Proceedings for 13th International Winds Workshop
27 June to 01 July 2016 Monterey, California USA

ATMOSPHERIC MOTION VECTORS FROM INSAT-3D: ISRO STATUS

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Abstract

At Space Applications Centre (SAC), Ahmedabad, the operational derivation of atmospheric motion vectors (AMVs) from Indian geostationary meteorological satellites started since 2007 using the data from Kalpana-1 and INSAT-3A under INSAT Meteorological Data Processing System (IMDPS) project. Later many improvements in the operational retrieval algorithm have taken place with the advancement in the retrieval techniques. The most recent advanced Indian geostationary meteorological satellite INSAT-3D was launched on 26 July 2013 and placed at 82^{0}E over the Indian Ocean region. The data from an improved six channel imager and nineteen channels sounder on-board INSAT-3D has enhanced the scope for better understanding of the different tropical atmospheric processes over this region. The retrieval techniques and accuracy of atmospheric motion vectors (AMVs) has improved significantly with the availability of improved spatial resolution data along with more options of spectral channels in the INSAT-3D imager. The present study, a brief summary of the INSAT-3D data and operational AMV retrieval algorithm using four different spectral channels (visible, infrared, mid-infrared and water vapour channels) of INSAT-3D at 4 km spatial resolution are discussed. The long-term quality assessment of INSAT-3D AMVs with different other observations viz. radiosonde winds, model analysis winds and other available AMVs over this region are also presented. To demonstrate the initial application, INSAT-3D AMVs are also assimilated into numerical model to assess the impact for forecast improvement for few case studies. The validation results and impact assessment from this study will provide some guidance to the international operational agencies for implementation of this new AMV dataset for future applications in the Numerical Weather Prediction (NWP) over the south Asia region.

1. INTRODUCTION

Space Applications Centre (SAC), Indian Space Research Organization (ISRO) has started producing AMV from three successive Kalpana-1 infrared and water vapor images with two times a day (00 & 12 UTC) over Indian Ocean area in 2007 by its own developed algorithm (*Deb et al. 2008, Kishtawal et. al. 2009*) and subsequently since 2009 AMV's from Kalpana-1 are being produced every 30-minute when 30-minute image acquisition of Kalpana-1 is being operationalized. With the advancement of retrieval algorithm the operational algorithm was upgraded number of times with respect to quality control techniques and height assignment methods (*Deb et al. 2014, 2015, Kaur et al. 2013*). The launch of advanced Indian geostationary meteorological satellite INSAT-3D on 26 July 2013 with improved spatial resolution imager channels has enhanced the scope for the retrieval of better quality of AMVs over the Indian Ocean region and subsequent up gradation in operational algorithm was done (*Deb et al. 2016*). The availability of MIR channel in INSAT-3D has provided an added advantage of retrieval of good quality low-level AMVs during night time. This is sometime difficult to retrieve from the traditional longwave TIR channels. The following sections describes the current status of ISRO AMVs retrieval algorithm and later the statistics related to present accuracy of INSAT-3D AMVs.

2. INSAT-3D OPERATIONAL AMV RETRIEVAL ALGORITHM

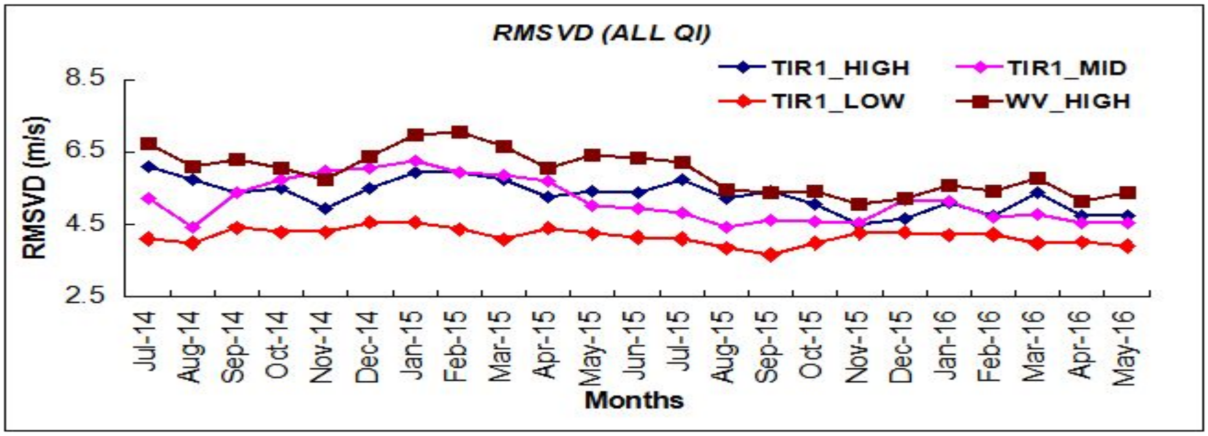
The major steps of AMV retrieval algorithm consists of: a) Tracer selection, b) Height assignment of selected tracers, c) Tracer tracking in the subsequent images and finally d) Quality control. The operational INSAT-3D AMV derivation processes for VIS,WV and TIR1 spectral channels are inherited from the latest operational version of Kalpana-1 AMV derivation algorithm (*Kishtawal et al., 2009, Deb et al., 2015, Kaur et al. 2013*), which has similar spectral channels. In the algorithm immediately after the selection of tracers in the images, height assignment is done for the selected tracers. In the next step, tracking of the selected tracers is being carried out in the next image by matching with height and wind is computed. During this step collocated forecast wind is used to optimize the search area. Finally, in the last step, different quality control processes are performed to get the final winds. (*Deb et al 2016*). The MIR channel in INSAT-3D has provided an additional advantage for the retrieval of good quality low-level AMVs during night time,which was not possible in Kalpana-1. This channel is a little more sensitive to warmer temperatures and less sensitive to thin cirrus than traditional long-wave TIR channel which is generally used to track low-level clouds at night. The use of MIR channel data leads to the retrieval of good quality lower mid-level (600–700 hPa range) and low-level (700–950 hPa range) winds during night-time. During the day-time this is complemented by using VIS channel.

In brief summary about the different retrieval steps is mentioned here. The tracers are selected by computing local image anomaly in 32 × 32 template window, both in cloudy and cloud free regions irrespective of spectral channels. The anomaly-based tracers are generally produced by a smooth feature field in comparison to the gradient based features and it helps in reducing the tracking errors (*Deb et al., 2008*). Since MIR channel is characterized by relatively small gradient in brightness temperature in the warmer low-level, which limits the detect-ability of good cloud tracer, hence before selecting any tracer in MIR channel, the images are enhanced by stretching the brightness temperature contrast in the warmer end of the spectrum (low-levels). This enhancement greatly improves the low-level wind at the cost of mid to upper-level. Due to the proximity of this channel to sunlight, the MIR channel data is used only during the night time for the AMV retrieval. The height assignments of the selected tracers in WV and TIR1 images are derived using the widely used methods such as the infrared window (WIN) technique or the water vapor histogram method (HIST), the H2O intercept method (*Nieman et al., 1993*) and the cloud base method (*LeMarshall et al., 1993*). The height assignment of selected tracers in VIS and MIR images are estimated using collocated TIR1 channel brightness temperature with infrared window (WIN) technique. The National Center for Environmental Prediction (NCEP) 6- hourly forecast temperature, humidity and wind profiles nearest at the retrieval time are used as first guess during the retrieval process. Once a tracer is identified in the first image and its height assignment is being done, the match of this tracer is searched in the second image within a bigger search window centered at the same point as the tracer window. The prior height assignment of tracer helps to employ a representative 6-hourly numerical wind forecast for optimizing the position of search domain as bigger search window in the second image. The degrees of matching between two successive images are calculated by the Nash-Sutcliffe model efficiency (*Nash and Sutcliffe, 1970*) coefficient (E). The use of this tracking procedure in estimation of winds has shown some improvement over the Indian Ocean region (*Deb et al., 2008).* The quality control procedure involves different checks based on vector acceleration checks. In this process the derived vectors are compared with their surrounding vectors and collocated forecast fields. The vectors that show an acceleration, directional deviation, or discrepancy to other observations larger than a predefined value are rejected. In the INSAT-3D operational algorithm, the automatic quality control procedure developed at European Organization for the Exploitation of Meteorological Satellites [EUMETSAT] (*Holmlund, 1998*) called as EUMETSAT Quality Indicator (QI) is implemented with little modification (*Deb et al., 2015*). The major difference between ISRO algorithm with other operational algorithm is that ISRO algorithm uses multiples images for retrieval while the derivation process used to estimate Meteosat-7 AMVs at EUMETSAT and Co-operative Institute for Meteorological Satellite Studies (CIMSS) where traditionally three images are used for retrieval. The value of QI is ranging from 0.0 to 1.0,while some operational center represents QI value as 0 to 100.

3. INSAT-3D AMV ACCURACY

The accuracy of retrieved winds is calculated according to the Coordination Group for Meteorological Satellites (CGMS) guidelines. It is suggested to report the mean vector difference (MVD), the root-mean-square vector difference (RMSVD), the standard deviation (SD), along with the mean radiosonde speed (SPD) and number of collocations (NC) with radiosonde data. Here the unit of MVD, RMSVD, SD, SPD and BIAS is m/s.

a)



b)

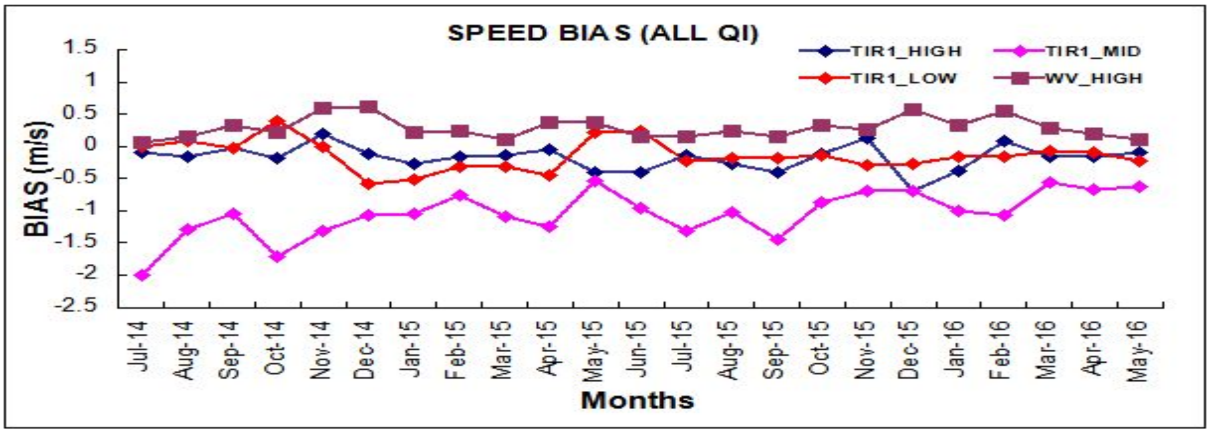
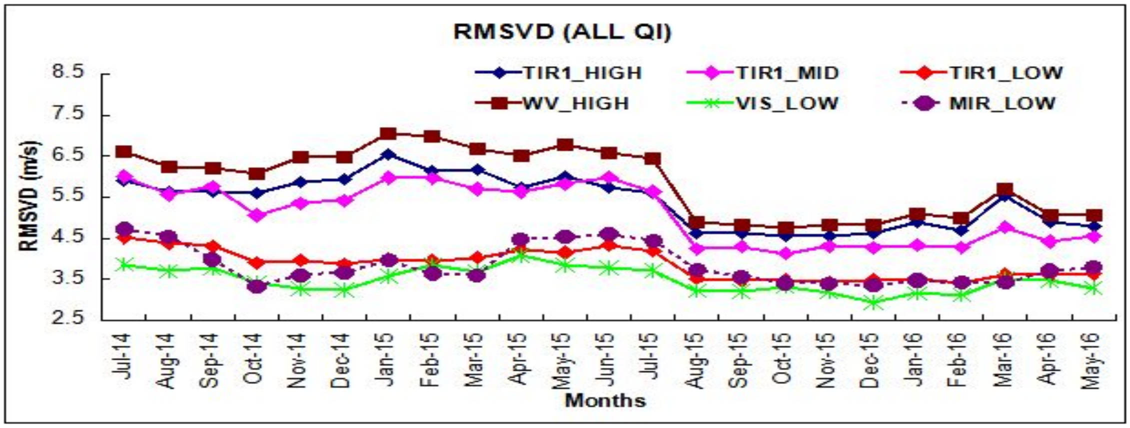


Figure 1: The monthly time series of: a) RMSVD and b) speed bias of INSAT-3D infrared AMVs for High (TIR1_HIGH), mid (TIR1_MID), low (TIR1_LOW) levels and WV (WV_HIGH) AMVs averaged over retrieval domain when validated with Radiosonde winds two times a day (00 and 12 UTC) from July 2014 to May 2016 .

The Fig 1(a-b) shows the RMSVD and BIAS for HIGH, MID and LOW levels of infrared winds (TIR1_HIGH, TIR1_MID and TIR1_LOW) and HIGH level water vapor (HIGH_WV) winds for INSAT-3D when compared with collocated observations starting from July 2014 to May 2016 respectively. The statistical analysis is done with respect to collocated radiosonde profile two times a day (i.e. for 00 UTC and 12 UTC) for each month. It is clearly visible from the figures that the INSAT-3D RMSVD and BIAS values are consistent through out two years time. However, slight improvement is noticed after August 2015 when algorithm related to image registration technique were upgraded. The above accuracy for infrared and water vapor winds are almost consistent with the accuracy of other satellite winds retrieved over this region at other operational agencies viz. EUMETSAT, CMA and JMA.

The analyses in Fig-1 are demonstrated by taking radiosonde winds as observations, which are available over land only. However the AMVs are available over oceanic regions as well. To validate over both land and ocean, winds profiles from numerical model analysis are used. The Fig 2(a-b) shows the RMSVD and BIAS for high, mid and low levels of infrared winds (TIR1_HIGH, TIR1_MID and TIR1_LOW), high level water vapor (WV_HIGH) winds, low level visible (VIS_LOW) winds and low-level mid-infrared (MIR_LOW) winds of INSAT-3D when compared with collocated model analysis winds starting from July 2014 to May 2016 respectively.

a)



b)

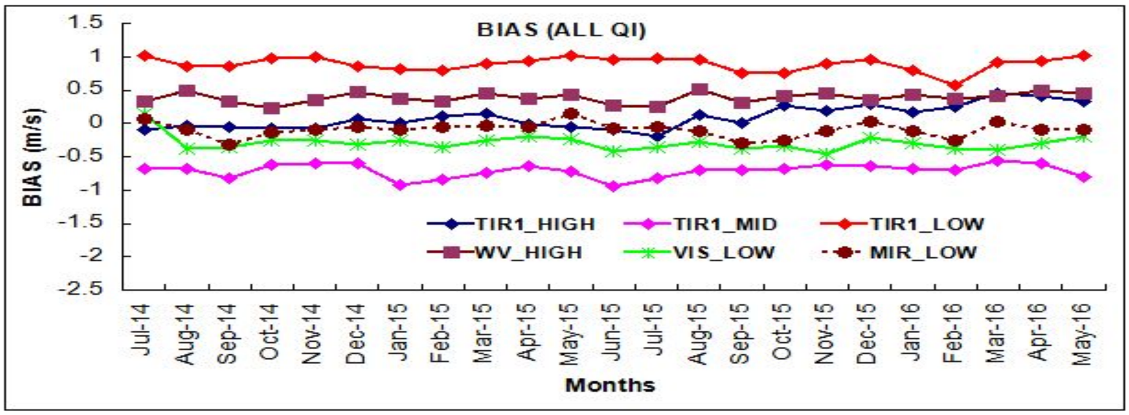


Figure 2: The monthly time series of: a) RMSVD and b) speed bias of INSAT-3D infrared AMVs for High (TIR1_HIGH), mid (TIR1_MID), low (TIR1_LOW) levels, water vapor (WV_HIGH) AMVs, visible (VIS_LOW) AMVs and mid-infrared (MIR_LOW) AMVs averaged over retrieval domain when validated with NCEP GFS analysis wind four times a day (00, 06, 12 and 18 UTC) from July 2014 to May 2016 .

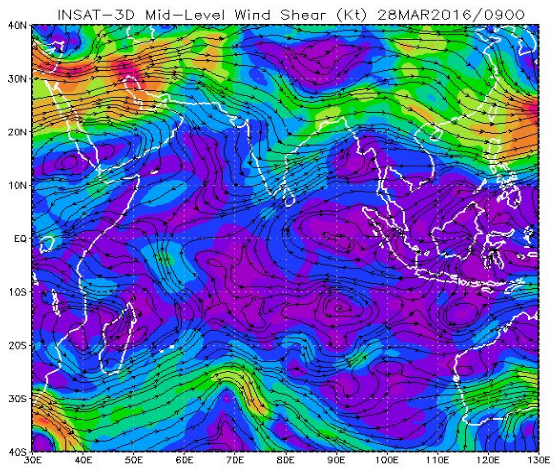
The statistical analysis is done with respect to collocated NCEP GFS model analysis profile four times a day (i.e. for 00, 06, 12 and 18 UTC) for each month. It is clearly visible from the figures that the INSAT-3D RMSVD and BIAS values are consistent through out two years time like in validation with radiosonde. However, slight improvement is noticed after August 2015 when algorithm related to image registration technique were upgraded. The above accuracy for infrared, water vapor, visible and mid-infrared winds are consistent with the accuracy of similar satellite winds retrieved over this region at other operational agencies viz. EUMETSAT, CMA and JMA.

4. DERIVED PRODUCTS FROM INSAT-3D

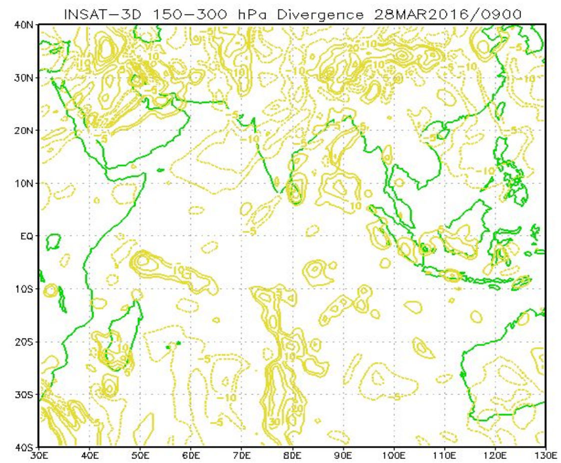
Recently the algorithm for deriving different derived products using INSAT-3D atmospheric motion vectors are made operational at India Meteorological Department New Delhi. These are i) Atmospheric Vorticity, ii) Atmospheric Divergence, iii) Atmospheric Convergence, iv) Deep mean atmospheric shear, v) Mid-level atmospheric shear and vi) 24-hour shear tendency. All these derived products are very important during the formation and decay of tropical cyclones (TC). Atmospheric vorticity is a measure of curvature in atmospheric flow and a positive value indicates counter clockwise motion in the northern hemisphere and clockwise motion in the southern hemisphere.

A positive vorticity environment is conducive to storm development. The upper-level atmospheric divergence can be used by TC forecasters to estimate the strength of the TC secondary circulation, including the low-level inflow into the TC core, the convective updraft strength within the TC eye-wall, and the resulting outflow at the top of the TC. Lower-level atmospheric convergence analysis can be used by tropical cyclone forecasters to identify potential areas where TC development may occur. The presence of atmospheric wind shear is vital to hindering of TC development, while lack of it supports the TC development. A low shear environment is favourable for tropical cyclone development, while a high shear environment will deter a immature TC region from (further) developing or destroy an already mature TC. The following Fig. 3 shows some sample examples.

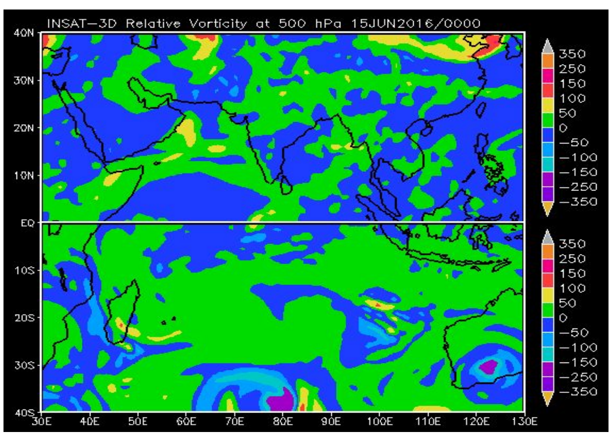
a)



b)



c)



d)

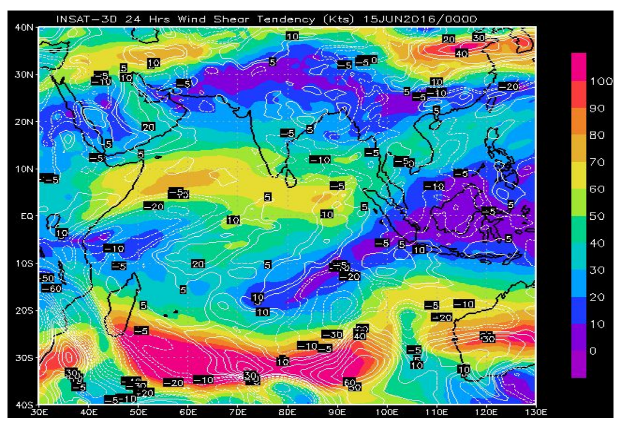


Figure 3: a) Mid-level wind shear, b) Upper-level divergence valid at 0900UTC of 28 March 2016. c) Relative vorticity at 500 hPa and d) 24-hour shear tendency valid at 00 UTC of 15 June 2016.

During the computation of all the above mentioned AMV derived products, in the first step, the retrieved AMVs are gridded into regular spatial grid using numerical model wind forecast as first guess. The Cressman objective analysis is a successive correction method and is widely used by numerical weather prediction community. This method is used for transforming the observations (i.e. here AMVs) at irregular spaced points into the points of regular grids. Apart from interpolation, it also performs several other functions viz. removal of data errors, smoothing and most important to maintain internal consistency.

5. IMPACT ASSESSMENT

Two case studies were undertaken to assess the impact of INSAT-3D AMVs by assimilating them in the WRF numerical model viz. by assimilating INSAT-3D AMVs i) for the predicting the track of the tropical cyclonic storm Nanuak over Arabian Sea, and ii) for forecasting the Indian summer monsoon July 2014.

a) b)

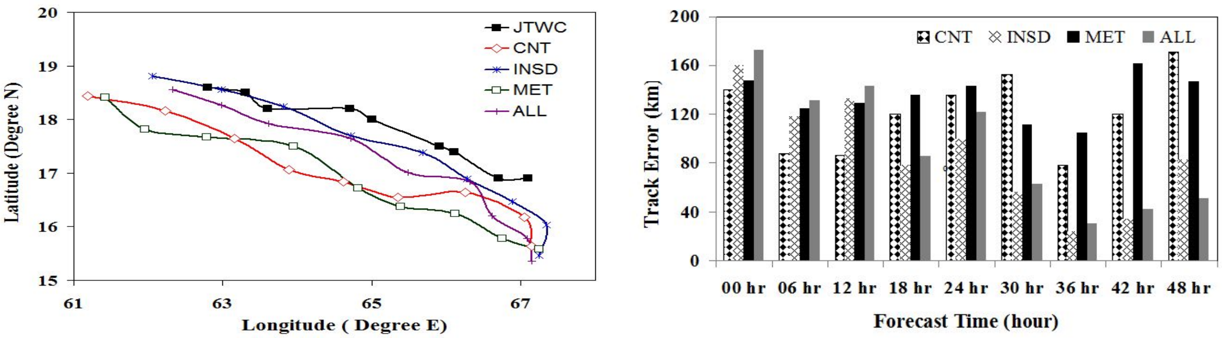


Figure 4: a) JTWC observed track along with forecasted track of cyclonic storm NANAUK from the control and different assimilation experiments. b) Track forecast errors in km for different forecast lengths from the control and assimilation experiments.

The Fig-4a shows the the observed track along with forecasted track of cyclonic storm Nanuak from different experiments. Here the different experiments CNT, INSD, MET and ALL represents control experiments, experiment where INSAT-3D data used, experiment where Meteosat-7 data and experiment where both Meteosat-7, INSAT-3D and other AMVs available in the GTS are used. It is visible from the figure that track from INSD experiment is closely matches with observed JTWC track. The Fig-4b shows the forecasted track errors at different forecast lengths from different experiments. The track errors in INSD experiment is less compared to other experiments.

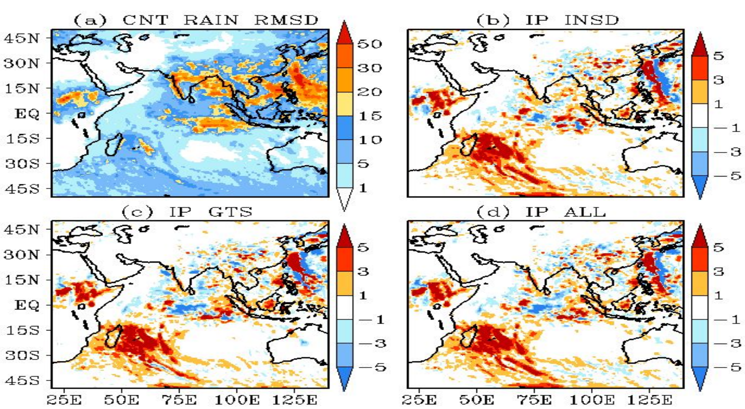


Figure 5: Impact of INSAT-3D AMVs on 24-hour Rainfall Forecast. A) RMSD for CNT experiment, b) Improvement factor for INSD experiment, c) Improvement factor for GTS experiment and d) improvement factor for ALL experiment.

The Fig 5a, shows the root mean square difference (RMSD) 24-hour rainfall forecast for CNT (i.e. Control experiment). The Fig 5(b-d) show the improvement factor for INSD, GTS and ALL experiments (INSD=only INSAT-3D AMVs are assimilated, GTS=only AMVs available in GTS are used for assimilation, ALL=both INSAT-3D and GTS available AMVs are used for assimilation). The positive IP represents the positive improvement while negative IP value represents negative impact. It is clearly visible from the figure that INSAT-3D AMVs have positive impact in the forecast length.

6. FUTURE PLANS

The INSAT-3D AMVs are available every 30-minutes and accuracy of INSAT-3D AMVs are now well established. The different national and international operational agencies have started using these winds for assimilation system for operational weather forecasts. With the recent launch of INSAT-3DR satellite on 06 September 2016 from Shriharikota, India, it will also provide winds at every 30-minutes interval over Indian Ocean region. However, INSAT-3D and INSAT-3DR winds will be available every 15-minutes interval. The availability of more number of accurate satellite winds from both the satellite over Indian Ocean area will enhance the forecast quality. It is also proposed to derive winds by merging of INSAT-3D and INSAT-3DR satellite images for retrieving winds at every 15-minutes.

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ACKNOWLEDGMENT

The first author (SKD) thankfully acknowledged the WMO for financial support through IWWG Co-chairs for attending the 13th International Wind Workshop at Monterey California USA during 27 June to 01 July 2016. The encouragement and support from Director Space Applications Centre (SAC), ISRO and Deputy Director EPSA SAC are acknowledged.