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RESEARCH REPORT

Validation of INSAT-3D Atmospheric Motion Vectors

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Abstract

Satellite derived Atmospheric Motion Vector (AMV) is one of the most important sources of tropospheric wind information assimilated in numerical weather prediction (NWP) system. Earlier studies showed that the quality of Kalpana-1 AMVs was not comparable to that of other geostationary satellites and hence not used in NWP system. This was due to the error associated with empirical height assignment method used to derive Kalpana-1 AMVs. Recently the height assignment method and quality control scheme for deriving INSAT-3D AMVs have been modified. The validation of INSAT-3D AMVs against NCMRWF's NWP short range forecasts (first guess) and in-situ observations has been carried out for January 2015, and compared with that of METEOSAT-7. Present study revealed noticeable improvement in the quality of INSAT-3D AMVs. The root mean square vector difference (RMSVD) and bias of INSAT-3D AMVs computed against NWP first guess and in-situ observations are lower compared to that of METEOSAT-7.

Contents

1. Introduction

Atmospheric Motion Vectors (AMVs) are the satellite derived winds, extracted from satellite imagery by tracking tracers such as clouds and water vapour through a series of consecutive satellite images. AMVs are one of the most important tropospheric wind information assimilated in numerical weather prediction (NWP) systems. AMVs from various geostationary satellites viz. METEOSAT-7 & 10 (Europe), GOES-E and W (USA), and MTSAT (Japan) and polar orbiting satellite viz. METOP (Europe), NOAA (USA) series are being assimilated regularly at NCMRWF and other major NWP centres .

AMVs from the Indian geostationary satellite Kalpana-1 disseminated through global telecommunication system (GTS) since 2011, and these winds are validated against NCMRWF short range predictions as well as in-situ winds for monsoon 2011 (Das Gupta and Rani, 2013) and compared with METEOSAT-7 AMVs (Rani and Das Gupta, 2013). These studies showed that the Kalpana-1 AMVs have high Root Mean Square Vector Difference (RMSVD) when compared against NWP first guess and in-situ observations and the same is almost double to that of METEOSAT-7. One of the possible reasons of this high RMSVD was the height assignment method used while deriving Kalpana-1 AMVs, based on empirical Genetic Algorithm method (Deb et al. 2008) at the Space Application Centre (SAC), India.

INSAT-3D launched in July 2013, generates images of the earth in six wavelength bands significant for meteorological observations viz., visible (0.52 - 0.72 μm), shortwave infrared (1.55 - 1.70 μm), middle infrared (3.80 - 4.00 μm), water vapour (6.50 - 7.00 μm) and two bands in thermal infrared regions - TIR1 (10.2 - 11.2 μm) and TIR2 (11.5 - 12.5 μm). The spatial resolution of visible (VIS) and shortwave infrared (SWIR) is 1 km , 4 km each for middle infrared (MIR), TIR-1 and TIR-2, and 8 km for water vapour (WV). Middle Infrared band provides night time pictures of low clouds and fog, which is not available in Kalpana-1. Three consecutive INSAT-3D images of 30-minute intervals are used to determine the AMVs, which consists of the following steps 1) Image registration, thresholding, filtering, 2) Features/tracer selection and tracking, 3) Quality control and 4) Height assignment. New height assignment scheme(using NWP first guess and replacing old empirical GA method) implemented for deriving AMVs of INSAT-3D is based on IR-window and H_2O intercept method (Deb et al. 2014). The quality control process is also modified by Deb et al. (2013) subsequently.

NCMRWF started validating INSAT-3D AMVs in active collaboration with SAC and shared continuous feedback to SAC since August 2013. There were several issues with the derived AMVs initially, which were rectified subsequently and the AMV derivation algorithm/process significantly stabilized in September 2014. In this report an attempt has been made to validate the INSAT-3D AMVs against NCMRWF first guess and in-situ winds. The validation statistics for INSAT-3D AMVs are compared with that of METEOSAT-7 AMVs.

2. Data and Methodology

NCMRWF receives INSAT-3D and METEOSAT-7 AMVs though GTS via India Meteorological Department (IMD). In this study, INSAT-3D and METEOSAT-7 infrared (IR), visible (VIS) and water vapour (WV) channel AMVs from NCMRWF operational data base, were validated against in-situ observations as well as against NWP first guess for January 2015. AMVs are being derived from Indian geostationary satellite INSAT-3D (82°E) using different spectral channels viz. IR (3.8 μm and 10.8 μm), VIS (0.65 μm) and WV (6.9 μm). AMVs from European geostationary satellite over the Indian Ocean METEOSAT-7 (57°E) are derived using three channels IR (11.5 μm), VIS (0.7 μm) and WV (6.4 μm).

AMVs (observed winds) are validated against in-situ winds (background winds) viz. radiosonde and pilot balloon winds following the criteria set by the Coordination Group for Meteorological Satellites (CGMS) (Tokuno 1998). Collocation of in-situ winds and AMVs are considered if they are horizontally within 150 km, vertically within 25 hPa and temporally within 30 minutes.

Collocated observations with speed difference more than 30 m/s or direction difference more than 60° are not considered for validation purpose.

AMVs are validated against NCMRWF NGFS (T574L64) first guess following the guidelines provided by NWP Satellite Application Facility (SAF) (Forsythe, 2008). INSAT-3D and METEOSAT-7 AMV's (IR, VIS and WV) are collocated with NCMRWF first guess (0.5° x 0.5°) and the difference between AMV and first guess has been computed. For plotting, collocated pairs are segregated and averaged over 0.5° x 0.5° latitude/longitude bins for daily plots and 5° x 5° bins for monthly plots. AMVs are subdivided into three different pressure levels in the vertical: low (1000 – 700 hPa), middle (700 – 400 hPa) and high (400 – 100 hPa) for validation purpose.

Statistical parameters like mean monthly wind speed, speed bias and RMSVD were computed for satellite winds with respect to the in-situ observation for January 2015. Vector plots and speed bias density plots, which show the difference in observed and predicted wind direction and speed if any, were generated for INSAT-3D & METEOSAT-7 winds with respect to the NWP short-term predictions. The statistical parameters are computed as follows:

$$Observation\ speed = \sqrt{obsu^2 + obsv^2}$$

$$Background\ speed = \sqrt{bgu^2 + bgv^2}$$

$$speed\ bias = Observation\ speed - Background\ speed$$

$$Vector\ difference(VD) = \sqrt{(obsu - bgu)^2 + (obsv - bgv)^2}$$

$$Root\ mean\ square\ vector\ differnce(RMSVD) = \sqrt{\frac{\sum VD^2}{N}}$$

Normalised root mean square vector difference $= RMSVD / (mean\ background\ speed)$

where N is the number of collocated points, 'obsu' and 'obsv' are the INSAT-3D zonal and meridional component of AMVs (ms^{-1}), 'bgu' and 'bgv' are zonal and meridional component of background winds (ms^{-1}).

3. Results and Discussions

After the launch of INSAT-3D in July 2013, NCMRWF started validating INSAT-3D AMVs along with SAC with an aim to improve its quality. NCMRWF received the first set of sample observations for a period of 16 -31 August 2013, from SAC. This dataset was derived using three consecutive images and quality indicator was absent in this dataset . It is noteworthy to mention that the derived winds are not full disk product but a sector generated product (SGP), like in Kalpana-1, which is required to overcome the navigational problem of INSAT-3D.

SAC provided the second dataset for a period of October-November 2013, which was derived using nine consecutive images. Though the second dataset contains the quality information, the number of winds having quality above 50% (0.5) was very less.

After modifying the quality control procedure, SAC provided the third dataset for a period of 11 - 26 February, 2014. Figure 1 shows the vector plot of high level AMVs from thermal infrared (TIR) channel from the third dataset.

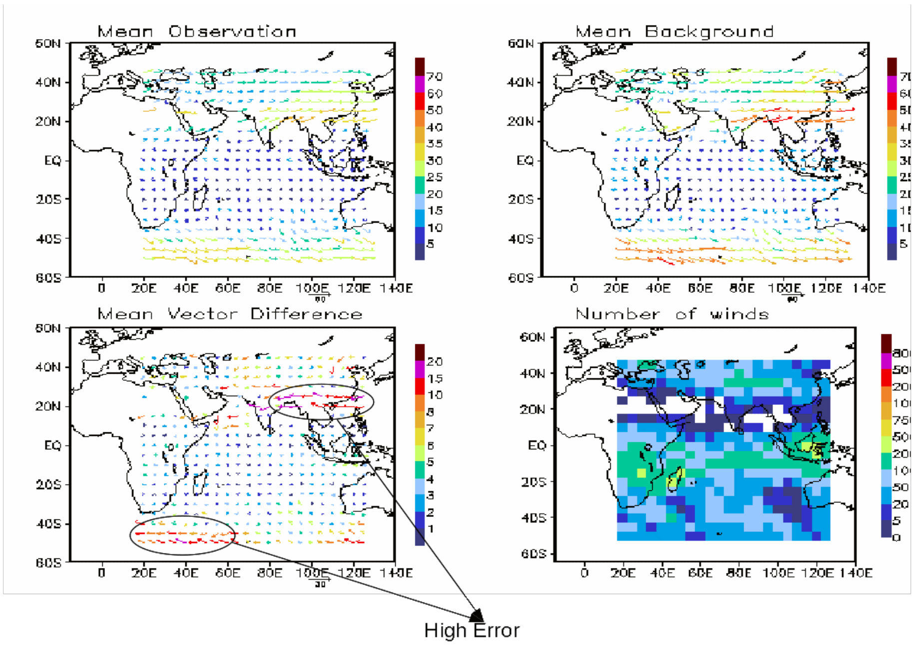


Figure 1: Vector plot of INSAT-3D high level TIR AMVs for the month of February 2014
(Third dataset provided to NCMRWF by SAC)

Vector plot has four panels, the Mean Observed AMVs, Mean Background vector winds, the Vector Difference between the observation and background and the number of collocated observations with respect to the first guess. It is noticed from the plot that the vector difference is high north of 15° N and south of 40° S. After providing feedback on the third dataset, SAC applied further modification in the AMV processing and provided the modified dataset to NCMRWF for further validation. This is the fourth dataset NCMRWF received from SAC. Figure 2 is the vector plot of the fourth dataset. The large vector differences observed in the third dataset has been highly reduced in the fourth dataset.

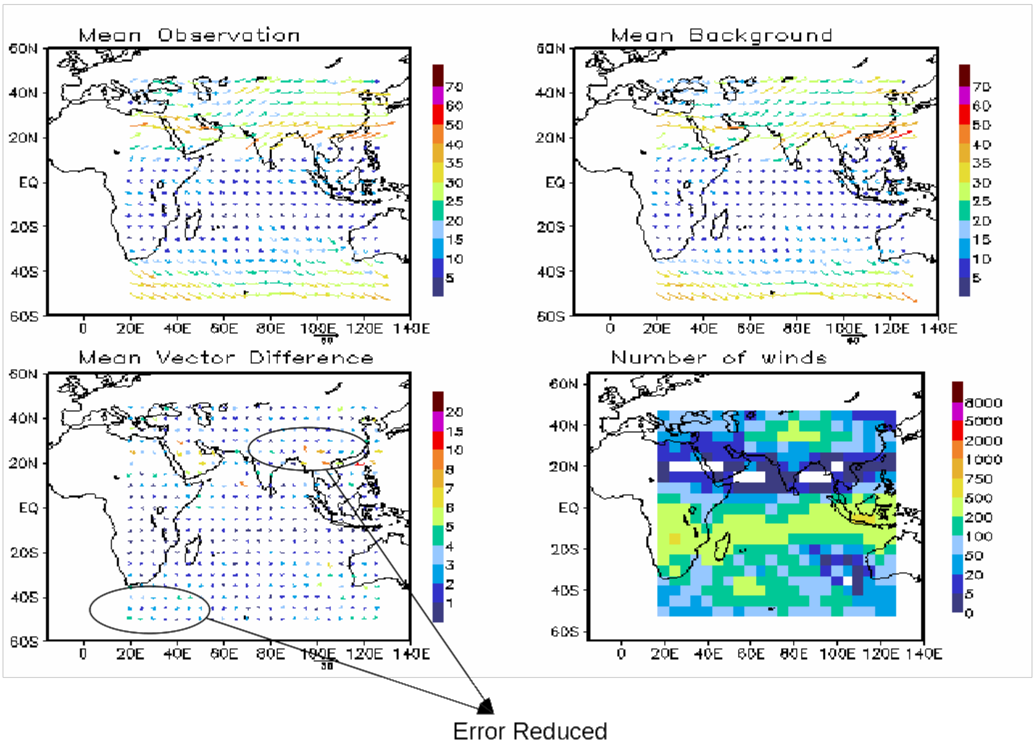


Figure 2: Vector plot of INSAT-3D high level TIR AMVs for the month of February 2014 (Fourth dataset provided to NCMRWF by SAC)

Another set of sample INSAT-3D AMV (TIR) data was received in March-April, 2014, from SAC. The same was validated and found to be consistent against NCMRWF first guess as well as in-situ observations. GTS transmission of INSAT-3D AMVs in BUFR format started since July 2014, however there were several issues initially including wind speed unit etc., most of these were rectified subsequently and the processing was significantly stabilized in September 2014. NCMRWF has started processing and monitoring these AMVs from September 2014. Complete online monitoring of all the three types of AMVs (IR, VIS and WV) at NCMRWF has started recently and the results of the same for January, 2015 are discussed here. INSAT-3D AMVs are generated at every 30 minute interval. The average numbers of AMVs for January, 2015 received at each 30 min interval are shown in Figure 3.

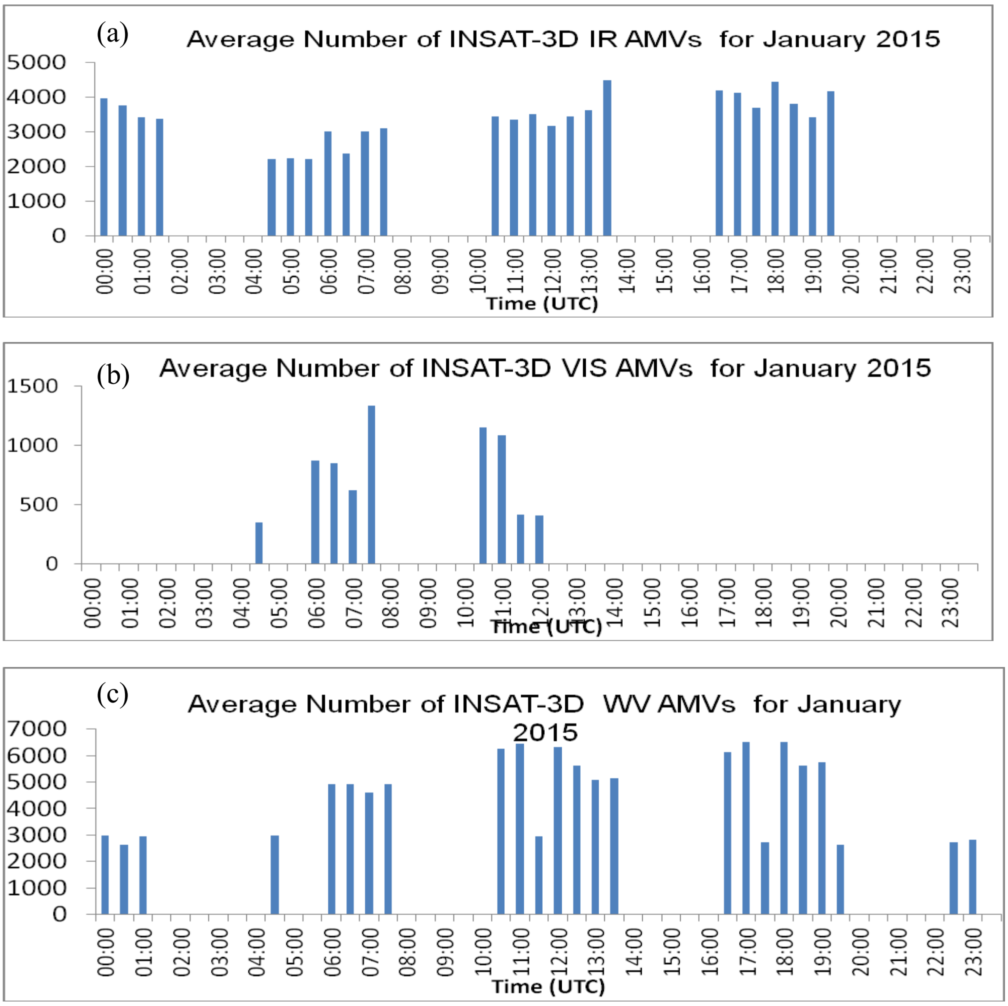


Figure 3: Average number of INSAT-3D AMVs received at each 30 minutes interval for January 2015 (a) IR, (b) VIS and (c) WV

METEOSAT-7 AMVs are transmitted in BUFR format at every 90 minute interval. The average numbers of AMVs for January 2015 received are shown in Figure 4.

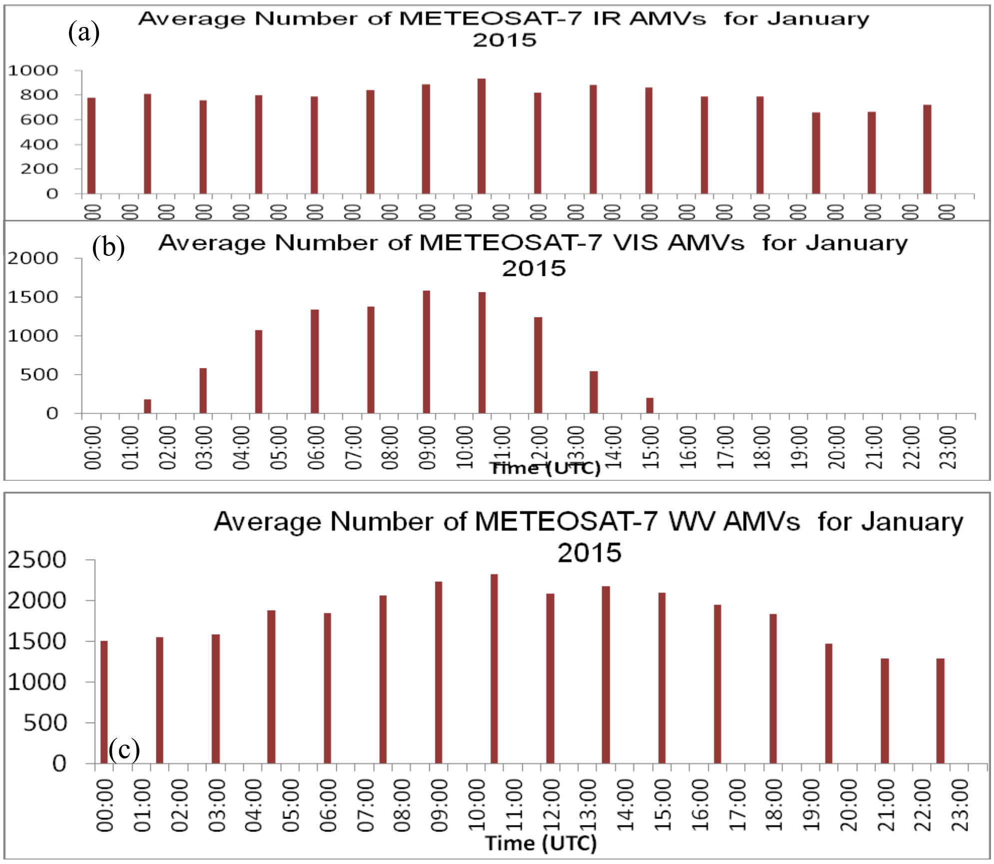


Figure 4: Average number of METEOSAT-7 AMVs received at each 30 minutes interval for January 2015 (a) IR, (b) VIS and (c) WV

Though it is expected to receive IR and WV AMV observations continuously at every 30 minutes, but intermittent data reception is observed. Observations 02-04 UTC, 08-10 UTC, 14-16UTC and 20-22UTC either not received or received late, whereas the reception of METEOSAT-7 AMVs is continuous.

Figure 5(a) depicts the difference between INSAT-3D high level IR (all, irrespective of quality flag) AMVs and NCMRWF first guess on a typical day. Figures 5(b) and 5(c) depict the same but for AMVs with quality flag above 50% and above 80% respectively.

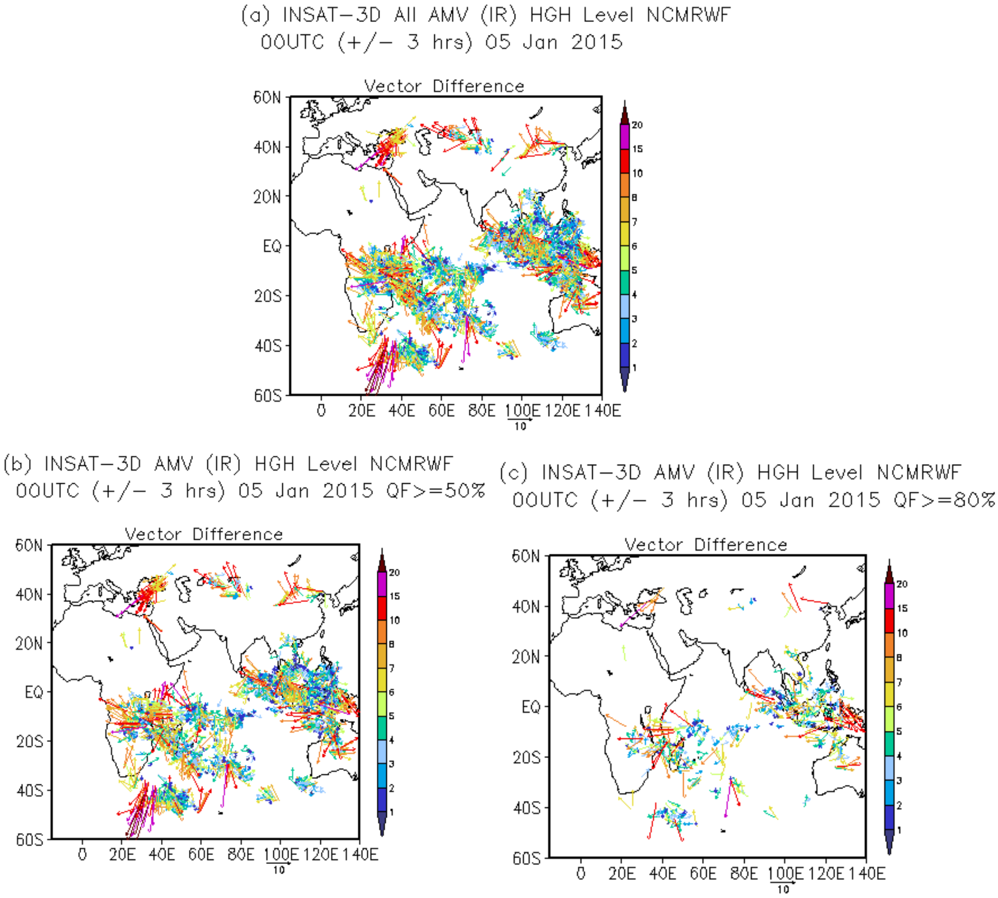


Figure 5: Vector difference (AMV- Background)) plot of INSAT-3D high level IR AMVs for 00 UTC 05 January 2015 (a) All winds , (b) wind with QF ≥ 50%, (c) wind with QF ≥ 80%

It is observed, a few AMVs are filtered using quality flag ≥ 50%. Though few AMVs of high disagreement with first guess are filtered using quality flags ≥ 80%, many good quality (agreeing with first guess and in-situ winds) AMVs are also filtered out. SAC is in the process of redefining the quality flags. Thus, for validation purpose all INSAT-3D AMVs irrespective of the quality flags are used, whereas, METEOSAT-7 AMVs with quality indicator (QI) >= 80 only are used for validation.

3.1 Validation against NWP First Guess

The differences between the AMVs (INSAT-3D, METOSAT-7) and NCMRWF first guess for high level IR along with total number of winds received for a typical day (0000 UTC of 5th January, 2015) are depicted in figure 6.

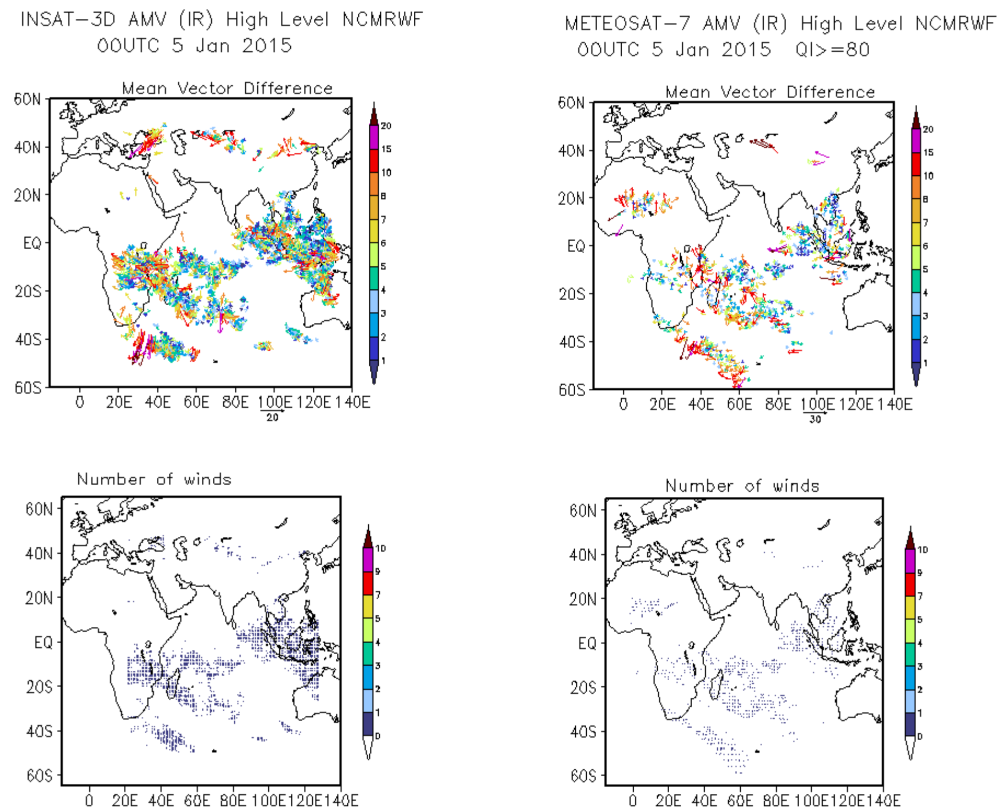


Figure 6: Comparison of vector differences (AMV- Background) along with number of AMVs with coverage for high level IR AMV, for 00 UTC(± 3 hrs) 05 January 2015 INSAT-3D(left panel) and Meteosat-7 (right panel)

As seen from the plots, number of winds received are larger for INSAT-3D compared to that of METEOSAT-7, however AMVs from both the satellite have shown similar vector differences against first guess over the same geographical region. Monthly mean vector plots for high level IR, middle level IR, low level IR, low level VIS and high level WV winds for INSAT-3D and Meteosat-7 for January 2015 are shown in figure 7(a) & (b),8(a) & (b), 9(a) & (b), 10(a) & (b) and 11(a) & (b) respectively.

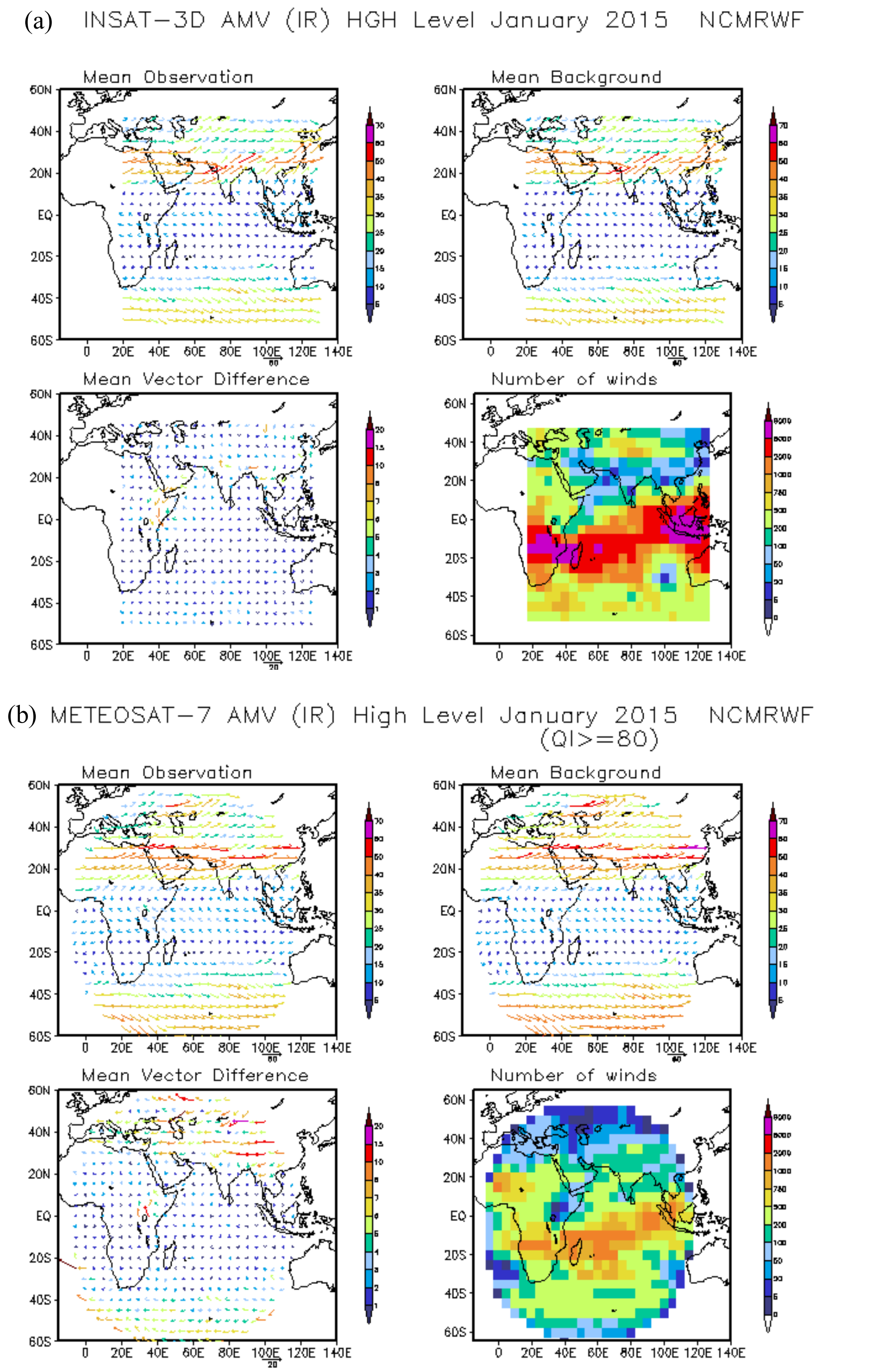


Figure 7: Mean Monthly Vector plot of high level IR AMVs for the month of January 2015
(a) INSAT-3D , (b) METEOSAT-7

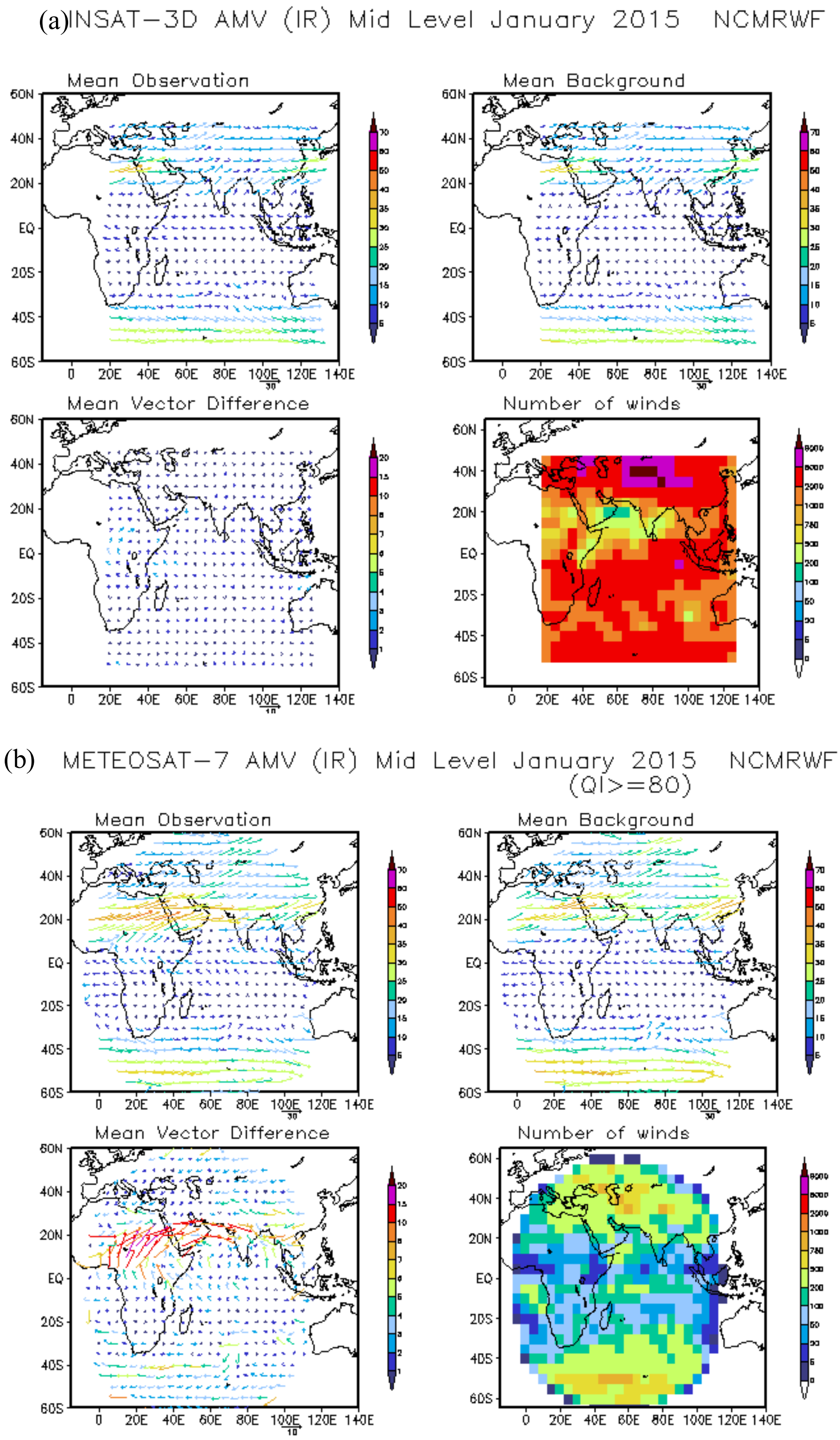
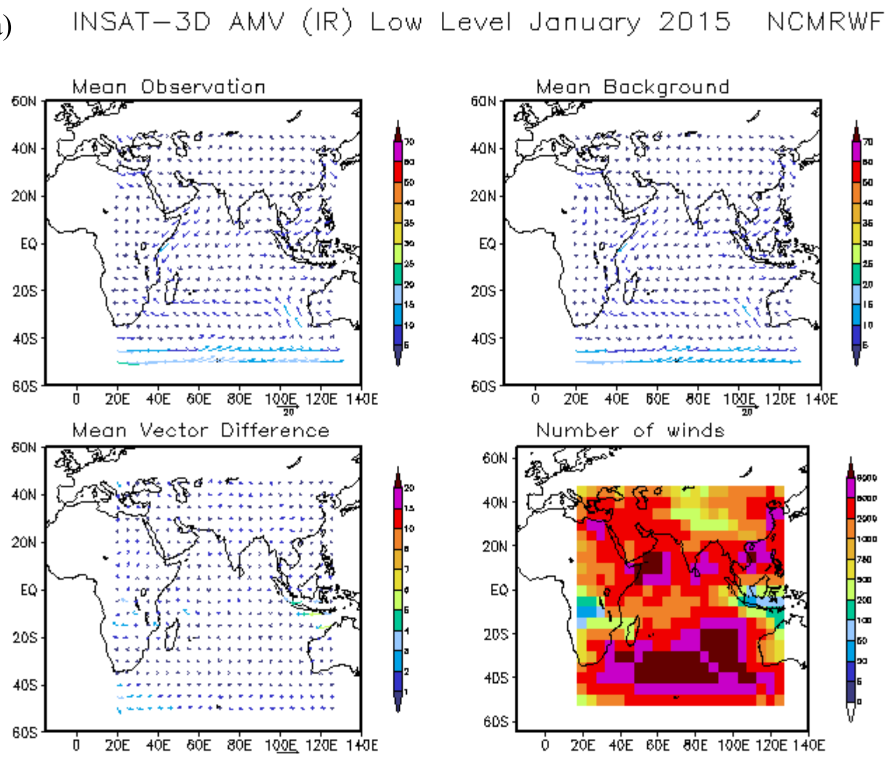


Figure 8: Same as Figure 7 but for middle level IR AMVs

(a)



(b)

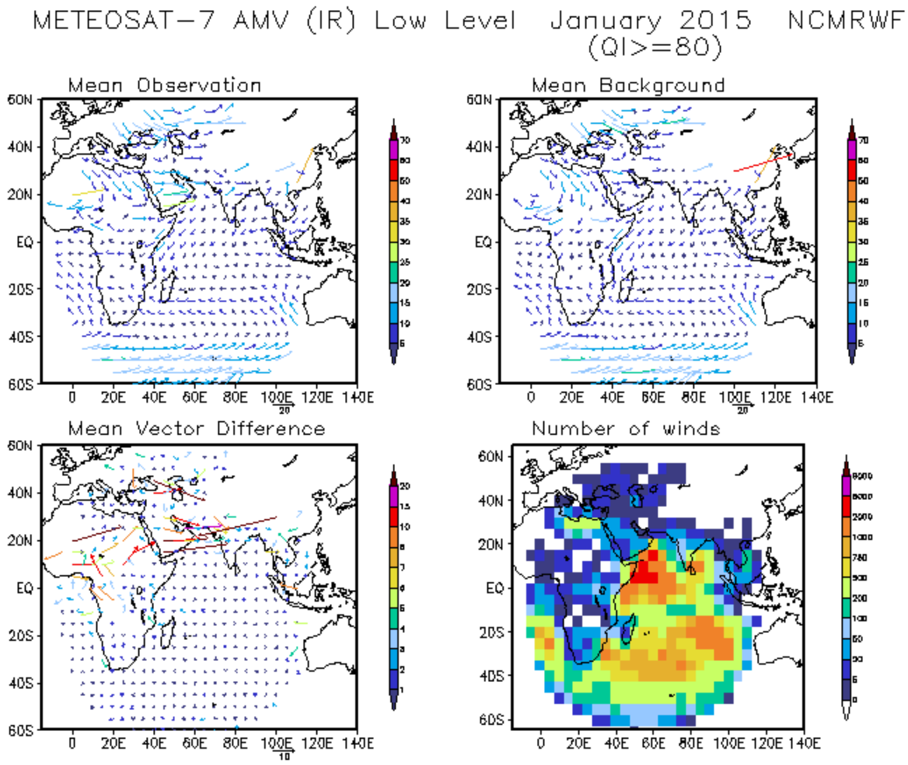
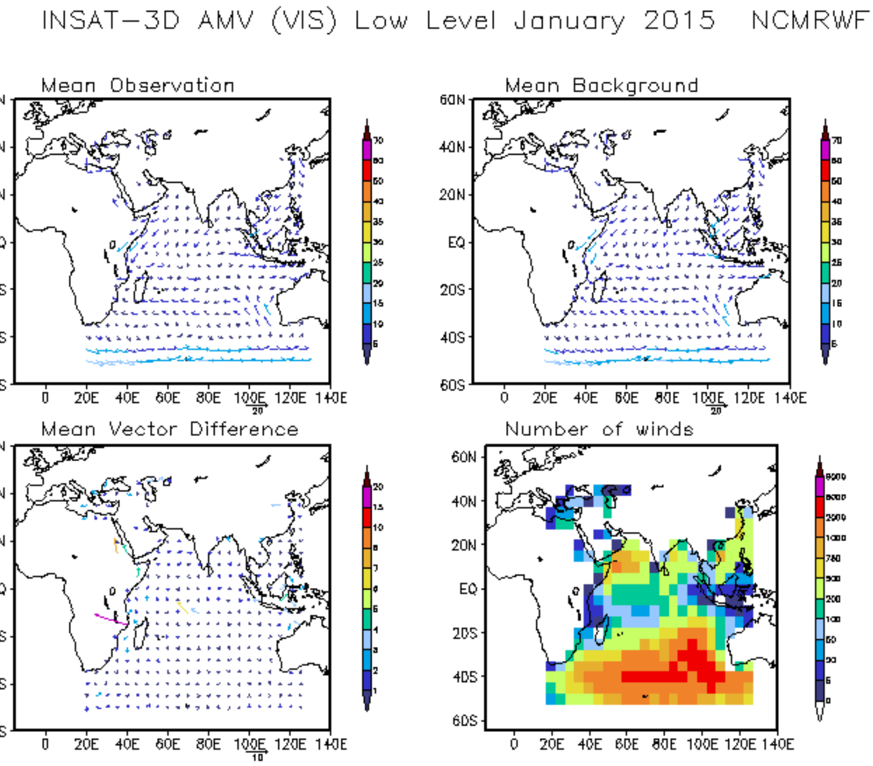


Figure 9: Same as Figure 7 but for low level IR AMVs

(a)



(b)

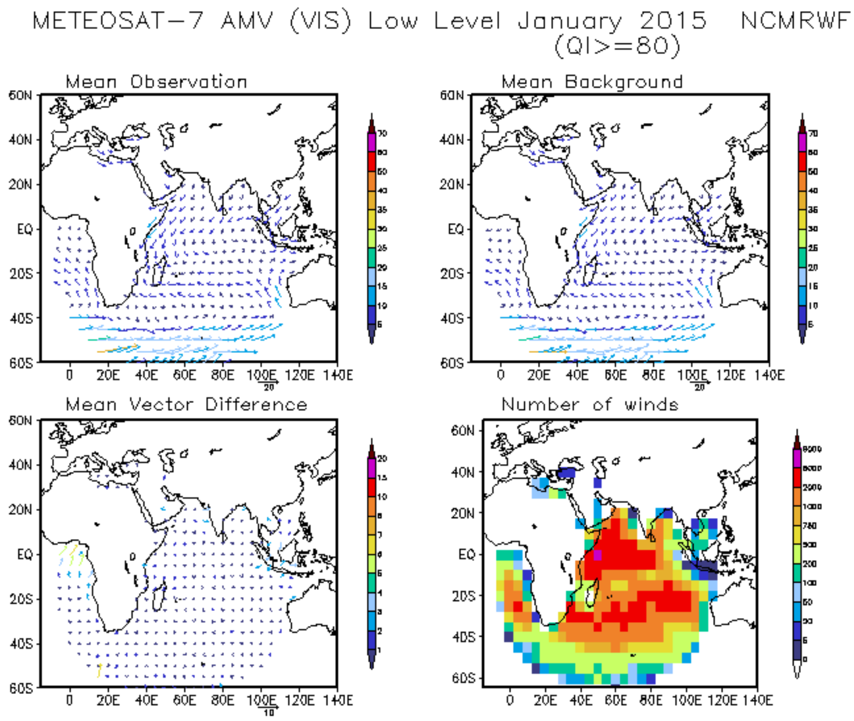
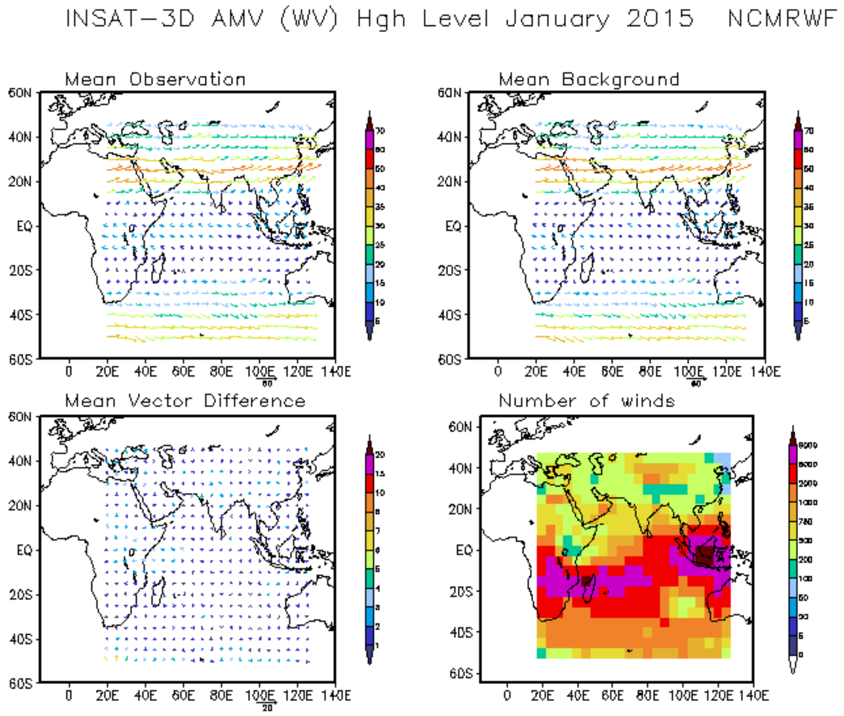


Figure 10: Same as Figure 7 but for low level VIS AMVs

(a)



(b)

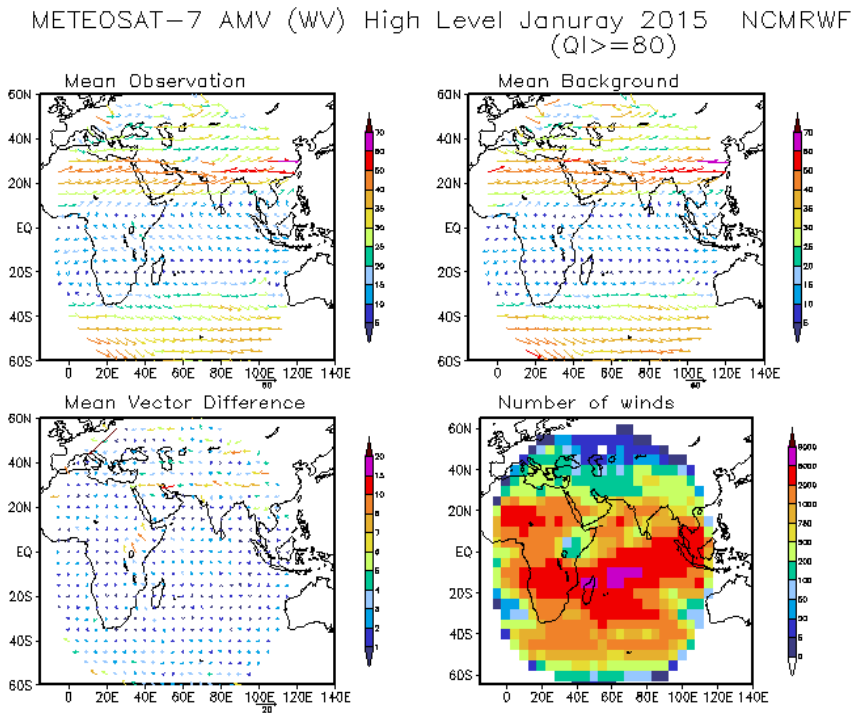


Figure 11: Same as Figure 7 but for high level WV AMVs

In the monthly mean vector plots, the mean vector difference represents the difference between the observation and the background. These vector plots are useful for highlighting any directional component to the bias. In the higher level monthly mean METOSAT-7 IR winds has shown slow bias over Tibetan region, which is not that prominent in case of INSAT-3D IR winds (Figure 7). In the middle level, very fast speed biases seen in the westerlies along 20°N for METEOSAT-7 AMVs, which are absent in INSAT-3D AMVs (Figure 8). In the lower level also, INSAT-3D IR matches better with NCMRWF first guess compared to METEOSAT-7 (Figure 9). As METEOSAT-7 AMVs are received at every 90 minutes interval compared to 30 minutes interval of INSAT-3D AMVs, the number of winds (depicted in 4^{th} panel of each plot) for INSAT-3D AMVs are always more than that of METEOSAT-7. Mean monthly vector plots for lower level VIS AMVs for both the satellite have shown almost nil bias (Figure 10). However, the number of METEOSAT-7 VIS AMVs is more than that of INSAT-3D winds, especially over Arabian Sea. In high level WV (Figure 11), high mean vector difference is seen along 30°N for METEOSAT-7 which is not prominent for INSAT-3D.

Speed bias density plots of INSAT-3D and METEOSAT-7 AMVs against background are generated by plotting the number of observed wind speed corresponding to different background wind speeds. These plots are used to identify the errors associated with AMVs of different speeds. Speed bias density are plotted for three regions viz. Northern Hemisphere (20°N-90°N), Tropics (20°S-20°N) and Southern Hemisphere (20°S-90°S) separately. Figures 12 (a) & (b), 13(a) & (b), 14(a) & (b), 15(a) & (b) and 16(a) &(b) depict the speed bias density plots for INSAT-3D and METEOSAT-7 for high level, middle level and low level IR, low level VIS and high level WV respectively. Speed bias density plots for IR high level winds (Figure 12 a & b) show less bias as well as lower standard deviation for INSAT-3D AMV compared to that of METEOSAT-7 in all the three geographical regions. However over the Southern Hemisphere there are mismatches associated with observed wind speed of low magnitudes for

INSAT-3D. For all other levels and types of AMVs the biases and standard deviations of INSAT-3D AMV are lower than that of METEOSAT-7 (Figures 13-16).

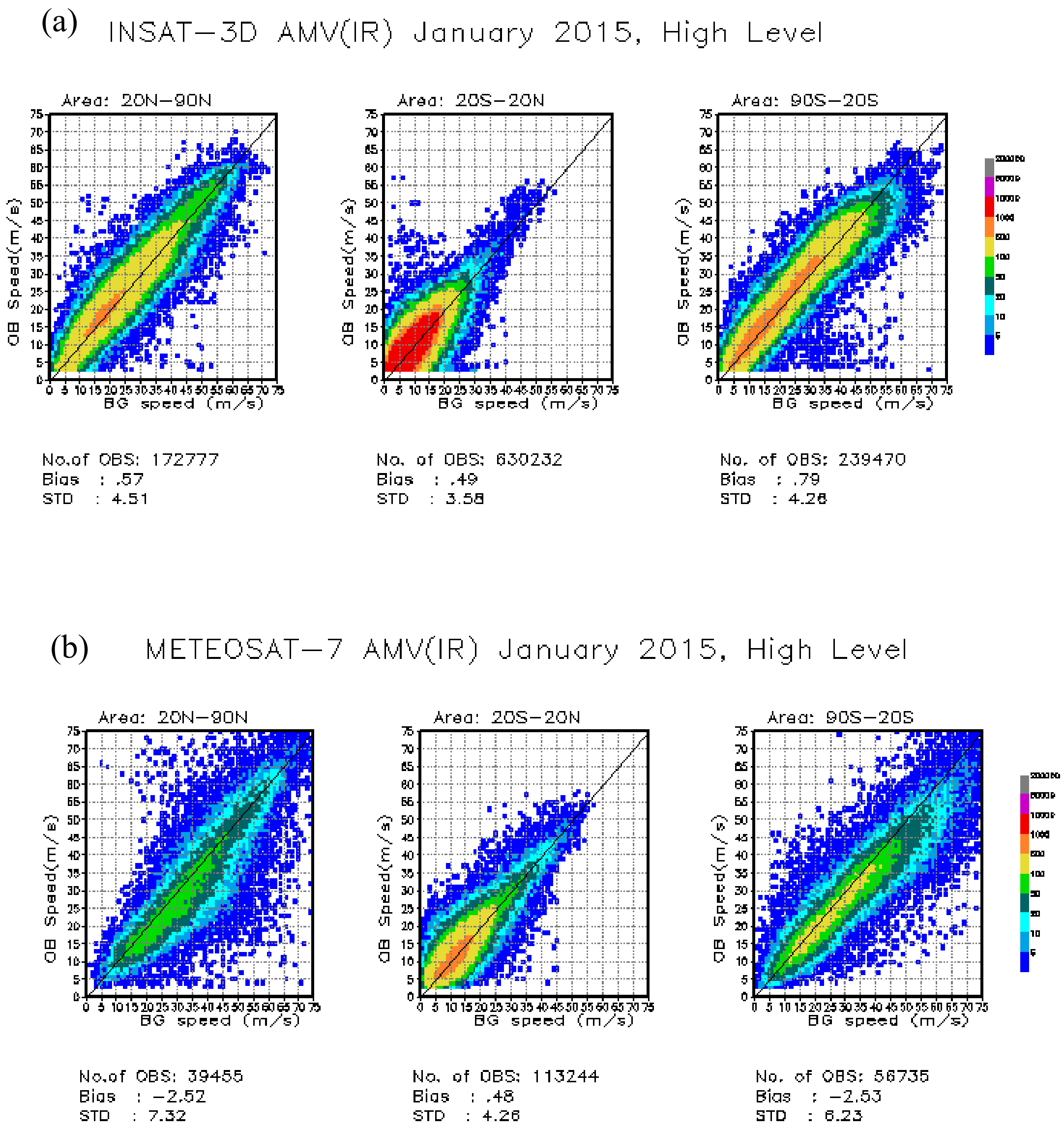
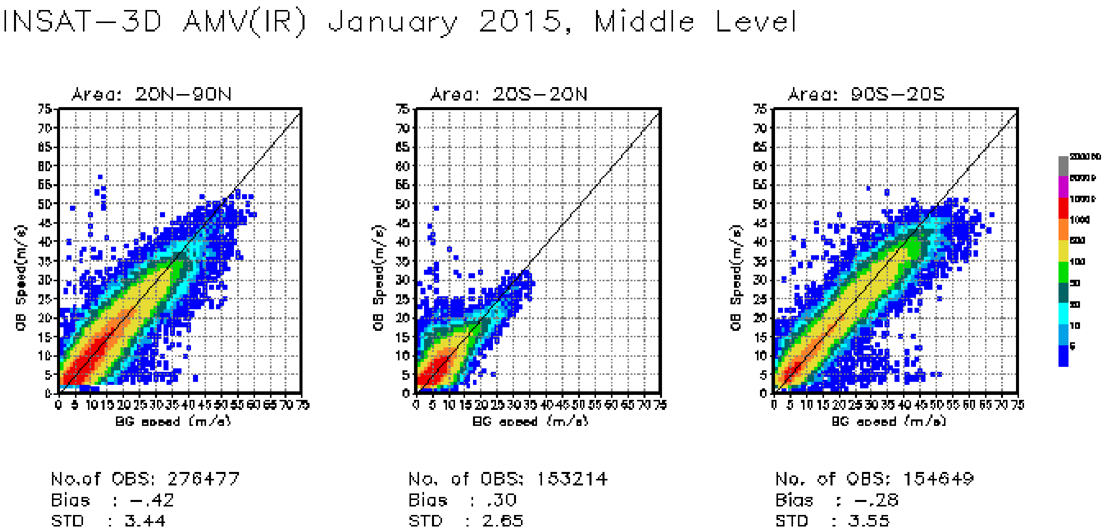


Figure 12: Speed bias density plots for high level IR AMVs for January 2015 over Northern Hemisphere, Tropics and Southern Hemisphere (a) INSAT-3D, (b) METEOSAT-7

(a)



(b)

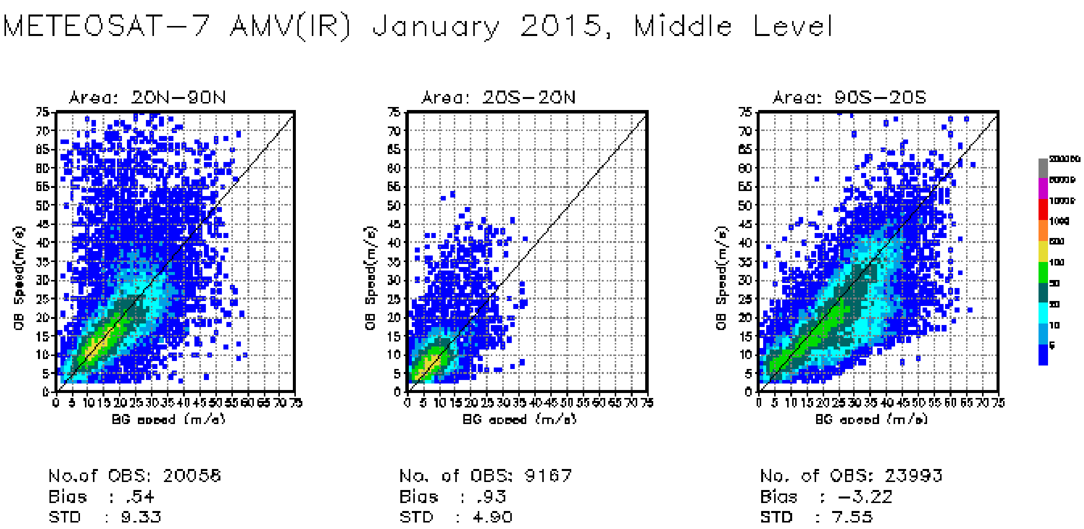


Figure 13: Same as Figure 12 but for middle level IR AMVs

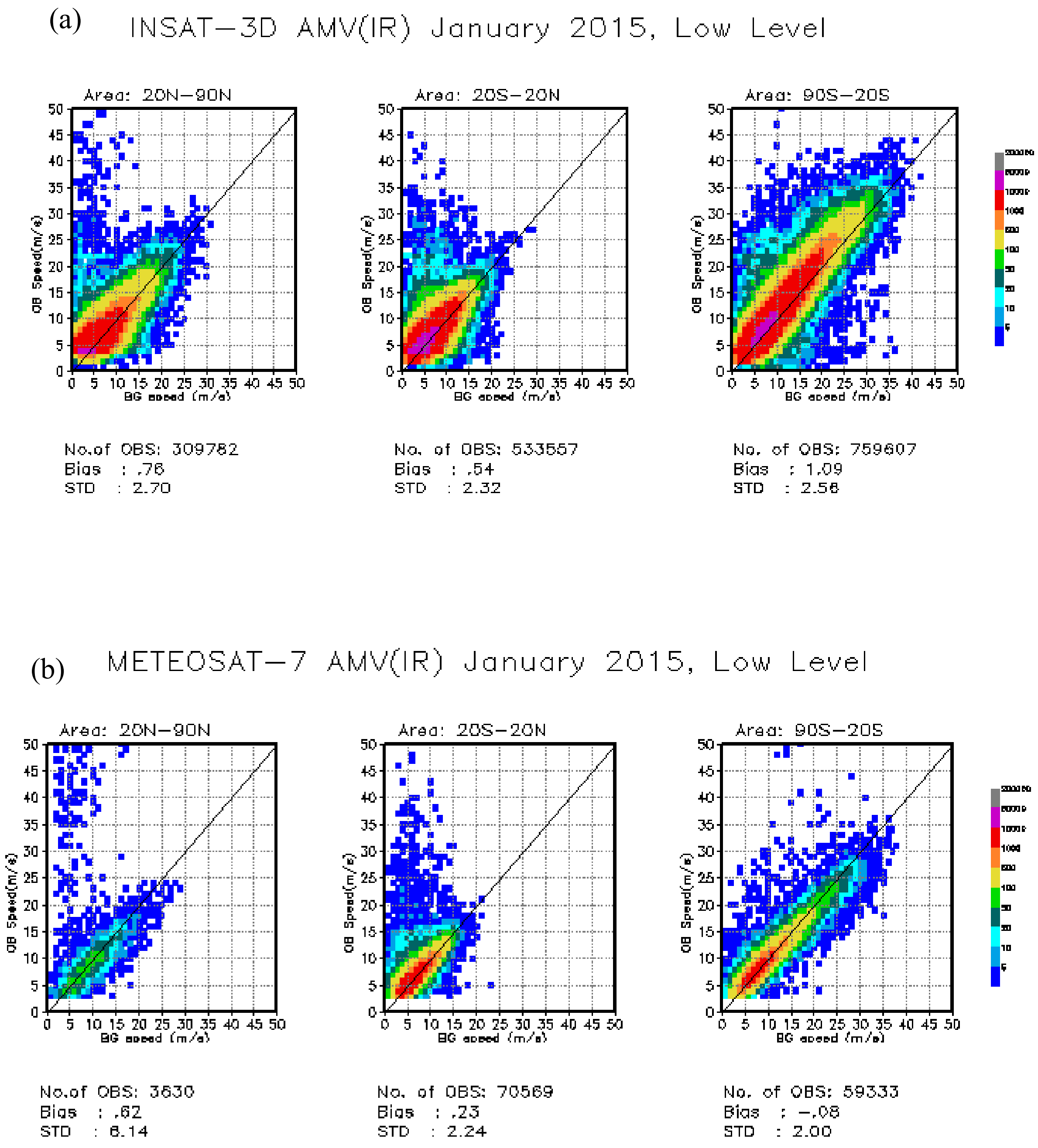
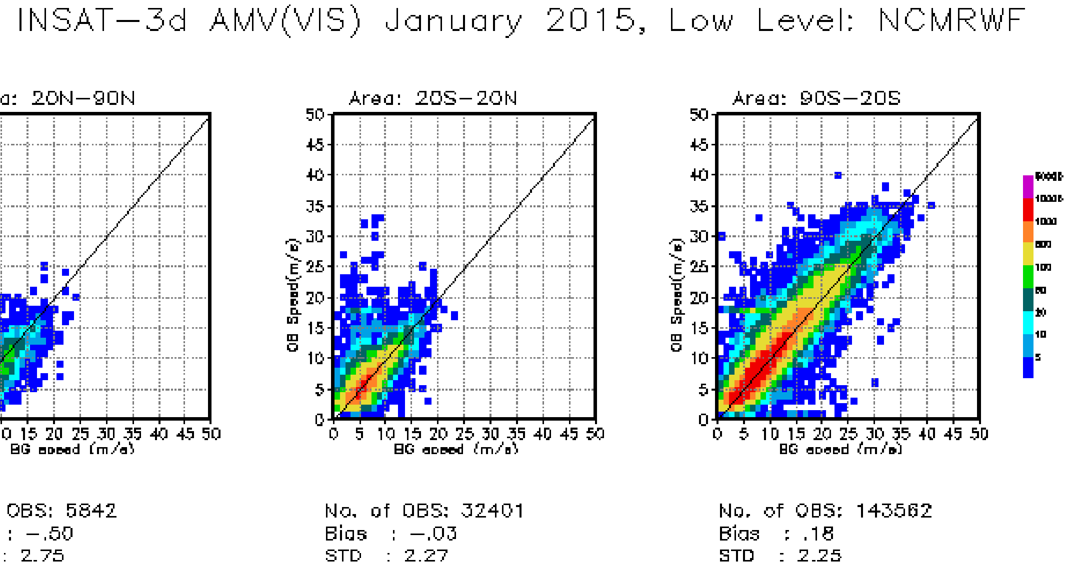


Figure 14: Same as Figure 12 but for lower level IR AMVs

(a)



(b)

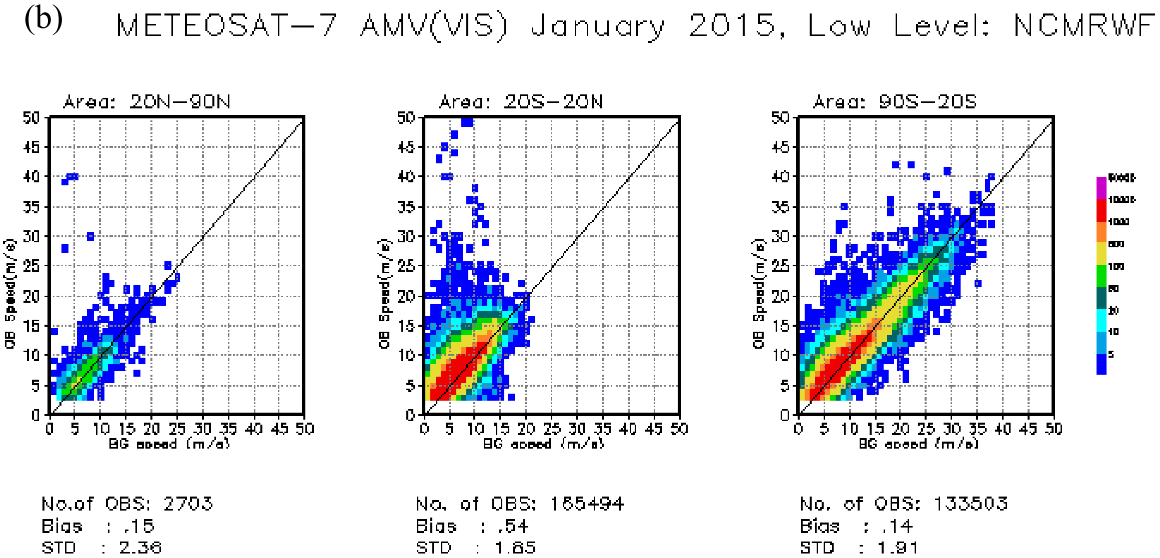


Figure 15: Same as Figure 12 but for lower level VIS AMVs

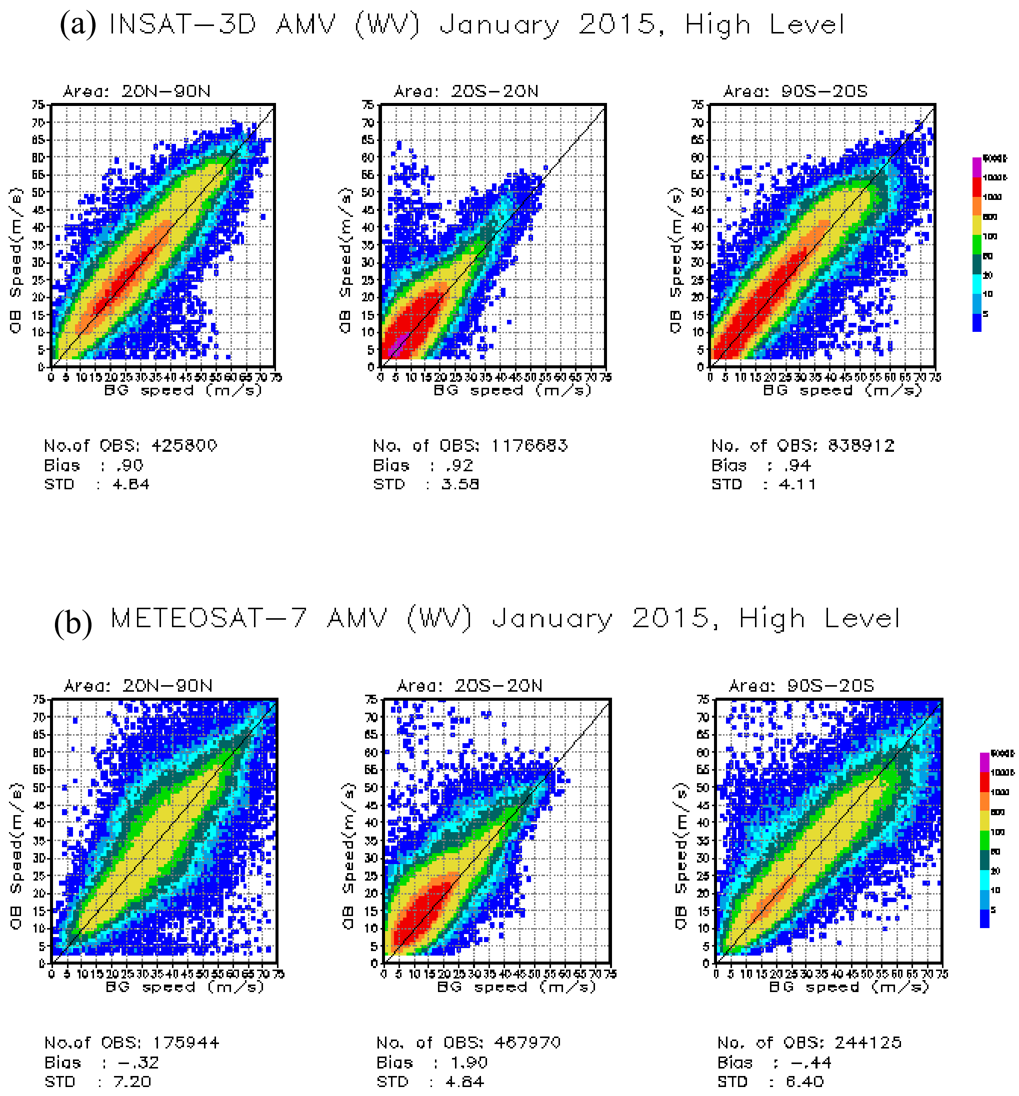


Figure 16: Same as Figure 12 but for higher level WV

Mean monthly normalised root mean square vector difference (NRMSVD) for high level IR AMVs for INSAT-3D and METEOSAT-7 are shown in Figure 17 (a) and (b) respectively.

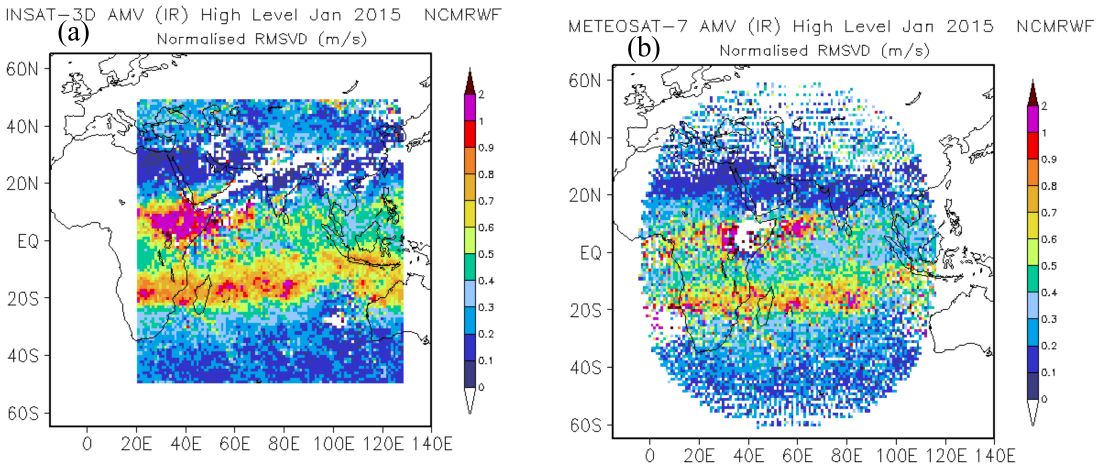


Figure 17: Mean monthly normalised root mean square vector difference for January 2015 IR High level AMVs (a) INSAT-3D (b) METEOSAT-7

High NMRSVD (>0.6 ms^{-1}) are seen along the 20°S latitudinal belt and over equatorial eastern part of Africa for both the satellites (Figure 17). The low NRMSVD (~0.1ms^{-1}) over mid-latitude region of both the hemispheres are also seen for both the satellites. NRMSVD plots for middle level IR, low level IR, low level VIS and high level WV for both the satellites are depicted in Figures 18(a)&(b), 19(a)&(b), 20(a)&(b) and 21(a)&(b) respectively.

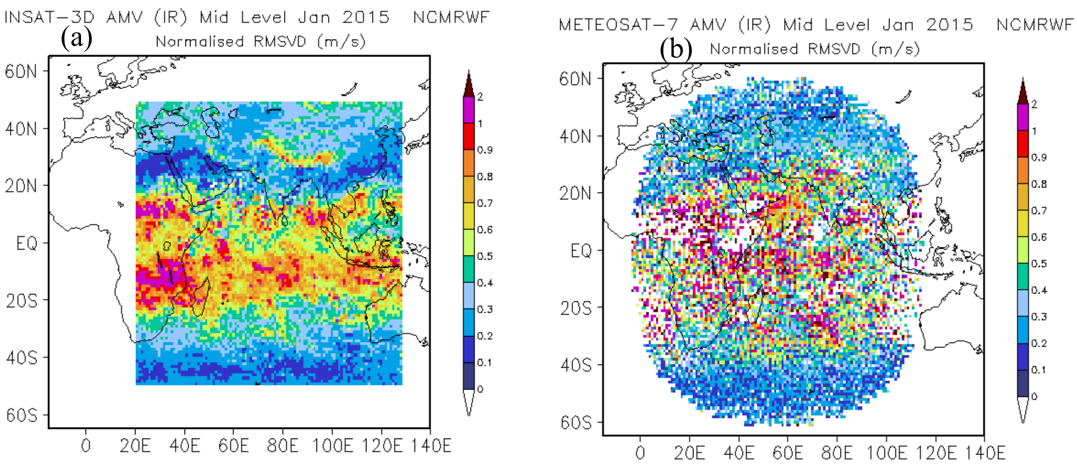


Figure 18: Same as Figure 17 but for middle level IR

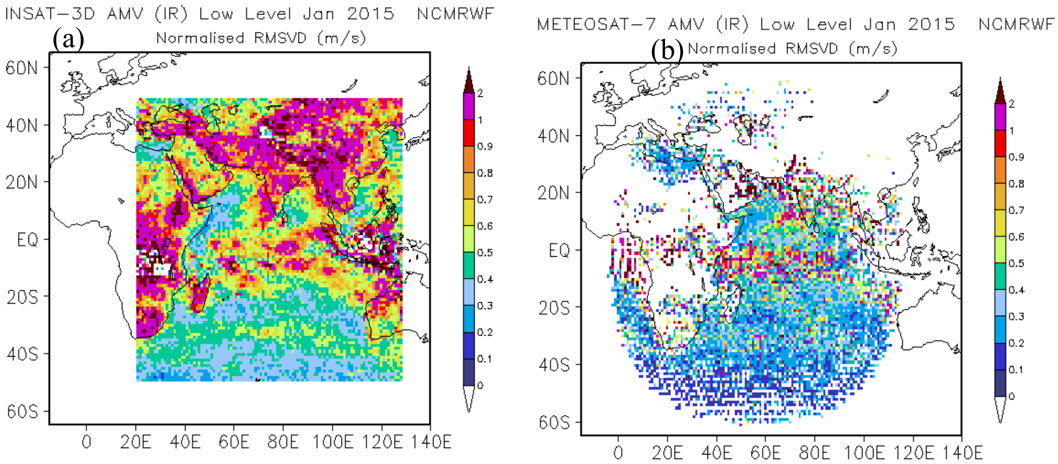


Figure 19: Same as Figure 17 but for low level IR

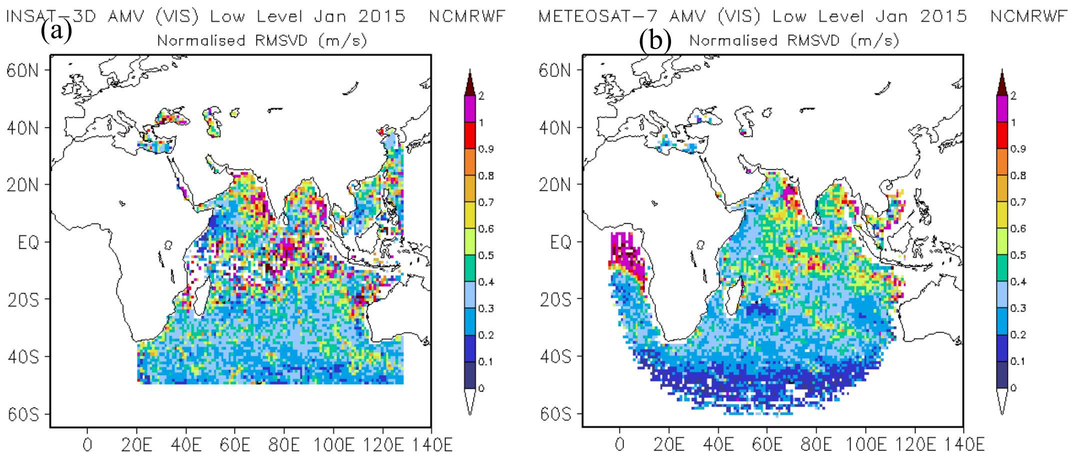


Figure 20: Same as Figure 17 but for low level VIS

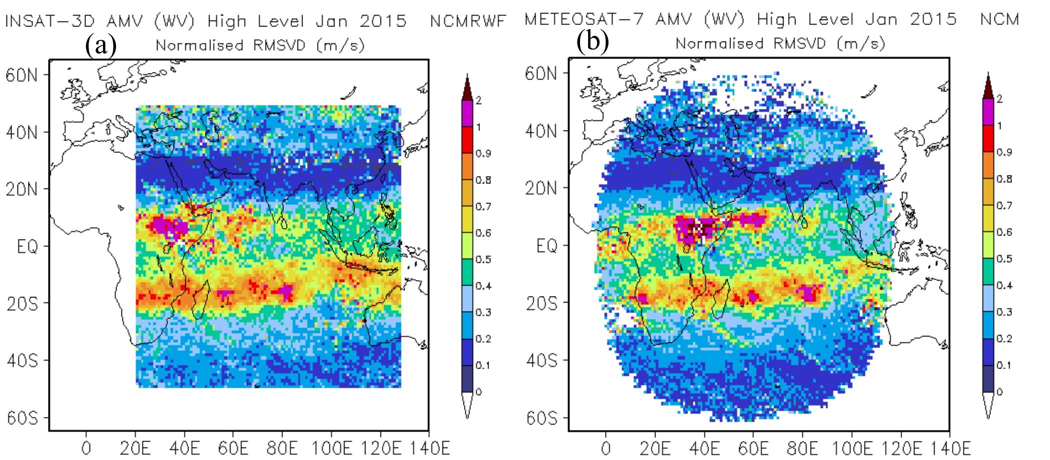


Figure 21: Same as Figure 17 but for high level WV

In the middle level, IR AMVs show high NRMSVD over the Tropics for both the satellites (Figure 18). High NRMSVD (> 0.6 ms^{-1}) is seen over Indian land mass for METEOSAT-7 in contrast to low NRMSVD (< 0.3 ms^{-1}) over India for INSAT-3D**.** However, for INSAT-3D significant high NRMSVD (> 0.6 ms^{-1}) is seen over the Himalayan range**.** METEOSAT-7 has very few low level IR AMVs over land, whereas for INSAT-3D, the density of low level IR AMVs (Figure 19) is very high and NRMSVD over land is also high (>1 ms^{-1}). These AMVS over land is mainly derived using 10.8μm channel. METEOSAT-7 has few low level IR AMVs over India and Africa showing high NRMSVD. For lower level VIS and upper level WV AMVs (Figures 20 and 21), both the satellites have shown similar type of NMRSVD distribution.

Zonal average of NRMSVD of INSAT-3D and METEOSAT-7 AMVs are computed at different level of atmosphere. For computing zonal averages AMVs are binned in pressure-latitude boxes of 10 hPa by 2°. Figures 22, 23 and 24 shows pressure level-wise zonal average of NRMSVD of INSAT-3D and METEOSAT-7 AMVs for IR, VIS and WV channel respectively.

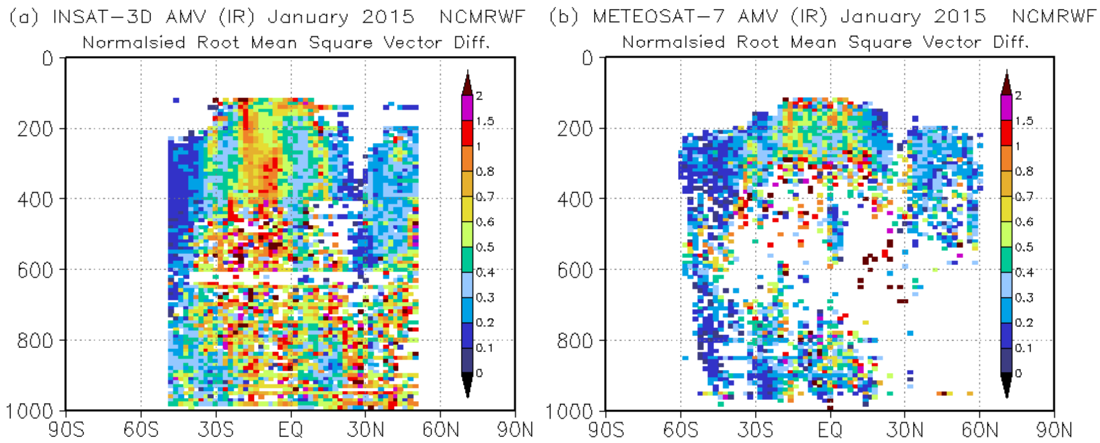


Figure 22: Zonal average of normalised root mean square vector difference at different level of atmosphere for January 2015
(a) INSAT-3D IR (b) METEOSAT-7 IR

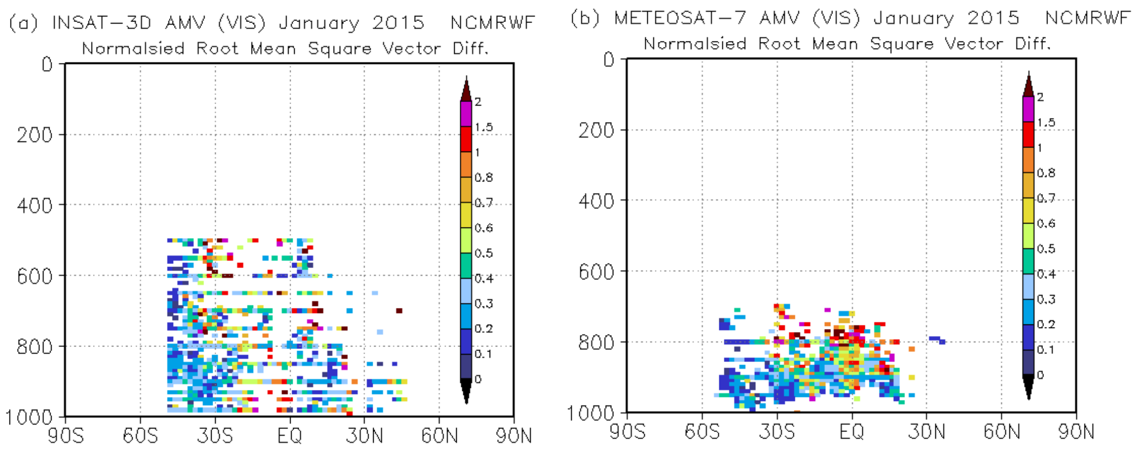
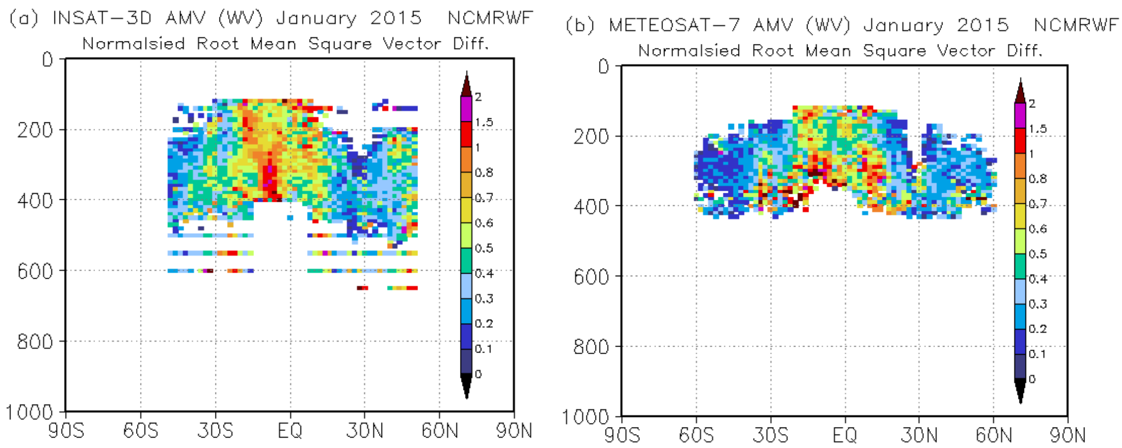


Figure 23: Same as Figure 22 but for VIS AMVs



NRMSVD for IR AMVs for both the satellites have shown higher value in the tropics compared to that over the northern and southern hemisphere. However for METEOSAT-7 there are very few AMVs with Q.I. ≥ 80 in the middle atmospheric level and also in the lower level over the northern hemispheric land. VIS and WV AMVs for both the satellites have also shown higher NRMSVD over the tropics and lower NRMSVD over both the hemisphere. INSAT-3D VIS AMVs are seen up to 500 hPa level in contrast to that up to 700 hPa level for METEOSAT-7 VIS AMVs (Figure 23). METEOSAT-7 WV AMVs are seen to be restricted between 400-100 hPa level, where as for INSAT-3D WV AMVs are seen in much lower levels viz. 650 -100 hPa (Figure 24).

3.2 Validation against in-situ observations

INSAT-3D AMVs are validated against collocated in-situ winds (viz. radiosonde and pilot balloons winds) from NCMRWF operational data archive. The validation results are compared to that of METEOSAT-7. Table 1 shows RMSVDs and biases of IR AMVs computed against in-situ winds averaged over January 2015.

Table 1: Monthly mean RMSVD and Biases of IR AMVs computed against in-situ observation

IR AMV (Low Level)						
Satellite	Northern Hemisphere		Tropics		Southern Hemisphere	
	RMSVD	Bias	RMSVD	Bias	RMSVD	Bias
INSAT-3D	4.35	0.15	3.91	0.22	5.38	-0.46
METEOSAT-7	6.34	-0.94	3.78	-0.33	5.66	-1.15
IR AMV (Middle Level)						
INSAT-3D	6.51	-1.45	4.17	-0.02	5.27	-0.38
METEOSAT-7	8.67	-2.61	6.19	-1.45	6.75	-2.27
IR AMV (High Level)						
INSAT-3D	7.98	0.60	5.65	-0.64	6.47	-0.48
METEOSAT-7	12.89	-7.15	6.17	-1.16	10.02	-4.30

Table 2 shows RMSVDs and biases of VIS and WV AMVs computed against in-situ winds averaged over January 2015.

Table 2: Monthly mean RMSVD and Biases of VIS and WV AMVs computed against in-situ observation

VIS AMV (Low Level)						
Satellite	Northern Hemisphere		Tropics		Southern Hemisphere	
	RMSVD	Bias	RMSVD	Bias	RMSVD	Bias
INSAT-3D	3.40	0.77	4.65	1.68	3.68	-0.64
METEOSAT-7	5.14	-1.23	4.40	1.66	3.14	2.87
WV AMV (High Level)						
INSAT-3D	8.66	-0.28	6.14	0.46	6.41	-0.16
METEOSAT-7	12.56	-4.2	7.93	-0.41	9.22	-1.66

Since the frequency of INSAT-3D reported AMVs are higher than that of METEOSAT-7 AMVs, the number of collocated points is also more for INSAT-3D AMVs. RMSVD of INSAT-3D AMVs are lower than that of METEOSAT-7 AMVs except for lower level IR over the Tropics and lower level VIS AMVs over the Tropics and the Southern Hemisphere (highlighted).

4. Conclusions

Validation of INSAT-3D and METEOSAT-7 AMVs against NCMRWF NWP first guess and in-situ winds for January 2015 shows that root mean square vector difference and biases of INSAT-3D AMVs are either comparable or lower than that of METEOSAT-7.

However there are still some issues with INSAT-3D AMVs, which are listed below:

(i) The reception of INSAT-3D AMVs is not regular throughout the day, resulting data gaps intermittently

(ii) The quality flag associated with AMVs could not be utilised effectively.

(iii) INSAT-3D IR (10.8μm) AMVs at lower level over land has shown large normalised root mean square vector difference

(iv) INSAT-3D VIS AMVs are seen above 700 hPa (up to 500 hPa level) where as METEOSAT-7 VIS AMVs are seen below 700 hPa only

(v) INSAT-3D WV AMVs are seen below 500 hPa level in contrast to that of METEOSAT-7 AMVs ,which are seen mainly between 400-100 hPa

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