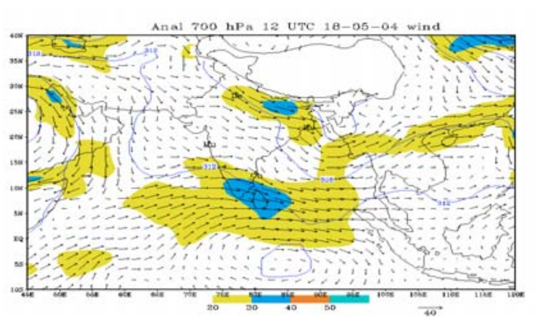

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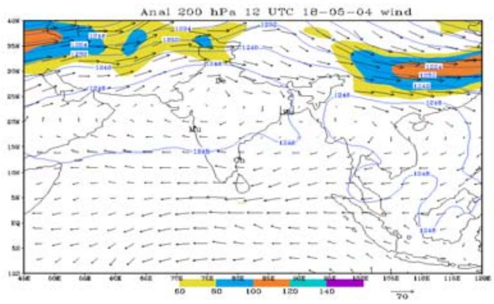

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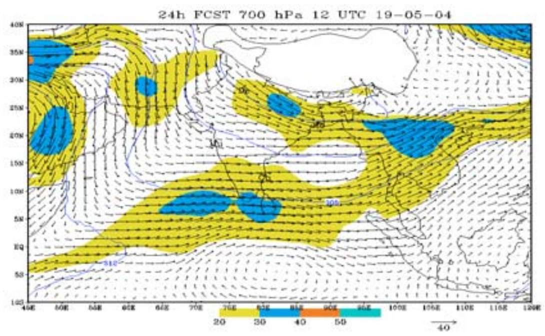

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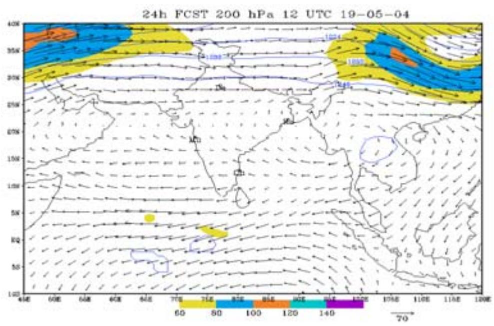

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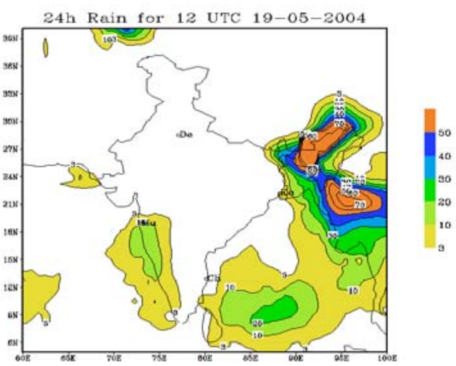

Fig.11. LAM analysis for 18th May 2004 and Day-1 forecast 700, 200 hpa wind and rainfall (mm).

6. VALIDATION OF CLOUD MOTION VECTORS WITH LAM FORECAST

The quantitative checks of the quality of CMV's were made by comparing them with the first guess from Limited Area Model (LAM) Forecast field generated operationally by IMD. Monthly Statistics on RMS errors and biases generated for the month of May 2004 is depicted in Table-1. It is seen that for medium level CMVs, the bias of Kalpana-1 CMVs is 2.0 m/sec or better. RMSE of Kalpana-1 CMVs is 6 m/sec for medium level CMVs which is fairly close to RMSE of METEOSAT-5 CMVs. Same is the case with high level CMVs where rmse and biases have about 7 m/sec and 1.5 m/sec respectively.

	ALL REGIONS	NH EX-TROPICS	SH TROPICS	EX-TROPICS		ALL REGIONS	NH EX-TROPICS	SH TROPICS	EX-TROPICS
ALL LEVELS					**MED. LEVEL**				
MVD	5.3	6.0	5.3	4.9	MVD	5.7	6.2	5.6	12.6
RMSVD	6.1	6.8	6.1	5.8	RMSVD	6.6	6.9	6.6	12.7
STDVD	3.1	3.2	3.1	3.0	STDVD	3.4	3.0	3.5	1.7
BIAS	2.1	2.0	2.0	2.6	BIAS	2.7	1.9	2.8	12.0
SPD	8.9	7.7	9.0	9.3	SPD	8.2	9.0	8.0	25.0
NUM	2835	310	2112	356	NUM	537	88	440	3
HIGH LEVEL					**LOW LEVEL**				
MVD	6.7	6.6	6.7	16.3	MVD	5.1	5.8	5.0	4.8
RMSVD	7.8	7.9	7.8	16.3	RMSVD	5.8	6.6	5.7	5.6
STDVD	4.0	4.3	4.0	0.0	STDVD	2.8	3.1	2.7	2.9
BIAS	3.1	1.6	3.3	4.2	BIAS	1.8	2.1	1.6	2.5
SPD	12.3	12.5	12.2	36.5	SPD	8.7	6.7	8.9	9.1
NUM	244	20	221	1	NUM	2054	202	1451	352

Table 1.

6.1 Comparison of Kalpana-1 CMV's with METEOSAT-5 CMV's

The Kalpana-1 derived CMVs were compared quantitatively with METEOSAT-5 derived CMVs since both satellites have fairly large common areas of coverage. It may be noted from Table 2 that for all level CMVs, the bias of Kalpana-1 CMVs is around 2.0 m/sec which indicates that the quality of Kalpana-1 CMV's is close to that of METEOSAT-5. RMSE of Kalpana-1 CMVs of various levels range from 3.4 to 6.5 m/s for the month of May 2004. The comparison does not indicate very high quality of Kalpana-1 CMV's.

	ALL REGIONS	NH EX-TROPICS	SH TROPICS	EX-TROPICS		ALL REGIONS	NH EX-TROPICS	SH TROPICS	EX-TROPICS
ALL LEVELS					**MED. LEVEL**				
RMSVD	5.77	4.05	6.07	6.13	RMSVD	5.09	4.13	4.75	6.47
BIAS	0.48	1.39	0.27	0.55	BIAS	1.30	-2.95	1.97	1.94
NCMV	93482				NCMV	10680			
NC	2199	389	1723	87	NC	104	14	68	22
HIGH LEVEL					**LOW LEVEL**				
RMSVD	6.65	--	6.59	6.02	RMSVD	3.90	3.41	4.27	4.71
BIAS	-0.29	--	-0.38	-0.01	BIAS	1.67	1.31	2.03	-4.19
NCMV	69068				NCMV	13734			
NC	1327	--	1257	70	NC	806	378	425	3

Table 2.

7. CONCLUSION

The comparison shows that the quality of Kalpana-1 CMVs compares well with the Meteosat-5 CMVs. However, the density of Kalpana-1 CMVs is less. Rapid scan winds are being produced as and when required for mesoscale studies. Their quality is being studied. Use of CMV's in the studies of onset of South-west Monsoon have proved to be great use in agriculture. The error-statistics of these observations and its utility in operation forecast and also the impact of the data in the limited area numerical model analysis and forecast system has been found positive.

8. ACKNOWLEDGEMENT

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