AN OPERATIONAL STATUS AND VALIDATION OF CLOUD MOTION VECTORS WITH IMPROVEMENT IN WATER VAPOR WINDS DERIVED FROM KALPANA-1 SATELLITE AT IMD

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ABSTRACT

The Cloud Motion Vector (CMV) is one of important meteorological products derived from satellite data and is known that it has a positive or neutral impact on global or middle scale numerical forecast results. Currently, CMV at India Meteorological Department, New Delhi , is being operationally generated using infrared (IR) data from Kalpana-1 satellite since April 2003. In the quality check procedure of the derivation technique, the output of the Limited Area Model (LAM) forecast data , which covers the area 40E-129E and 29S-45N, produced operationally in IMD, has been preferred over climatology. These CMVs are put on GTS for end users in both SATOB as well as BUFR format. The error analysis has been carried out for the validation of CMV with the available LAM forecast and Meteosat-5 winds. The comparison shows that the quality of Kalpana-1 CMVs compares well with the LAM forecast. The error statistics of these observations and its improvement using neural network (NN) technique is also presented. The result indicates that the pattern of NNCMV (ANN model output CMV) is much closer to the Meteosat derived winds. The vital changes have also been incorporated in the Kalpana-1 CMVs and WVWs derivation. The changes include improved hight assignment technique using H2O interception method,better navigation and use of LAM forecast field in quality controls. As a result of these changes the quality of Kalpana-1 derived WVW has improved. Further, Kalpana-1 derived water vapor winds (WVW) have also been compared with the available mid-upper level winds derived from Meteosat-7 as a part of validation. A case study of a '*sidr*' cyclone has examined and it has found that the Kalpana-1 derived WVW has shown fairly good agreement with the Meteosat-7 winds.

Key words: ANN, CMV, WVW, RMSE, NNCMV, BUFR

1. INTRODUCTION

One of the key meteorological parameters for weather forecasting, meteorological studies and climate applications is wind. It has therefore been a major task for the science and operational community to exploit the imagery data from geostationary satellites in order to derive Cloud Motion Vectors (CMVs) by tracking observed cloud and moisture features. The globally derived CMV fields are an established and essential product, especially for Numerical Weather Prediction, and are complemented by other satellite-based observations of the atmospheric flow. The biennial International Winds Workshops provide a forum used for cooperation in the operational and research community and have strongly contributed to the improvement in the quality of the derived wind fields. Kalpana-1 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.

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. 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.

Limited Area Model (LAM) is being used operationally since 1995. The model has horizontal grid of 1 x 1 in Lat/Long. And uses 12 sigma levels. The model uses conventional as well as satellite-derived information in its assimilation scheme covering vast data sparse Oceanic areas around India. It was therefore felt that presently generated IMD LAM forecast is more reliable for Quality Assurance (QA) tests. The only limitation of LAM model forecast is the limited area. The quality of numerical weather forecast has direct impact on the quality of CMVs since the forecast is used in QA tests for CMVs. It is therefore desirable that the numerical forecast system should use conventional as well as improved satellite derived data from Indian ocean area in its data assimilation scheme.

2. Current CMV and WVW system of IMD

It has been known that height of CMV make a very important role in determining the accuracy of CMV. Image instrument onboard most of geo-stationary satellite lacks the CO_2 channel and thus the height assignment for semi-transparent cloud is dependent on the water vapor channel combination method, so called, IR/WV intercept method. The new software has also been upgraded in the IMDPS system in which height assignment is being done by the H2O- IRW Intercept Method (Neiman et al, 1997) for CMV and WVW computation. The H2O intercept is predicted on the fact that the radiances from a single-level cloud deck for two spectral bands vary linearly with cloud amount. Radiances from the infrared window and H2O absorption band (WV Channel) are measured and compared to Plank body radiances as a function of cloud top pressure. A numerical forecast of temperature and humidity profile in the region is used for the necessary radiative transfer calculation for measured and opaque cloud conditions. The cloud top height is inferred from the linear extrapolation of measured radiances onto the calculated curve of cloud opaque radiance.

The measured radiances used to infer the linear relationship between the two bands are the average radiances for the cluster of clearest (warmest) fields of view and the cluster of cloudiest (coldest) fields of view within the observation area. If the calculated water vapor radiance for clear sky is less than the measured water vapor radiance, the calculated water vapor radiances are adjusted to agree with the measured and the difference is attributed to an inaccurate transmittance used in the computation of clear column radiance. Calculated warm radiances that are greater than measured are not adjusted since the low measurement may be the result of cloud contamination (Neiman et al, 1997). The advantage of this method is well seen on WVWs compared to the CMVs becouse water-vapour track winds can be estimated in the area of free clouds. The H2O-intercept method is generally not useful for clouds lower in the atmosphere than above 500 hPa because upwelling radiation comes primarily from the atmosphere above the cloud. so very low clouds cannot be detected with the commonly-used water vapor channels centered near 6.7 µm. The automated quality control is based on EUMETSAT approach (Hayden 1993; Hayden and Nieman 1996).

Research activities in recent years have demonstrated the ability of water vapor (WV) bands.. The upper-level moisture patterns can be tracked in water vapor images (Laurent 1993). The resulting product or water vapor wind (WVW) has an improved coverage with respect to the CMV product, the major advantage being the availability of many more targets in the image. However, there are indications of some problems in the height assignment of WV winds when extremely dry atmospheric profiles occur and the best quality is still achieved in the cloudy areas (Holmlund 1993).

In particular, the upper level winds derived from Meteosat-7 have proved to be very useful for predicting the future track position of depressions and well marked low pressure areas with deep vertical extent. On the basis of their future track predictions it is possible to give more accurate heavy rainfall warnings to the areas likely to be affected by these weather systems. It is possible to give more precise warnings to the affected area at least 48 to 72 hours in advance since these types of weather systems are steered by the upper level winds. In view of the above problems the improvement in CMVs have also been attempted using neural network technique. The CGMS Working Group on Satellite Tracked Winds recommended that evaluation of operational wind production quality should be accomplished with a new standardized reporting method. In this study the CMVs were evaluated with the statistical formulae given on CGMS wind evaluation reporting guidelines. The error analysis has been carried out for the validation of WVW with the available mid-upper level winds derived from Meteosat-7 for the months of October 2007 to February 2008.

3. METHODOLOGY AND DATA SOURCES

The CMV data are matched with the LAM observations for the period of June 2007 to September 2007. The criteria for selecting CMV measurements with collocated LAM data are based on the following: (1) The absolute distance between the position (latitude and longitude) of the LAM and the CMV data has considered for 2º (2) The observational time of LAM and CMV measurements was 00 UTC.

CGMS WIND EVALUATION REPORTING GUIDELINES

The mean vector difference (MVD) is given by

$$(MVD) = 1/N \sum_{i=1}^{N} (VD)i$$

Where the vector difference (VD), between an individual CMV report (i) and collocated first-guess fields of LAM (m) used for verification is,

$$(VD)i = [(Ui - Um)^2 + (Vi - Vm)^2]^{1/2}$$

The root-mean-square error (RMSE) traditionally reported is the square root of the sum of the squares of the mean vector differnce and the standard deviation about the mean vector difference,

$$(RMSE) = [\ (MVD)^2 + (SD)^2\ ]^{1/2}$$

where the standard deviation (SD) about the mean vector difference is

$$(SD) = 1/N \sum_{i=1}^{N} [(\ VDi) - (MVD\ )]$$

The speed bias is given by

$$(BIAS)\ i = 1/N \sum_{i=1}^{N} [(\ Ui^2 + V\ i^2\ )^{1/2} - (Ur^2 + Vr^2\ )^{1/2}\ ]$$

NEURAL NETOWORK

During recent years, the technique of Neural Network (NN) has drawn considerable attention towards handling this kind of complex and non-linear problems (Nath and Mitra 2007). It has a strong potential for pattern reorganization and signal processing problems and also has the ability to predict values of the time series from itself. The tool, which is one of the most effective methods for pattern reorganization and signal processing problem, has been applied in this study to improve Indian Geostationary Satellite (Kalpana-1) derived Cloud motion vector (CMV). The strategy for applying the NN technique involves three phases. In the first phase, known as training period, which utilizes CMVs for all there level separately and forecast field of LAM to derive statistics and in the second phase, known as a testing period, it utilizes the improved CMVs (NNCMV) for the comparison with monthly statistics of rms errors and biases generated by Meteosat-7 derived CMVs . In the present study a neural network (NN) technique has been developed to improve the quality of CMVs for the southwest monsoon season 2007. Data for the period of January 2007 to May 2007 have been used as the training sample. The method is tested with the independent sample data for the August 2007.

4.RESULTS AND DISCUSSION

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 June to September 2007 is depicted in Table-1. It is seen that for higher and middle level of CMVs , the bias of Kalpana-1 CMV is 2 to 4 m/s whereas for the lower level it has reduced to almost less than 2.0 m/s. RMSE of Kalpana-1 CMVs were 6 to 8 m/s for all the levels.

June 2007

	ALL LEVELS	HIGH LEVEL	MIDDLE LEVEL	LOW LEVEL
MVD	7.31	10.05	7.24	7.03
RMSVD	8.33	12.01	8.04	8.07
STDV	3.99	6.56	3.49	3.97
BIAS	2.26	1.85	3.67	1.44
NCMV	15801	1062	5595	9144
NC	15801	1062	5595	9144

July 2007

	ALL LEVELS	HIGH LEVEL	MIDDLE LEVEL	LOW LEVEL
MVD	7.2	8.57	7.13	7.09
RMSVD	8.16	9.39	7.91	8.19
STDV	1.5	2.38	2.87	1.29
BIAS	3.86	3.83	3.42	4.11
NCMV	14404	1005	4918	8480
NC	14404	1005	4918	8480

August 2007

	ALL LEVELS	HIGH LEVEL	MIDDLE LEVEL	LOW LEVEL
MVD	6.29	7.64	6.55	5.95
RMSVD	6.88	8.36	7.15	6.51
STDV	2.79	3.40	2.87	2.6
BIAS	2.41	3.27	2.96	1.94
NCMV	18355	1491	6432	10433
NC	18355	1491	6432	10433

September 2007

	ALL LEVELS	HIGH LEVEL	MIDDLE LEVEL	LOW LEVEL
MVD	5.93	7.03	6.54	5.43
RMSVD	6.53	7.63	7.20	5.97
STDV	2.74	3.08	3.02	2.48
BIAS	2.7	2.72	4.07	1.97
NCMV	17458	1559	5532	10367
NC	17458	1559	5532	10367

TABLE :1

KALPANA-1 minus LAM Analysis, Differences (m/s) or (deg)
MVD = Mean Vector Difference,
RMSVD = Vector Difference RMS
BIAS = Speed Bias
NCMV = No. of disseminated SATOB Winds,
NC = No. of Collocations

COMPARISON OF KALPANA-1 CMV'S WITH METEOSAT-5 CMV'S AND NNCMV

The Kalpana-1 derived CMVs were compared quantitatively with METEOSAT-5 derived CMVs for the month of August 2007 since both satellites have fairly large common areas of coverage. It may be seen from the Table-2 that all level CMVs, the bias of Kalpana-1 CMVs is quite higher than METEOSAT-5 and NNCMV. RMSE of Kalpana-1 CMVs, METEOSAT-5 and NNCMV of various levels for the August 2007 ranges from 6 to 8 m/s, 4 to 7 m/s and 5 to 7 m/s respectively. The comparison iindicates that the NNCMV is close to that of METEOSAT-5 than the quality of Kalpana-1 CMV's.

	ALL LEVELS			HIGH LEVEL			MIDDLE LEVEL			LOW LEVEL		
	CMV	MET-5	NNCMV	CMV	MET-5	NNCMV	CMV	MET-5	NNCMV	CMV	MET-5	NNCMV
RMSE	6.88	6.59	6.71	8.36	7.06	7.92	7.15	5.41	6.55	6.51	4.55	5.32
BIAS	2.41	-2.18	1.84	3.27	-2.45	2.58	2.96	-1.22	1.98	1.94	-1.53	2.12

TABLE:2 **Comarision of Kalpana-1 CMVs, Metosat-5 and NNCMVs**

COMPARISON OF KALPANA-1 WVW'S WITH METEOSAT-7 AND A CASE STUDY OVER BAY OF BENGAL DURING THE PERIOD 10-15 NOV, 2007 (SIDR).

The track of the cyclone *'sidr'* over Bay of Bengal during the 10-15 Nov, 2007 is shown in figure-1. A low level circulation formed over South-East Bay of Bengal on 1700 UTC of 09th November, 2007 and organized into a vortex at 1700 UTC on 10th of November, 2007 centre near 9.5N/93.0E with Intensity T 1.0. The system Initially it moved in a Northerly–Westerly direction and intensified further at 0600 UTC of 11th November, 2007 with centre at 10.0N/92.5E**.** and intensity T 1.5 . It further intensified at 1200 UTC of the same day with centre 10.1N/91.8E and intensity T2.0 (.) Moving in a North-Westerly direction,it intensified into cyclonic storm (**SIDR) at 0000 UTC of 12th November, 2007** and lay centred at **10.3N/91.2E** with intensity T2.5**.** It continued to move in the same direction and further concentrated into severe cyclonic storm and lay centred at 1200 UTC of the same day near 11.3N/90.1E and Intensity T3.5.The system further concentrated into a very severe cyclonic storm (T4.0) and lay centre at 1700 UTC near 11.5N/89.8E. **SIDR** moved in a Northwestward direction and lay centred at 0000 UTC of 13th November,2007 at 11.9N/89.6E with intensity T5.0. Afterwads the system moved northerly direction upto 1200 UTC of 15th November, 2007 and lay centred near 21.1N/89.0E with Intensity T6.0. Afterwards it took northwestward movement and crossed West Bangladesh coast around 1500 UTC near 22.0N/89.8E .The Meteosat-7 and Kalapna-1 derived water vapor upper level winds are shown in figure-2(a&b) for 15 November 2007 at 00 UTC. These winds clearly show the steering effect on weather system and likely movement of the system over land. Under the influence of the cyclone, widespread rainfall with isolated heavy to very heavy rainfall occurred in West Bengal and neighborhood. From the figure 2(a&b) it is seen that the Kalpana-1 derived WVW has shown fairly good agreement with the Meteosat-7 winds. Eventhough the wind speed is slightly higher but the synoptic scale flow pattern has very well brought out in the Kalpana-1 WVW.

Table-3 shows a quantitative RMS comparison between WVWs derived from Kalapana-1 and Meteosat winds for the months of October 2007 to March 2008 with the radiosonde observation. The comparison is based on co-located points within the 150 Km radius of radiosonde measurements. The comparison shows that the Kalpana-1 WVWs are comparable to those of Meteosat winds.

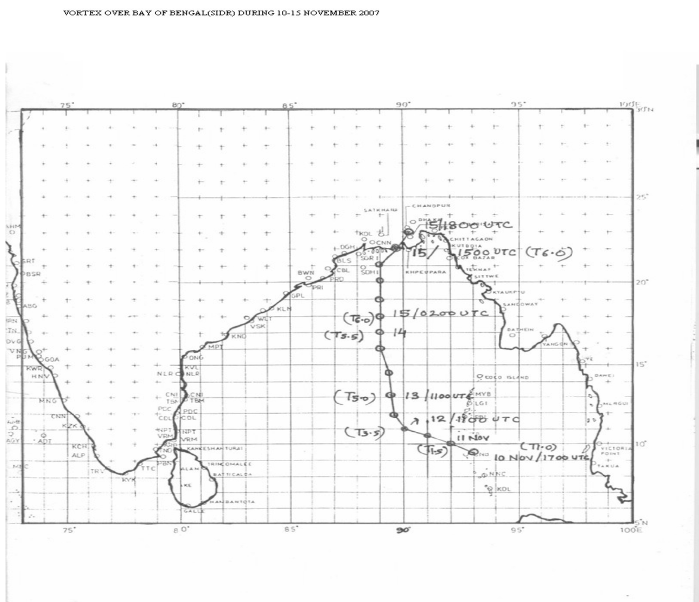
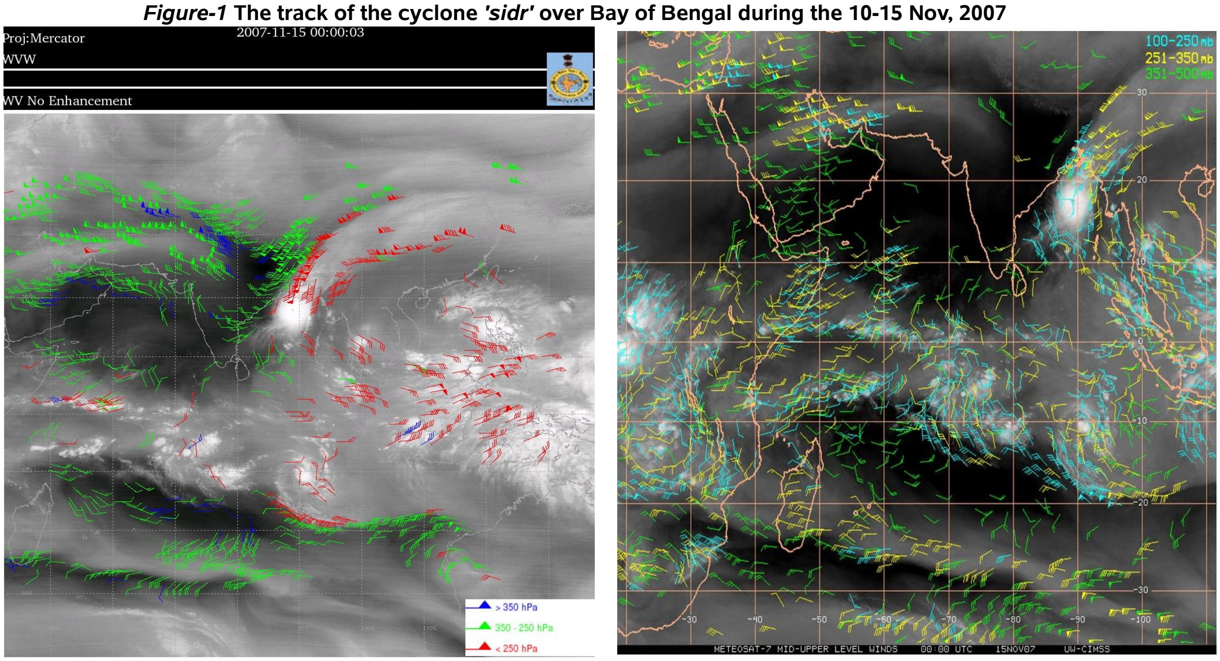


Figure-1 **The track of the cyclone *'sidr'* over Bay of Bengal during the 10-15 Nov, 2007**



(a) (b)

Figure-2 **The Kalapna-1 (a) and Meteosat-7 (b) derived water vapor upper level winds of 15 November 2007 at 00 UTC**

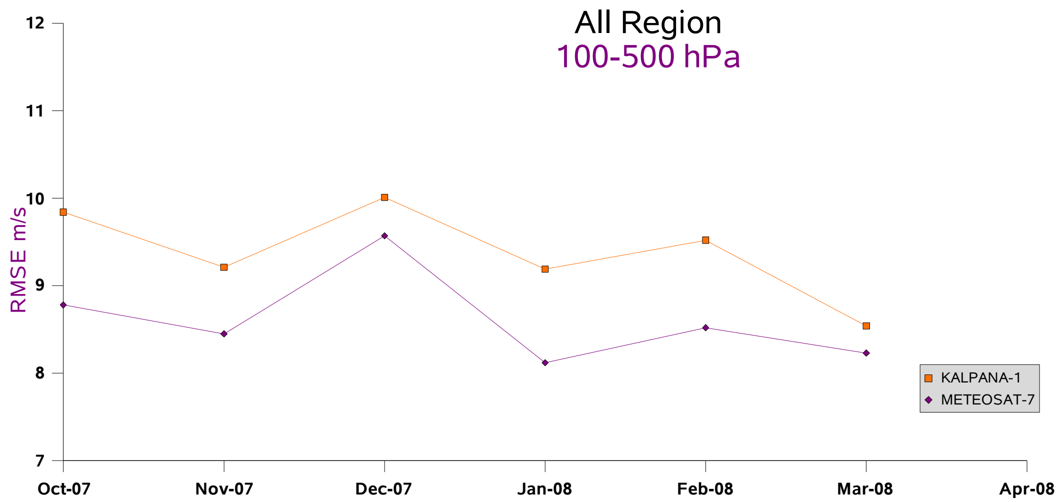


Table:3 **RMSE Comparison between WVWs derived from Kalapana-1 and Meteosat winds with radiosonde.**

5. CONCLUSIONS AND FUTURE WORK

The comparison shows that the quality of Kalpana-1 CMVs comparable to that of Meteosat-5 CMVs. Although the bias is higher but the RMSE of Kalpana-1 CMVs and METEOSAT-5 of various level, ranges from 6 to 8 m/s and 4 to 7 m/s respectively, is in acceptable range. The comparison of these winds with neural network derived CMVs has also been presented. The hight assignment technique using H2O interception method has been used for the derivation of CMVs and WVWs. As a result , the quality of Kalpana-1 derived WVW has improved and comparable to the Meteosat derived upper level winds. A case study has examined and it has seen that the Kalpana-1 derived WVW has shown fairly good agreement with the Meteosat-7 winds. The upper level water vapor winds derived from Kalapana-1 satellite could be very useful for predicting the future track position of intense cyclones, depressions and well marked low pressure areas.

The performance of CMVs and WVWs reflects the overall effect of satellite system and NWP system. To have high quality CMVs and WVWs to be produced, both the satellite system and the first guess field from NWP system should be well performed. Image navigation quality influences wind derivation greatly. Image navigation, calibration and proper registration of the satellite imageries and NWP model are all sensible issues which affect these winds performance. The crossing point position of the IR/WV regression straight line and the opaque cloud curve for thin cirrus targets is uncertain. This is one of the error sources. Height assignment scheme still should improve. The numerical forecast data from ECMWF or UKMET over the Indian region may be useful as a first guess for Quality Assurance (QA) tests to improve the performance of these winds.

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