MAUSAM, **57**, 2 (April 2006), 315-322

551.508.826 : 551.509.313

Operational use of improved CMVs derived from INSAT IR data in NWP Model over Indian region

DEVENDRA SINGH, R. C. BHATIA, S. K. SRIVASTAV, SANT PRASAD and R. K. GIRI.

India Meteorological Department, New Delhi – 110 003, India

(*Received 13 February 2004, Modified 29 October 2004*)

सार – इंसैट से प्राप्त सी. एम. वी. की गुणता आश्वासन (क्यू. ए.) जाँच प्रारंभ में एन. सी. ई. पी. वाशिंगटन अथवा ई. सी. एम. डब्ल्यू. एफ. से प्राप्त 12 घंटे के निम्न विभेदन पूर्वानुमान के आँकड़ों का उपयोग करके की जाती है। हिंद महासागर के अपर्याप्त आँकड़ों वाले क्षेत्र से इंसैट अथवा अन्य उपग्रहों से प्राप्त सी. एम. वी. का उपयोग इन पूर्वानुमानों में प्रारंभ में नहीं किया जाता था। अन्य केन्द्रों को इंसैट से प्राप्त सी. एम. वी. की गुणता विश्वसनीय स्तर की नहीं लगी। जुलाई 98 से पहले, इंसैट के अलावा किसी अन्य उपग्रह से हिंद महासागर के अपर्याप्त आँकड़ों वाले क्षेत्र के आँकड़े प्राप्त नहीं हुए। जुलाई 98 में, मीटिओसैट–5 को हिंद महासागर के ऊपर 63 डिग्री पूर्व की ओर खिसकाया गया। इंसैट मौसम विज्ञान आँकड़ा संसाधन तंत्र (आई. एम. डी. पी. एस.) में इंसैट से सी. एम. वी. प्राप्त करने की प्रचालनात्मक योजना में कुछ महत्वपर्ण सुधार किए गए जिससे उपयोगकर्ताओं को बेहतर गुणता के उपग्रह से प्राप्त पवन के आँकड़े उपलब्ध करवाए जा सकें। संशोधित एलगोरिथ्म में गुणता आश्वासन जाँच में एल. ए. एम. पूर्वानुमान का उपयोग किया गया है। स्पैक्ट्रम की शीत परिधि पर मेघों के कुछ प्रतिशत के औसत तापमान के आधार पर दाब और उँचाईयाँ निर्धारित की जाती हैं। इंसैट और मीटियोसेट–5 से प्राप्त सी. एम. वी का विस्तार से तुलनात्मक अध्ययन किया गया है। इंसैट और मीटियोसेट-5 से प्राप्त परिष्कृत सी. एम. वी. के बीच गुणता के आधार पर अच्छी अनुरूपता का पता चला है। अभिनति और आर. एम. एस में भी सुधार हुए हैं। सी. एम. वी. में पहले प्रेक्षित क्षेत्रीय पवनों में भी सुधार हुआ है। मीटियोसेट–5 की तुलना में इंसैट से प्राप्त सी. एम. वी. की कम संख्या का कारण इंसैट रेडियोमीटर का निम्न स्थानिक विभेदन है। चित्रों के त्रिक से तैयार सी. एम. वी. के दो सैटों को सम्मिलित किया गया जिसमें दो सैटों में स्थापित सी. एम. वी. को शामिल नहीं करने का ध्यान रखा गया है। इंसैट से प्राप्त परिष्कृत सी. एम. वी. से मॉडल द्वारा किए जाने वाले पूर्वानुमान पर सकारात्मक प्रभाव पडा है।

ABSTRACT. Earlier Quality Assurance (QA) tests of INSAT derived CMVs were done using low resolution 12 hour forecast from NCEP Washington or ECMWF. These forecasts earlier did not use satellite derived CMVs from INSAT or other satellites from data sparse Indian Ocean. Other centers did not find INSAT CMVs of reliable quality. Before July 1998, no other satellite except INSAT covered the data sparse Indian Ocean. In July 1998, METEOSAT-5 was shifted over Indian Ocean at 63 degree East. Certain vital changes have been incorporated in the operational scheme of INSAT CMVs derivation at INSAT Meteorological Data Processing System (IMDPS) for providing satellite derived winds of improved quality to the users. The modified algorithm uses LAM forecast in QA tests. Pressures and heights are assigned on the basis of mean temperature of certain percentage of cloud population at the cold end of the spectrum. Detailed comparison of CMVs from INSAT and METEOSAT-5 has been done. The improved CMVs from INSAT and METEOSAT-5 show quite good agreement qualitatively. The bias and RMS also show improvements. Zonal winds observed earlier in CMVs have shown improvement. The lesser number of INSAT CMVs is due to lower spatial resolution of INSAT radiometer compared to METEOSAT-5. The two sets of CMVs generated from triplet of images are being combined, taking care of excluding the collocated CMVs in the two sets. The improved INSAT derived CMVs have shown positive impact on the Model forecast.

Key words – Cloud Motion Vector (CMV), Tracers, Target, Height Assignment, Local Area Model (LAM), Indian Satellite (INSAT), Quality Assurance (QA).

1. Introduction

The Cloud Motion Vector derivation is a challenging job. The challenges involve, (*i*) Tracer, Target image registration and navigation, (*ii*) Passive tracer selection, (*iii*) Pattern matching of the reference window of tracer image at different lag positions in search window of target image, (*iv*) Vector computation, (*v*) Height assignment to derived vector, (*vi*) Quality Assurance (QA) tests on derived vectors (*vii*) Manual editing any spurious vectors. Height assignment is the most challenging. LAM (Krishnamurti and Kumar 1990) is being used operationally in IMD since 1995. The model has horizontal grid of 1° × 1°, in Latitude/Longitude 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 QA tests. Recently METEOSAT-5, an additional data source over Indian

TABLE 1

Comparison of CMV (IR) R.M.S. error (m/s) of METEOSAT 5 and INSAT 1D

Region		METEOSAT - 5		INSAT 1D	
		Sep – Nov 1999	Dec – Feb 2002	Sep – Nov 1999	Dec – Feb 2002
NH EXT TROP	1000 – 701 hPa	5.3	7.3	7.5	5.8
TROPICS	1000 – 701 hPa	3.6	4.1	7.5	4.9
SH EXT TROP	1000 – 701 hPa	2.6	2.8	9.0	5.3
NH EXT TROP	700 – 401 hPa	6.0	8.0	9.1	8.0
TROPICS	700 – 401 hPa	5.8	7.6	7.5	5.5
SH EXT TROP	700 – 401 hPa	7.1	7.0	15.5	6.8
NH EXT TROP	400 – 100 hPa	6.7	7.9	11.8	6.6
TROPICS	400 – 100 hPa	4.9	5.5	8.4	7.6
SH EXT TROP	400 – 100 hPa	8.1	7.2	11.7	9.2

NH EXT TROP Northern Hemisphere Extra Tropic >20 degree north
SH EXT TROP Southern Hemisphere Extra Tropic >20 degree south
TROPICS. Between 20 degree north and 20 degree south

Ocean has become available. However, it will take some time before this data can be assimilated into the model. The only limitation of LAM model forecast is the limited area (40° East to 129° degree East, 29° South to 45° North). There is scope for improvements in quality of INSAT derived CMVs. The approach needed improvement in image to image registration, and image navigation. Any error in registration translates into additional vector thereby resulting in poor quality of CMVs. The quality of the numerical weather forecast has also 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 satellite derived information from Indian Ocean area in its data assimilation scheme. The model forecasts from NCEP and ECMWF did not assimilate INSAT CMVs into the model. This resulted in rejection of CMVs in QA tests. The zonal flow, high speed bias and RMS compelled other centers not to use INSAT CMVs. Forecast over Indian region is likely to be improved, when model for the region starts assimilating INSAT or METEOSAT-5 CMVs. Any other approach only marginally improved CMVs. In view of the above problems the improvements in CMVs were attempted in phased manner. After every change, the quality of CMVs were monitored by analyzing the statistics. These statistics were computed using the formulae given below used in ECMWF SATOB Monitoring report.

The mean vector difference (MVD) is given by,

$$(\mathrm{MVD}) = \frac{1}{N}\sum_{i=1}^{N}(\mathrm{VD})_i$$

where the vector difference (VD), between an individual CMV report (*i*) and the collocated rawinsonde (*r*) report used for verification is,

$$(\mathrm{VD})_i = \sqrt{(U_t - U_r)^2 + (V_t - V_r)^2}$$

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

$$(\mathrm{RMSE}) = \sqrt{(\mathrm{MVD})^2 + (\mathrm{SD})^2}$$

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

$$(\mathrm{SD}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[(\mathrm{VD}_i) - (\mathrm{MVD})]^2}$$

The speed bias (BIAS) is given by

$$(\mathrm{BIAS})_t - \frac{1}{N}\sum_{i=1}^{N}\left(\sqrt{U_t^2 - V_t^2} - \sqrt{U_r^2 + V_r^2}\right)$$

2. CMV generation prior to the improvements

Before the improvement, the selection of cloud tracers was done on four-bin histogram basis (Szejwach, 1982). The four-bin histogram classified cloud tracers to low, medium, high or of mixed type. In the case of mixed clouds, the computation was not attempted. The

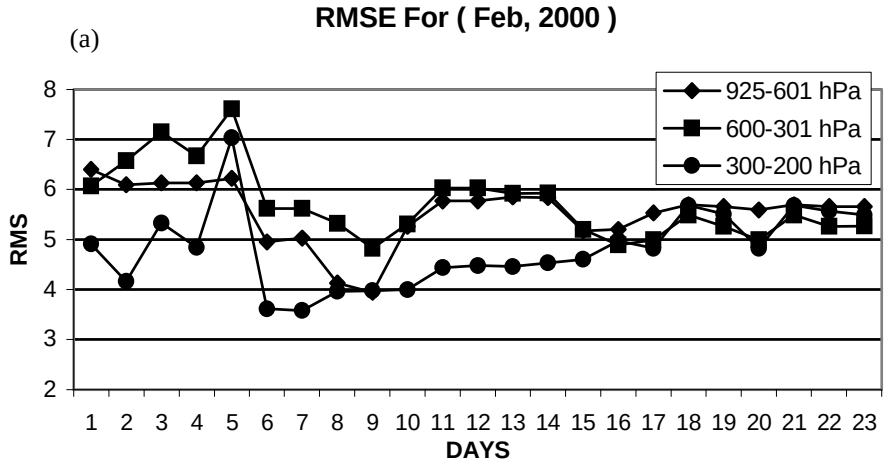
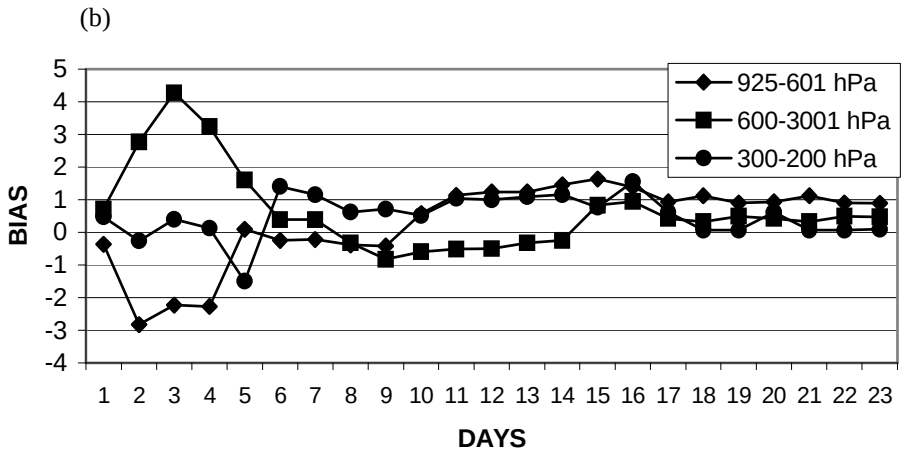


Fig. 1(a). Statistics of INSAT CMVs with LAM Analysis



Figs. 1(b). BIAS for INSAT CMVs (Feb, 2000)

same approach was applied for various lag positions of search window and CMVs were computed using Sequential Similarity Detection Algorithm (SDDA) for pattern matching at different lag positions (Kelkar and Khanna, 1986). Later pattern matching has been done, using cross-correlation technique. The navigated images provided wind vectors. The two sets of images taking middle image as tracer image and 30 minutes before and after the tracer image as target images are used for CMVs computation. After going through spatial, temporal consistency and QA test CMVs were submitted for the manual editing. CMVs were flagged at each stage when they failed. Finally the second set was transmitted on GTS. This provided CMVs with zonal flow and fewer in number. The coarser resolution of model forecast used in QA tests and coarser resolution of imagery resulted in zonal flow.

3. Improvements made in the derivation of CMVs

The improvements in INSAT CMVs were attempted in phased manner. After each attempt the CMVs were monitored to ensure steady and gradual improvements. The attempts were made in three phases.

(a)

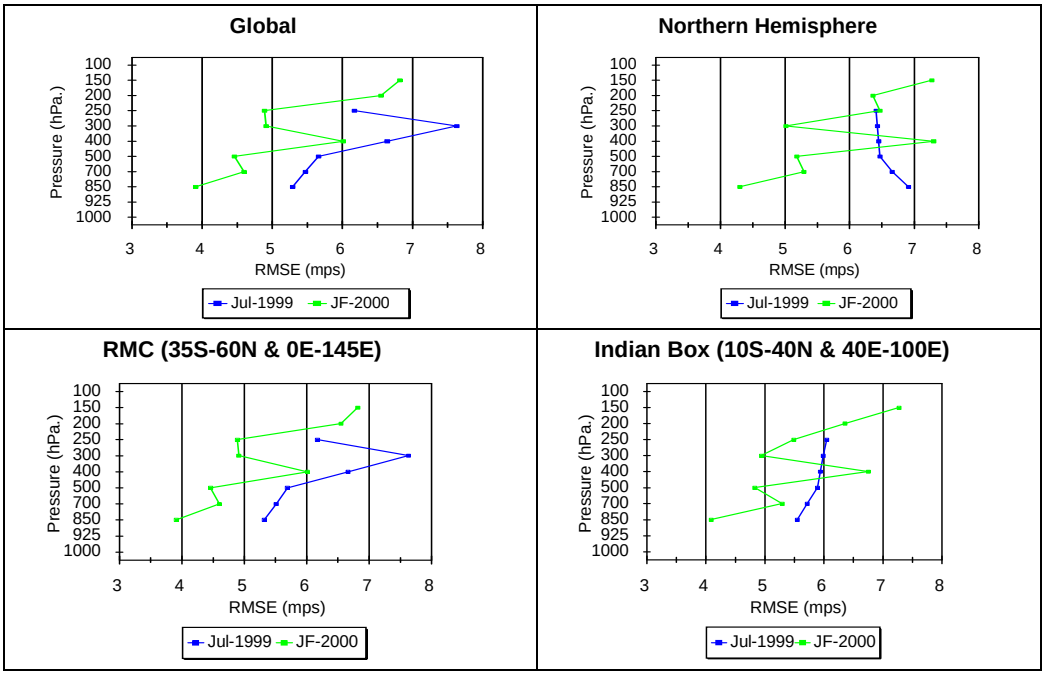
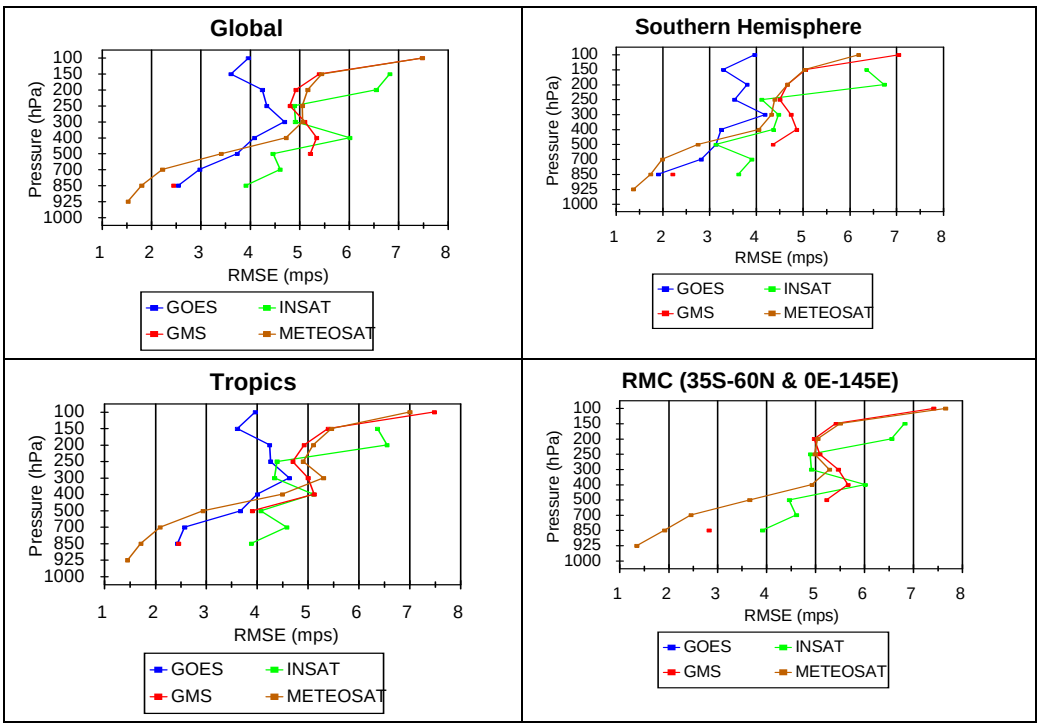


Fig. 2(a). INSAT Vector Wind RMSE with NCMRWF Forecast

(b)



Figs. 2. (b). Vector Wind RMSE of different Satellite with NCMRWF Forecast (Jan - Feb, 2000)

3.1. *Phase 1 (Introduced from 1st November, 1999)*

The existing registration and navigation approach was not changed and the tracer selection was done on the basis of four-bin histogram. The histogram with maximum frequency was the basis of cloud tracer selection. Low medium and high clouds were assigned pressure 925 to 601 hPa, 600 to 301 hPa and 300 to 200 hPa. The tracer image chip in tracer image and target image chip for different lag positions were pattern matched using cross-correlation. This has been the approach by most of the centers generating CMVs. The tracers in southern hemisphere south of 20° South bring out cloud motion clearly and the coverage of CMVs is also very good over this area. These tracers are generally passive and provide CMVs with good coverage and high confidence. The derived CMVs were assigned height and pressure level using LAM forecast to the level at which temperature of cloud cluster matched best with LAM forecast. Since LAM has been assimilating INSAT CMVs, it showed gradual improvement as a result of continued use. RMS error [Fig. 1 (a)] and Speed bias [Fig. 1(b)] for INSAT CMVs show improvement.

3.2. *Phase 2 (Introduced from 2nd December, 1999)*

At present INSAT-1D is the only operational Indian satellite, providing meteorological services much beyond the normal expected life. It is now operating in an inclined orbit with its inclination close to 1.8°. The successive half–hourly images show poor registration when the images are seen in line/pixel coordinate system. Since all the images are navigated individually, the images in geocentric coordinates system are reasonably registered. The land features showed appreciable movement in the line/pixel coordinate system but in Lat./Long. coordinate system these features show very little movement. The tracer selection for passive tracers was retained to use four-bin histogram. These tracers were tracked using cross-correlation for pattern matching. The height assignment and QA tests were done in the same way. These CMVs have been used by many NWP centers, NCMRWF is one of them. Rizvi *et al*., 2000 used these CMVs and found remarkable improvements after the changes incorporated in the CMVs retrieval algorithm. The RMSE in CMVs derived from INSAT data showed improvements, since, November 1999 compared to July 1999 and January, February, 2000 [Fig. 2 (a)]. NCMRWF further compared INSAT derived CMVs with GOES, GMS, METEOSAT-5 and found very close agreement [Fig. 2(b)].

3.3. *Phase 3 (Introduced operationally from 2nd February, 2000)*

Registration of images was further improved and height was assigned on the basis of the cloud top temperature using mean temperature of 25% of the coldest pixels (Nieman, *et al*. 1997). The cloud types and cloud heights were reassigned on this basis. INSAT CMVs agreed very closely with METEOSAT–5 CMVs. QA tests with LAM forecast have improved INSAT CMVs. The CMVs were then quality controlled using collocated forecast from LAM NWP model run operational at IMD, New Delhi, because it uses INSAT derived CMVs in its assimilation scheme and is of high spatial resolution. The quality of INSAT CMVs as reported by UKMO showed smaller speed bias and rmse [Figs. 3(a-d)] and are very well comparable with METEOSAT-5 bais and rmse. After these changes INSAT derived CMVs showed better agreement with METEOSAT-5 derived winds in qualitative terms.

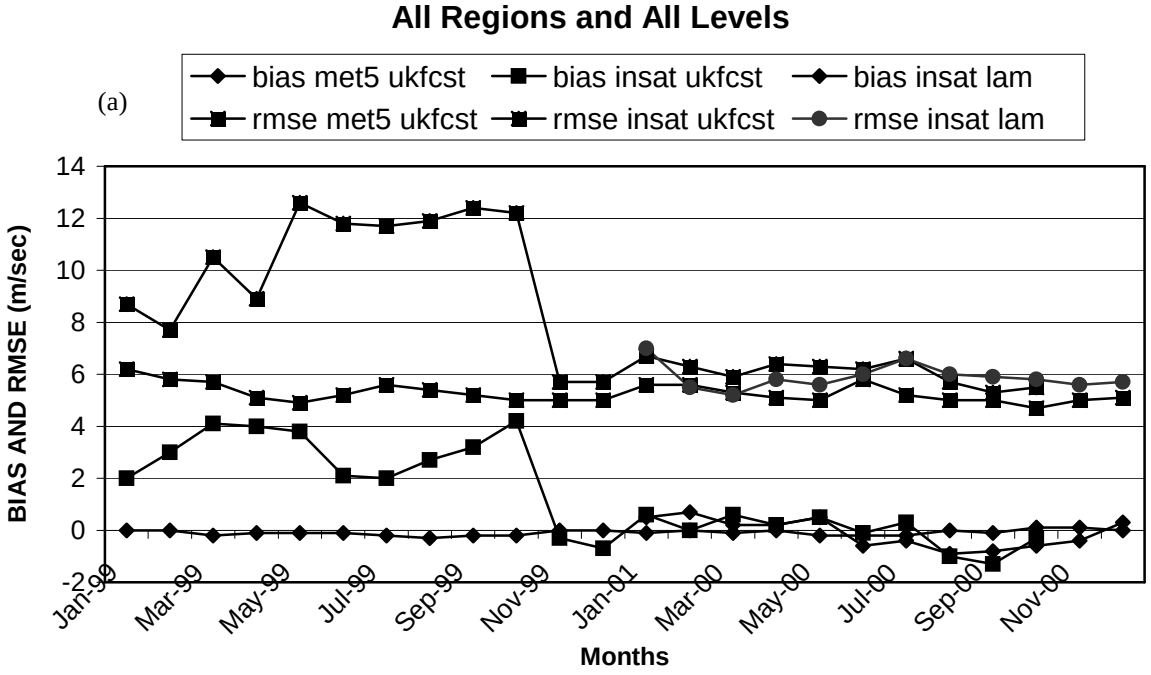
European Centre for Medium-Range Weather Forecasts (ECMWF), U.K. produces quarterly reports on the quality of satellite derived winds transmitted by all satellite operators on the GTS. The quality statistics given in these reports are based on the comparison of satellite winds against the first guess forecast field and the aircraft reports. A comparison of statistics of METEOSAT-5 derived CMVs and INSAT-ID derived CMVs for the periods November, 1999 and February, 2002 is shown in Table 1. It is seen that biases of INSAT CMVs are now comparable to those of METEOSAT-5 for most of the cases indicated in the Table 1.

The LAM (Local Area Model) has been run operationally by IMD at New Delhi. These CMV's have been assimilated in the LAM model for studying the impact of these CMV's. It has been observed that the CMV's has brought out a distinct positive contribution in the analysis and forecast of the limited area model of IMD, which suffers in the oceanic region due to sparsity of data. Though both operational as well as experimental run is able to capture the circulation features of Indian summer monsoon, strength of lower tropospheric cross equatorial flow, subtropical westerly jet in both hemispheres and tropical easterly jet over the southern latitude of Indian region are better captured both in the analysis and forecast with the additional CMV data. The impact of these data is found to be positive and useful (Bhowmik *et al*., 2004).

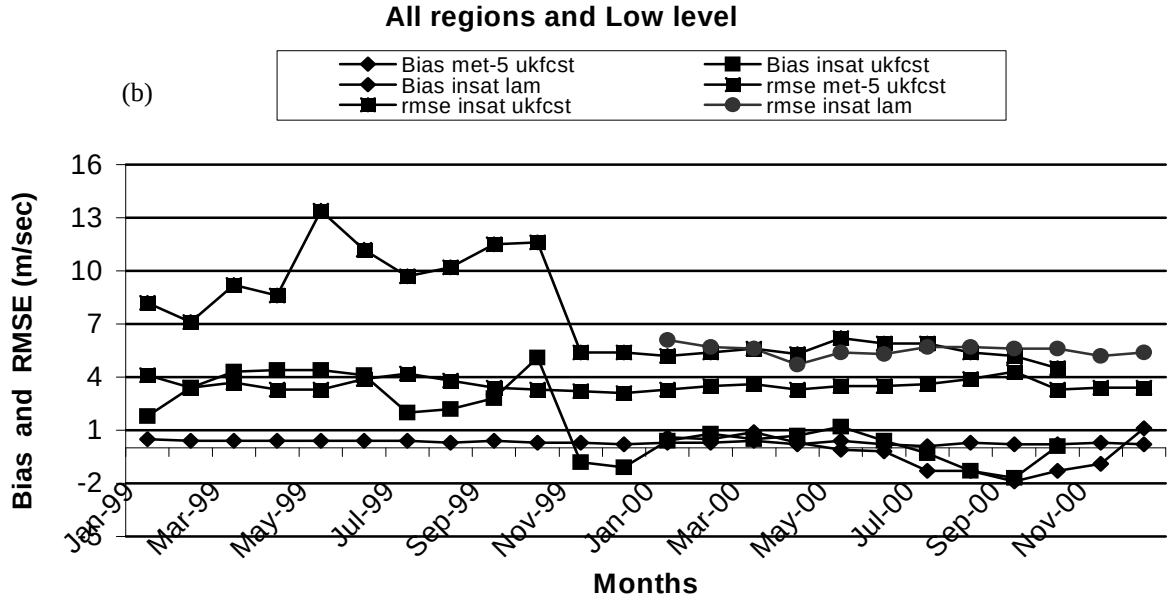
4. Development plan for future

Further improvements have been planned based on the cluster classification using objective analysis (Coakley

(a)

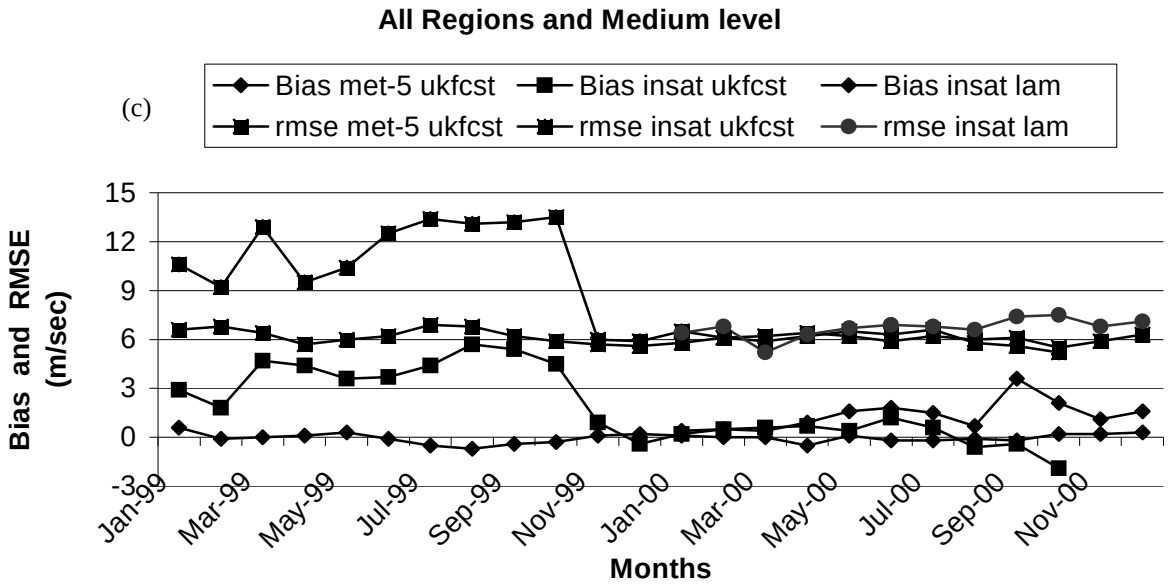


(b)

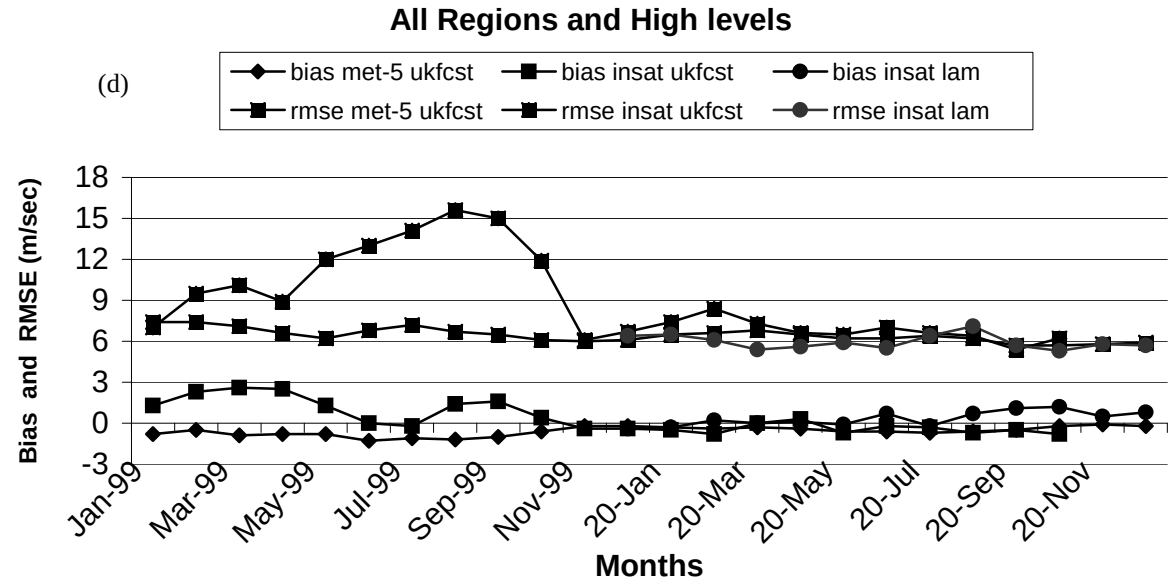


Figs. 3(a&b). Comparison of RMSE and BIAS between INSAT and METEOSAT-5 (1999-2000). (a) All regions and all levels and (b) All regions and low level

(c)



(d)



Comparison of RMSE and BIAS between INSAT and METEOSAT-5 (1999-2000)

Figs. 3(c&d). Comparison of RMSE and BIAS between INSAT and METEOSAT-5 (1999-2000). (c) All regions and medium levels and (d) All regions and high level

and Bretherton 1982; Schmetz *et al*., 1993). This is expected to improve the quality of CMVs, bringing their overall quality closer to those generated by other centers. This new scheme would further improve the quality of CMVs derived from Kalpana-1 and INSAT-3A VHRR with Infrared, visible and water vapor channels of higher spatial resolution, than that of INSAT 1D. INSAT-3A also has a CCD payload with 1 km resolution in Visible, Near IR and Short-wave IR bands. For this purpose the ground processing system is being upgraded for additional processing load. It will provide CMVs more frequent and have better quality. In addition Water Vapor Winds (WVWs) will also be derived operationally providing extensive coverage more frequently. CCD will provide capability of more rapid scanning which will be useful to provide high resolution CCD CMVs more frequently using thermal IR and WV bands from VHRR for correct height assignment using IR - WV intercept approach (Nieman *et al*., 1997). This is expected to provide more frequent, extensive coverage of satellite-derived winds from CCD, IR and WV bands of VHRR (Velden *et al*., 1997).

5. Conclusions

Use of high spatial resolution LAM forecast produced in IMD has shown the improvements in the derived CMVs. This is because the model assimilates INSAT derived CMVs and has higher spatial resolution. The spatial resolution also partially removed the zonal flow reported earlier. INSAT does not have CO_2 ratioing or IR – WV intercept option, this caused poor height assignment resulting in CMV rejection in case of sub-pixel sized clouds or thin Cirrus with lower emissivity. Taking recourse to mean temperature of certain percentage (25 %) of coldest cloudy pixels helped reducing the emissivity problem. RMSE of high and medium level CMVs has now reduced from 10 m/sec to about 5.5 m/sec. Bias has also reduced from 10 m/sec to less than 1m/sec. Low level CMVs have also improved considerably.

Acknowledgements

The authors are thankful to Director General of Meteorology, IMD, New Delhi for his encouragements during course of this study. Thanks are also due to U. K. Met. Office for providing the monthly wind statistics reports. Authors also wish to acknowledge the help rendered by Mr. S. K. Mukherjee of Satellite Division for providing lot of useful technical assistance for completion of work.

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