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RESEARCH REPORT

Validation of Kalpana-1 Atmospheric Motion Vectors against Radiosonde Observations and NWP Products

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10	Abstract	Improvements in Kalpana-1 AMVs are observed from mid February 2011 through the real-time observation monitoring package operational at NCMRWF. This study presents the validation of Kalpana-1 AMVs against radiosonde observation and NWP products from January to July 2011.
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Contents

Abstract

Atmospheric Motion Vectors (AMVs) derived using Kalpana-1 images are validated against radiosonde winds and NCMRWF T382L64 first guess (six-hour forecast) for a period of seven months, January to July, 2011. Kalpana-1 Cloud Motion Vectors (CMVs) and Water Vapor channel Winds (WVWs) are collocated with radiosonde winds as well as first guess at different vertical levels of atmosphere. Various statistics such as mean wind speed, speed bias, root mean square vector difference, etc. are computed. Validation of AMVs against radiosonde winds showed that since March 2011, Kalpana-1 AMV improved in terms of speed bias, and root mean square vector difference, and this improvement is more pronounced in high level CMVs and WVWs. The agreement between Kalpana-1 winds and first guess is found to be poor especially in low and middle level. However, an improvement in high level CMVs and WVWs is noticed since March 2011. One limitation of WVWs received at NCMRWF through GTS is that since March 2011, the maximum wind speed is limited to 45 m/s and reported to Space Application Centre (SAC), which was rectified operationally by SAC at IMD from mid June 2011.

1. Introduction

Atmospheric Motion Vectors (AMVs) commonly known as Satellite winds provide excellent coverage in a region otherwise poorly sampled by the conventional observing network. The production of satellite winds were started during 1970s using a combination of automated and manual techniques (*Leese et al. (1971); Young (1975)*). The initial phase of the operational derivation of AMVs such as CMV and WVW from Infra-red (IR) and Water Vapor (WV) channels was described in *Fujita (1968); Hubert and Whitney (1971)*. During the last decade the satellite derived CMVs and WVWs have become an important component of operational Numerical Weather Prediction (NWP). Presently AMVs are one of the essential inputs to state-of-the art data assimilation system. CMVs and WVWs from different geostationary satellites are being regularly received at the National Centre for Medium Range Weather Forecasting (NCMRWF) through Global Telecommunication System (GTS) and these winds are monitored in real-time and assimilated in NCMRWF's T382L64 Global Forecasting System (GFS).

Kalpana-1 is the first dedicated meteorological satellite launched by the Indian Space Research Organization (ISRO) using Polar Satellite Launch Vehicle (PSLV) on 12th September 2002. The satellite located at the central latitude 74° E, carries a Very High Resolution scanning Radiometer (VHRR) for three band images: one in visible (0.55µm-0.75µm), second in thermal infrared (10.5µm-12.5µm) and third in water vapor infrared (5.7µm-7.1µm) bands with their ground resolutions of 2km, 8km and 8km, respectively. Its coverage in the east-west direction is roughly from 14°E to 134°E.

AMVs are essentially generated by tracking clouds or areas of water vapor in consecutive satellite images, and it composed of several steps, viz. correct and rectify raw data, locate a suitable tracer within the image, perform a cross-correlation to locate the same feature in an earlier or later image, calculate the vector from the displacement in tracer location, assign a height to the vector, and finally perform basic quality control. The final AMV is an average of two or three component vectors generated from a sequence of three or four images. Further information of AMV derivation methods is available in *Schmetz et al, (1993),* and *Nieman et al. (1997).* It is important to note, like any other observing system, satellite-derived AMVs are inherently unable to perfectly depict the ‘‘true’’ flow at any given point and level in the atmosphere, even if optimal AMV target characteristics (horizontal dimension, cloud-top opacity/emissivity) and time behavior are present. The underlying assumptions of satellite-derived motion estimation are that features move *i)* within a short-term image sequence at a constant height level, *ii)* without changing shape and acceleration, and *iii)* with speeds equal to the true atmospheric flow at a given level over the time interval of an image sequence *(Bedka et al., 2009).*

Velden and Bedka (2008) reported that the mean AMV observation errors were ~ 5-5.5m/s when large volumes of multispectral AMV datasets produced using the NESDIS (National Environmental Satellite, Data and Information Service, USA) automated algorithm were compared to collocated rawinsonde wind profiles. It was also found that height assignment of the vector wind is the dominant factor in AMV uncertainty. Most of the AMV producer’s (e.g. EUMETSAT, NESDIS, etc) use H_2O/CO_2 intercept technique for height assignment, which uses a NWP first guess as the background, whereas in the case of Kalpana-1, an empirical method based on Genetic Algorithm (GA) is used (*Deb et al., 2008*) for the same.

Kishtawal et al. (2009) verified Kalpana-1 AMVs using a database consisting of three months from September through November 2007, and reported that the mean vector difference computed against radiosonde winds for Kalapna-1 high and middle level CMVs and WVWs were very close to that for Meteosat-7(57.7° E) winds when both were compared with radiosonde winds. The same study also depicted high mean vector difference in Kalpana-1 low level CMVs compared to the same for Meteosat-7. Recently Kalpana-1 winds are being generated using GA in the India Meteorological Department (IMD) and the same are made available to all through GTS (Global Telecommunication System) in BUFR format since October 2010.

In this study, an attempt has been made to validate the AMVs from Kalpana-1 against radiosonde winds and NCMRWF’s T382L64 model first guess. Seven months AMVs from Kalpana-1 (January to July, 2011) are used for validation purpose. A short overview of the NCMRWF T382L64 Global Data Assimilation System (GDAS) is given in section2. The data and methodology of the present study is described in Section 3. Validation results of Kalpana-1 AMV against radiosonde are discussed in section 4 and the same against NCMRWF NWP products in section 5. Conclusions of the present study are listed in section 6.

2. T382L64 Global Data Assimilation System

The Global Data Assimilation System (GDAS) operational at NCMRWF is a six hourly intermittent three dimensional scheme. Meteorological observations from all over the globe and from various conventional and remote sensing observing platforms are received at Regional Telecommunication Hub (RTH), New Delhi through GTS and the same is made available immediately to NCMRWF. The data are assimilated four times a day at 0000, 0600, 1200, and 1800 UTC in the GDAS. Meteorological observations from various types of observing platforms assimilated in T382L64 (~ 32 km horizontal resolution) global analysis scheme at NCMRWF include SYNOP, BUOY, METAR, TEMP, PILOT, AIREP, AMDAR, ACARS, Atmospheric Motion Vectors (AMVs) from geostationary satellites, viz. GOES, METEOSAT and GMS, NOAA and METOP satellite radiances, Global Positioning System Radio Occultation (GPSRO), etc . A six hour prediction from model with a previous initial condition valid for current analysis time is used as the background field or first guess field for subsequent analysis. The Global Forecast System (GFS) of NCMRWF is described in *Rajagopal et al., (2007)* and *Prasad et al., (2011).*

3. Data and Methodology

NCMRWF started receiving Kalpana-1 AMVs in BUFR format and started monitoring the same in real-time with T382L64 model first guess as background since October 2010. Regular monitoring of Kalpana-1 AMVs showed an abrupt decrease in RMSE from mid February 2011. Present study utilizes NCMRWF's archived dataset of Kalpana-1 AMVs along with global RS/RW observations and T382L64 model first guess for a period of January to July 2011. The frequency of Kalpana-1 AMVs is of approximately 3 hour. Global RS/RW data are being received at NCMRWF twice in a day at 0000 UTC and 1200 UTC in real time through GTS. The monthly average number of Indian RS/RW observations received at NCMRWF for 0000 UTC is ~ 30, whereas the same for 1200 UTC is ~10 since August, 2010 (ftp://ftp.ncmrwf.gov.in/pub/outgoing/obs_mon). So, Kalpana-1 AMVs are validated against radiosonde winds for 0000 UTC only.

The AMVs are broadly classified into two categories, CMV and WVW depending on satellite channel used for its derivation. For validation purpose, CMVs are categorized into three classes based on their heights in the vertical, viz. Low Level Winds (1000 -700 hPa), Middle Level Winds (700 hPa– 400 hPa) and High Level Winds (400 hPa -100hPa). Unlike CMV, where the winds are distributed in three levels in the vertical, the derived WVW are generally from high level, i.e. 500 hPa to 100 hPa. AMVs are validated over three regions viz, Northern Hemisphere (between 20°N and 90°N), Tropics (between 20° S and 20°N) and Southern Hemisphere (between 20°S and 90°S). In this study, the validation of AMV with respect to radiosonde winds follows the criteria set by the Coordination Group for Meteorological Satellites (CGMS) (*Tokuno, 1998*). Magnitudes of AMVs below 2.5 m/s are not considered for computation of statistics. Collocation of radiosonde and AMVs are considered if they are horizontally within 150 km and vertically within 25 hPa. Collocated observations with difference (AMV-RS/RW) of speed more than 30 m/s or of direction more than 60° are not considered for validation purpose.

Different statistical parameters such as mean observation speed, speed Bias, Vector Difference (VD), and Root Mean Square Vector Difference (RMSVD) are computed using collocated observations. The radiosonde wind is considered as background wind whereas AMVs are considered as observation. The statistical parameters are calculated as follows:

$$Observation\ Speed = \sqrt{obu^2 + obv^2} \quad \text{--------(1)}$$

$$Background\ Speed = \sqrt{bgu^2 + bgv^2} \quad \text{--------(2)}$$

$$Speed\ Bias = Observation\ speed - Background\ speed \quad \text{-----------(3)}$$

$$Vector\ difference\ (VD) = \sqrt{(obu - bgu)^2 + (obv - bgv)^2} \quad \text{---------(4)}$$

$$Root\ Mean\ Square\ Vector\ Difference\ (RMSVD) = \sqrt{\sum VD / N} \quad \text{-------(5)}$$

where, N is the Number of Collocation (NC) points, '*obu*' is the AMV zonal component in m/s, '*obv*' is the AMV meridional component in m/s, '*bgu*' is the background zonal component in m/s, and '*bgv*' is the background meridional component in m/s.

There are both advantage and disadvantage of collocating AMVs against radiosonde observations. The main advantage is that it represents an evaluation against independent, unbiased observations, whereas the disadvantage is the limited geographical coverage of radiosonde observations, which shows an uneven distribution over land and very few observations over sea. The temporal sampling of the radiosondes is also limited, which implies that a possible diurnal signal will not reveal itself in the statistical record (*de Smet et al., 2010*). Short-term NWP forecast or analyses products can also be collocated with satellite winds in the same way as radiosonde observations. The main advantage of this is the complete geographical coverage and the better temporal sampling of the forecast profiles. This enables a comparison for every AMV, with the consequence that a relatively short period is sufficient to obtain meaningful statistics. Forecast model data are not free from biases and errors though, and these will have an impact on the collocation results. A potential error source is the biases in the observational data (AMV data and others) that are used by the NWP forecasts and analyses.

Validations of Kalpana-1 AMVs against NCMRWF T382L64 model first guess are conducted following guidelines provided at UK Met Office NWP Satellite Application Facility (NWPSAF)(http://research.metoffice.gov.uk/research/interproj/nwpsaf/satwind_report/nwpmon_instructions.html). AMVs with quality above 80% and magnitude greater than 2.5 m/s are considered for validation against first guess *(Forsythe, 2007).* Monthly mean vector plots and speed bias density plots are constructed for each month. The vector plots consist of four panels, each representing the mean observed wind speed, mean background wind speed, mean vector difference and the number of collocated observations. 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. For CMV, vector plots are made for three different pressure levels in the vertical viz., low, middle and high, and for WVW only in the high level.

Speed bias density plots of Kalpana-1 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.

4. Validation of Kalpana-1 AMVs against Radiosonde Winds

Kalpana-1 AMVs validation statistics against radiosonde winds over Northern Hemisphere, Tropics and Southern Hemisphere from January to July, 2011 at different pressure levels are listed respectively in tables 1, 2, and 3.

Table1: Kalpana-1 AMV collocation statistics over Northern Hemisphere (January-July 2011)

Parameters	Northern Hemisphere						
	Jan	Feb	Mar	Apr	May	June	July
Low level CMV							
Mean WS (AMV)	10.23	15.48	13.17	12.22	11.01	10.81	10.51
Mean WS (RS)	5.90	7.38	10.44	8.67	7.09	6.75	6.52
SPDB	4.33	8.10	2.72	3.54	3.91	4.05	3.99
RMSVD	5.76	10.30	7.11	8.64	7.61	7.10	7.52
NC	28	97	291	332	506	292	443
Middle Level CMV							
Mean WS (AMV)	22.87	20.44	19.68	18.19	17.04	14.09	14.35
Mean WS (RS)	24.56	19.74	18.52	15.31	13.29	10.40	8.96
SPDB	-1.69	0.70	1.16	2.88	3.74	3.69	5.38
RMSVD	9.06	8.82	9.16	9.30	8.77	7.76	8.47
NC	85	595	2104	1835	1732	1106	1300
High Level CMV							
Mean WS (AMV)	25.92	25.52	27.90	23.84	23.17	18.30	15.13
Mean WS (RS)	34.02	26.86	29.13	24.95	22.33	15.57	12.95
SPDB	-8.09	-1.34	-1.22	-1.11	0.84	2.76	2.17
RMSVD	12.76	8.97	8.92	8.75	8.37	7.30	7.01
NC	175	757	1722	2057	1821	1520	2129
WVW							
Mean WS (AMV)	31.93	26.96	25.84	23.95	21.75	16.20	15.39
Mean WS (RS)	37.15	28.83	25.66	23.72	19.66	13.21	11.44
SPDB	-5.22	-1.87	0.17	0.22	2.08	2.98	3.94
RMSVD	11.05	9.43	8.08	9.20	8.73	7.46	8.24
NC	210	363	841	932	1265	1039	1081

Observed Kalpana-1 monthly mean AMV speed (considered only 0000 UTC AMV and radiosonde winds) is seen to be higher than that of radiosonde wind (RS) especially since March 2011 and the number of collocated points (NC) is also increased since March 2011 in vertical over the three latitudinal regions. High speed bias (~ 10m/s) for Kalpana-1 low level CMVs over Tropics is observed during January and February 2011 and the same is seen to be reduced (~ 6 m/s) since March 2011 (Table 2). Similar reduction in RMSVD over tropics is also observed in middle and high level CMVs and in high level WVWs since March 2011. The RMSVD of middle level CMV, which was ~ 15 m /s during January and February 2011, is reduced approximately between 8 and 6 m/s since March 2011. For high level AMVs (both CMVs and WVWs), the RMSVD reduced from ~ 12 m/s during January and February 2011 to ~ 5.5 m/s since March 2011.

Even though, reduction in RMSVD is observed over Northern Hemisphere since March 2011, this is not as pronounced as seen over Tropics. The RMSVD of ~ 5.76 m/s observed for low level CMVs over the Northern Hemisphere during January 2011 was found be doubled ~ 10.3 m/s in February 2011, and thereafter it is reduced approximately between 8.6 and 7 m/s. There was no clear observed reduction in RMSVD in the middle level. For the high level CMVs and WVWs, the RMSVD reduced from ~ 12 m/s in January 2011 to 7 m/s since March 2011 (Table 1).

The number of collocated points in three different levels over Southern Hemisphere was lesser compared to that over Northern Hemisphere and Tropics. A drastic reduction in RMSVD of low level CMVs over Southern hemisphere is observed from January 2011 (~12 m/s) to March 2011 (4 m/s), at the same time no such reduction in RMSVD is noticed over middle level and high level winds.

Table2: Kalpana-1 AMV collocation statistics over Tropics (January –July 2011)

Parameters	Tropics						
	Jan	Feb	Mar	Apr	May	Jun	Jul
Low level CMV							
Mean WS (AMV)	14.29	13.81	9.96	10.28	9.79	9.71	10.62
Mean WS (RS)	5.53	5.79	7.64	5.47	6.09	7.65	6.45
SPDB	8.76	8.01	2.32	4.81	3.69	2.05	4.17
RMSVD	9.88	10.66	5.80	6.66	5.90	4.23	6.37
NC	69	61	68	128	90	69	95
Middle Level CMV							
Mean WS (AMV)	21.54	16.85	12.78	12.48	10.67	11.68	11.82
Mean WS (RS)	7.80	6.99	8.52	6.97	6.94	7.68	6.77
SPDB	13.73	9.86	4.25	5.50	3.72	4.00	5.05
RMSVD	14.84	12.19	7.51	8.26	6.26	6.91	7.93
NC	125	158	512	501	307	260	451
High Level CMV							
Mean WS (AMV)	22.01	18.98	12.38	12.72	11.30	11.41	13.68
Mean WS (RS)	16.69	14.11	13.77	13.63	11.75	12.68	15.13
SPDB	5.32	4.86	-1.38	-0.91	-0.44	-1.27	-1.45
RMSVD	10.19	11.0	6.56	6.56	5.38	6.68	7.80
NC	1413	800	2396	1696	1335	1045	1772
WVW							
Mean WS (AMV)	23.24	20.37	13.29	13.43	11.84	13.12	15.04
Mean WS (RS)	15.42	12.21	11.95	11.53	9.98	11.23	12.68
SPDB	7.81	8.16	4.87	1.90	1.86	1.88	2.36
RMSVD	11.04	11.79	6.27	6.20	5.55	7.07	7.55
NC	684	591	1906	995	1241	1110	2039

The maximum of RMSVD which was ~15m/s over the three regions and different vertical levels in January 2011 is reduced to ~ 6-5m/s since March 2011. This reduction in RMSVD is more visible especially over Northern Hemisphere and Tropics, whereas over Southern Hemisphere, even though the RMSVD is reduced, it is still high compared to other two latitudinal belts.

Table 3: Kalpana-1 AMV collocation statistics over Southern Hemisphere January –July 2011)

Parameters	Southern Hemisphere						
	Jan	Feb	Mar	Apr	May	Jun	Jul
Low level CMV							
Mean WS (AMV)	21.69	10.59	9.38	11.72	9.05	11.44	11.74
Mean WS (RS)	9.17	7.44	7.73	8.96	7.68	10.53	10.73
SPDB	12.52	3.14	1.64	2.76	1.37	0.90	1.01
RMSVD	12.87	5.02	4.57	6.68	3.73	4.26	3.72
NC	16	25	152	127	98	122	201
Middle Level CMV							
Mean WS (AMV)	23.33	16.57	14.84	20.51	18.70	26.62	17.60
Mean WS (RS)	16.01	10.06	8.98	13.29	13.04	22.78	17.09
SPDB	7.32	6.51	5.85	7.21	5.65	3.83	0.51
RMSVD	7.91	8.17	8.02	11.07	9.70	10.05	6.49
NC	20	47	82	108	159	114	255
High Level CMV							
Mean WS (AMV)	21.54	18.62	16.02	22.47	24.98	31.75	25.34
Mean WS (RS)	18.82	12.97	13.93	21.22	25.32	33.57	32.26
SPDB	2.72	5.65	2.08	1.24	-0.34	-1.82	-6.91
RMSVD	8.24	8.09	6.02	6.35	9.27	11.41	11.26
NC	129	61	54	98	161	106	112
WVW							
Mean WS (AMV)	23.36	19.62	17.45	23.07	24.73	31.15	28.48
Mean WS (RS)	13.96	10.08	12.66	19.21	23.74	28.13	24.89
SPDB	9.40	9.54	4.78	3.86	0.99	3.01	3.58
RMSVD	10.73	11.73	6.93	8.16	8.60	9.12	9.38
NC	59	63	78	60	153	72	94

Le Marshall et al., (2002) reported the annual RMSVD with radiosonde within 150 km for low level Infrared image based AMVs from GMS-5 (Japan) having quality index above 80 as ~5m/s over Tropics. *Mitra et al. (2010)* also reported RMSVD of same range over Tropics and mentioned that these statistics are generally comparable with similar results produced by other centers in the world.

5. Validation of Kalpana-1 AMV against T382L64 First Guess

As discussed earlier, the error of AMVs have reduced since March 2011. As an example, plots depicting the vector difference between Kalpana-1 AMVs and NCMRWF T382L64 first guess at different atmospheric levels are being generated regularly at NCMRWF. Fig 1.1 and 1.2 depict the same for typical days 0000 UTC of 10th Jan 2011 and 10th March 2011.

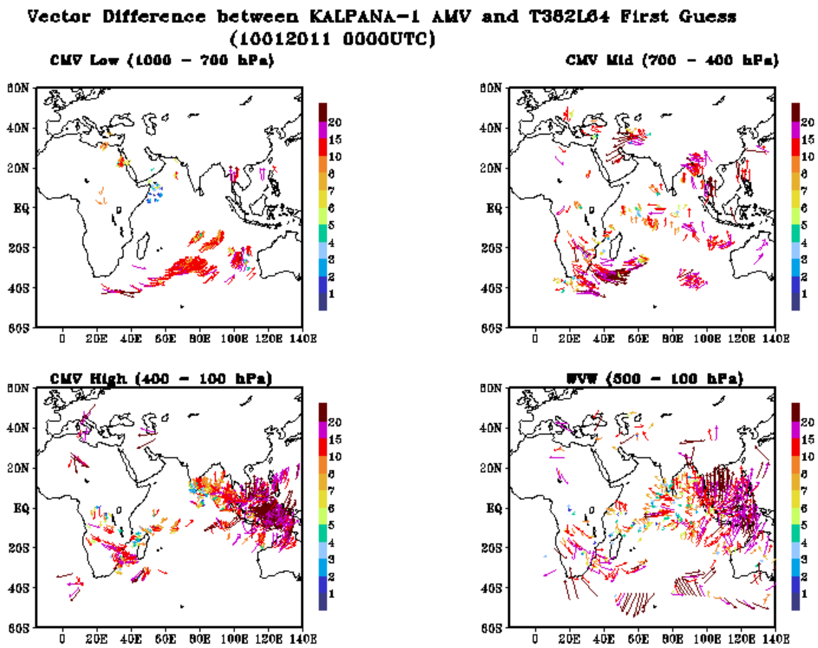

Figure 1.1: Vector difference between different level Kalpana-1 AMV and T382L64 first guess for 0000 UTC of 10th January, 2011

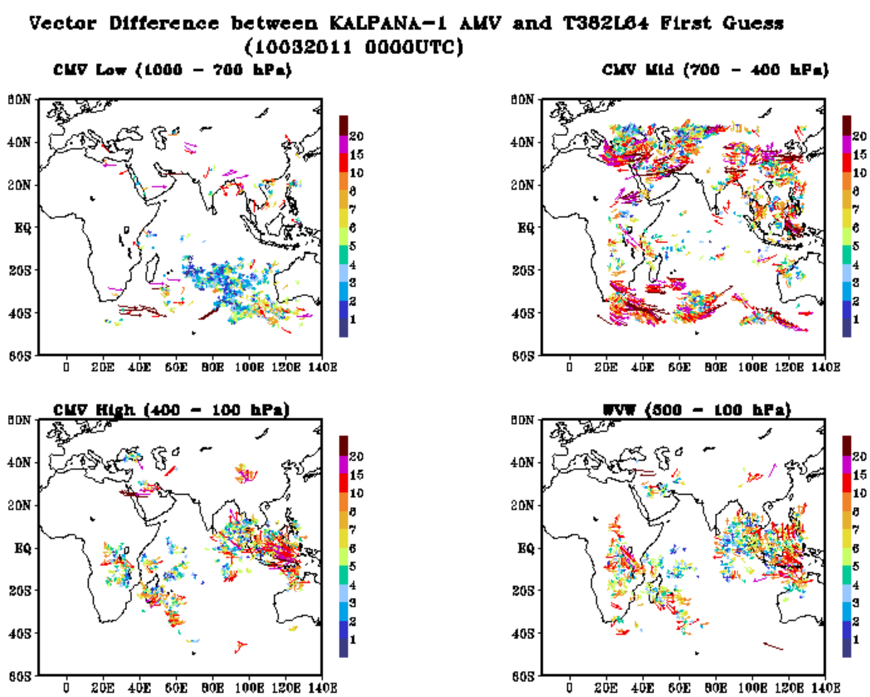

Figure 1.2: Vector difference between different level Kalpana-1 AMV and T382L64 first guess for 0000 UTC of 10th March, 2011.

As seen from the plots, vector differences between Kalpana-1 AMVs and first guess at various levels were as high as 15m/s at various locations on 10 Jan 2011 (figure 1.1), which seems to be reduced to 4-5m/s for the same on 10th March 2011 (figure 1.2).

Monthly mean vector plots depicting the agreement or otherwise between AMVs and T382L64 first guess, as discussed in section 3, for Kalpana-1 low level, and high level CMVs and WVWs for January 2011 are shown in figure 2. The mean vector difference for Kalpnana-1 is seen to be larger (~ 15 m/s) specifically over west Pacific and Africa. Figures 3 4 and 5 are same as figure 2 but for middle level CMV, high level CMV and WVW. Similar to low level CMV, the mean observation error in Kalpana-1 middle level, high level CMV and WVW are large (> 15 m/s) specifically over mid-latitude.

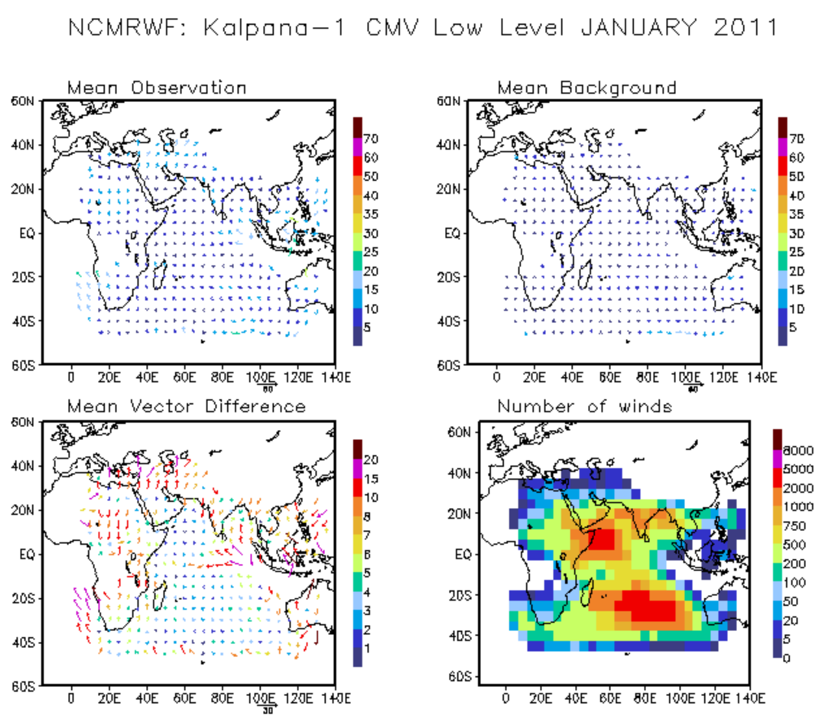

Figure 2: Vector plot for Kalpana-1 low level CMV for January, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds.

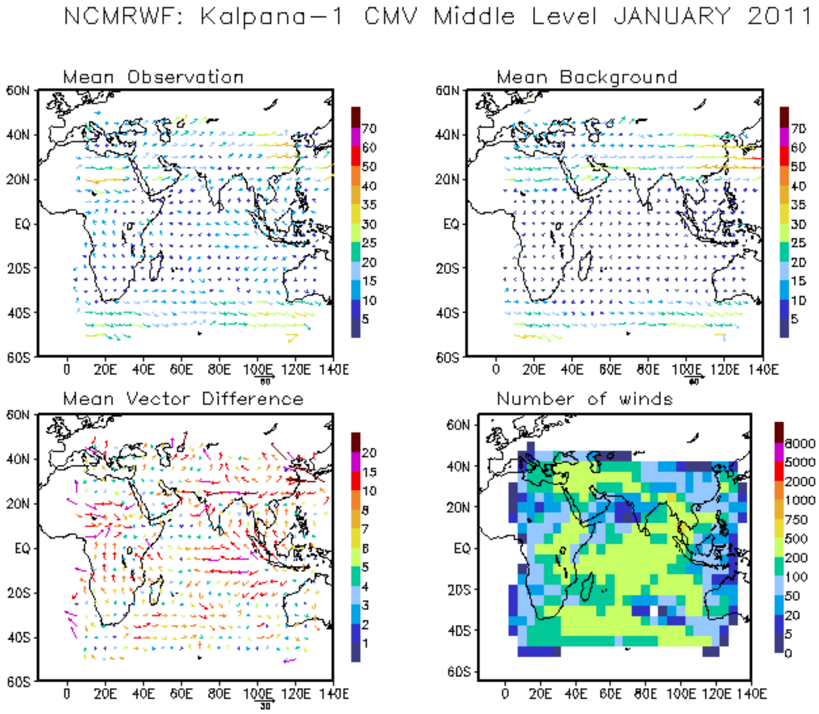

Figure 3: Vector plot for Kalpana-1 Middle level CMV for January, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds

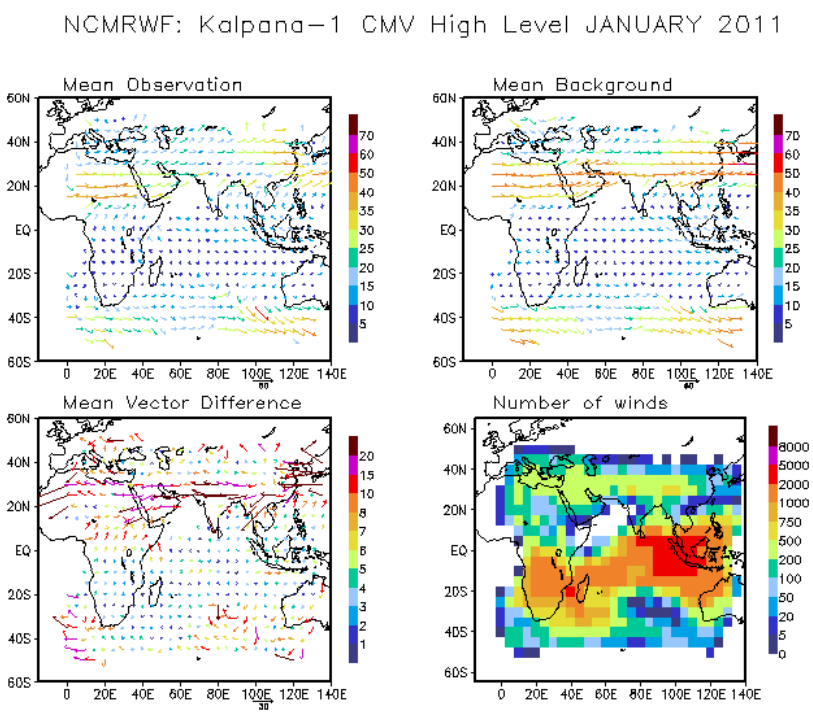

Figure 4: Vector plot for Kalpana-1 High level CMV for January, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds

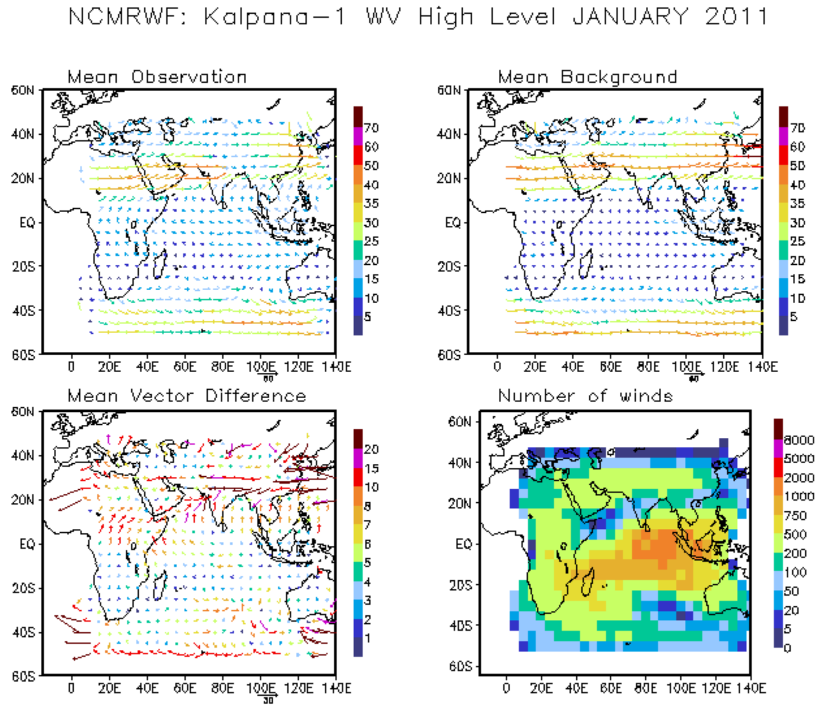

Figure 5: Vector plot for Kalpana-1 WVW for January, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds.

Figures 6.1, 6.2, 6.3 and 6.4 are the speed bias density plots for low, middle and high level CMVs and WVW for Kalpana-1 for January 2011. Bias and standard deviation of AMV's computed against first guess along with total number of AMVs over the region at corresponding levels are also shown in the plots.

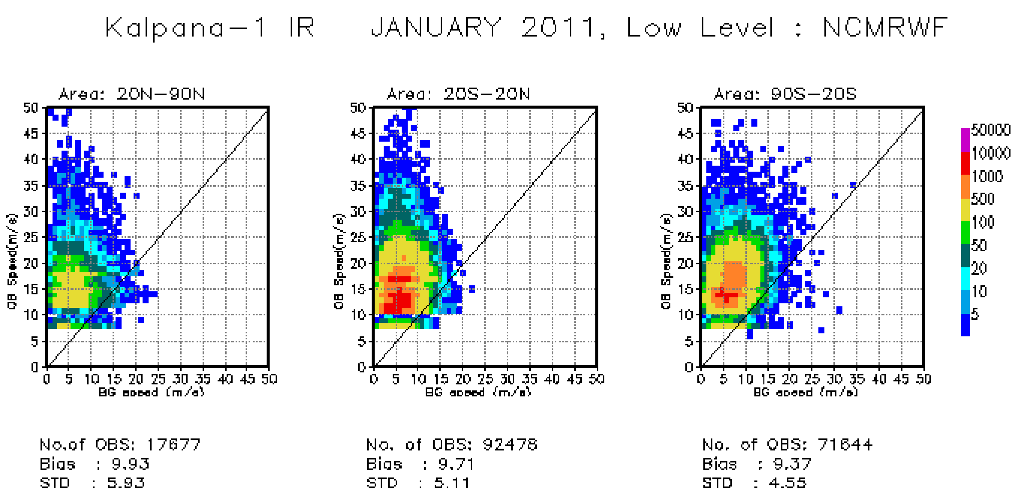

Figure 6.1: Speed Bias Density plots for Kalpana-1 low level CMV over Northern Hemisphere, Tropics and Southern Hemisphere for January 2011

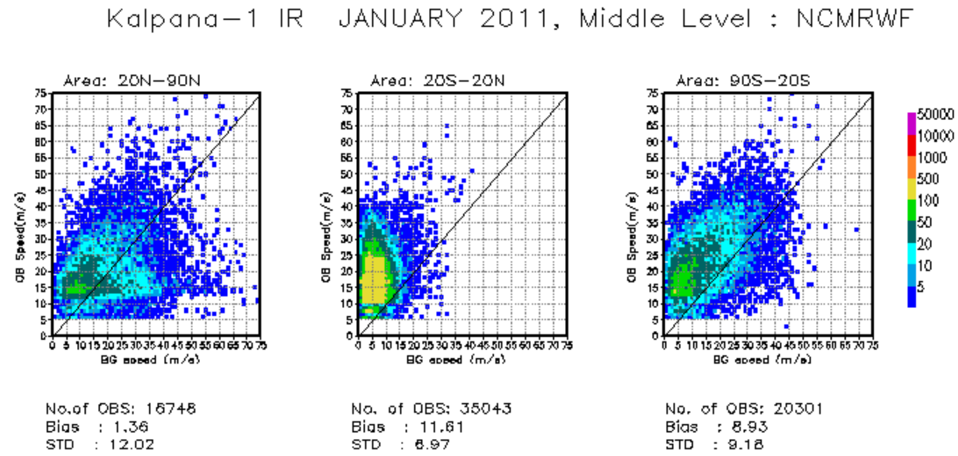

Figure 6.2: Speed Bias Density plots for Kalpana-1 middle level CMV over Northern Hemisphere, Tropics and Southern Hemisphere for January 2011

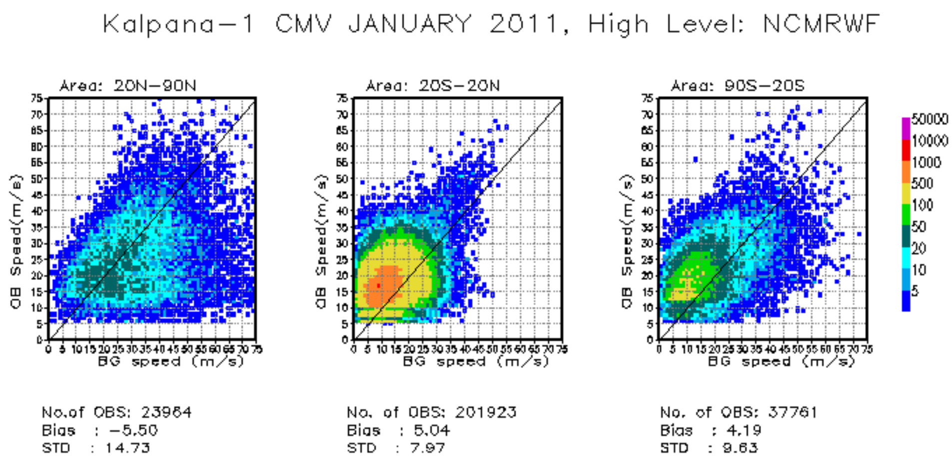

Figure 6.3: Speed Bias Density plots for Kalpana-1 high level CMV over Northern Hemisphere, Tropics and Southern Hemisphere for January 2011

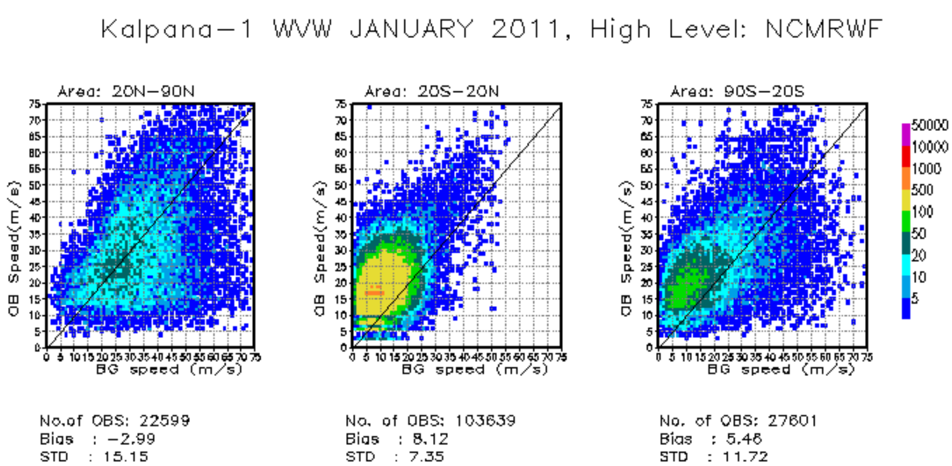

Figure 6.4: Speed Bias Density plots for Kalpana-1 WVW over Northern Hemisphere, Tropics and Southern Hemisphere for January 2011

As seen from figures 6.1, and 6.2, for Kalpana-1 low and middle level CMVs, the observed speed is higher than the background speed over the three latitudinal belts, whereas for Kalpana-1 high level CMV (6.3) and WVW (6.4), observed speed is less than that of background speed especially over Northern Hemisphere and opposite over tropics and Southern Hemisphere. It is also noticed that the observed speed of Kalpana-1 CMV (all levels) are always above 5 m/s. These types of vector plots and speed bias density plots though computed for all five months, but for brevity, January and March 2011 are shown here.

The vector plots for Kalpana-1 low, middle and high level CMVs and WVW for March 2011 are shown in figures 7, 8, 9 and 10. The monthly mean vector difference for Kalpana-1 low level CMV, high level CMV and WVW for March 2011are seen to be reduced from the high values observed in January 2011, especially over West Pacific and Africa. No significant improvement was seen in the middle level CMV in March 2011 compared to that in January 2011 (figure 8). It is also noticed that over mid-latitude (north of 20° N) the mean vector difference of Kalpana-1 low level CMVs are still above 10 m/s (figure 7). *Le Marshall et al., (2002)* reported the mean wind difference between AMV and first guess is situation dependant and should typically be less than ~ 12 m/s to consider for assimilation.

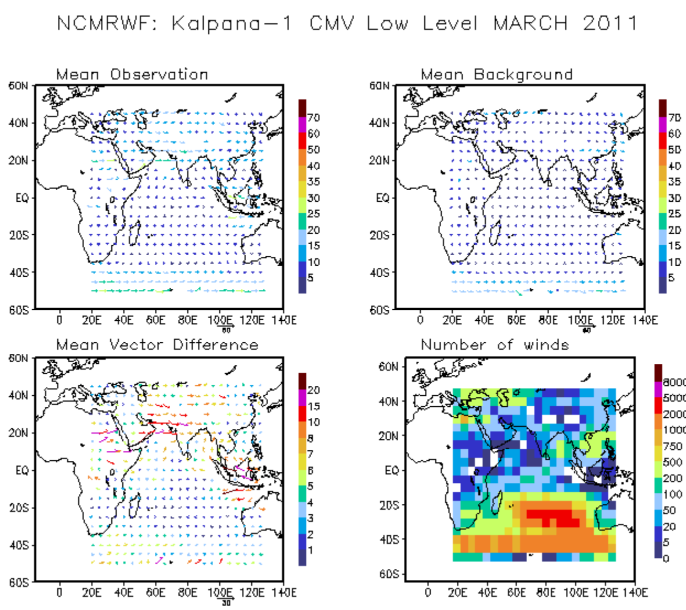

Figure 7: Vector plot for Kalpana-1 low level CMV for March, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds

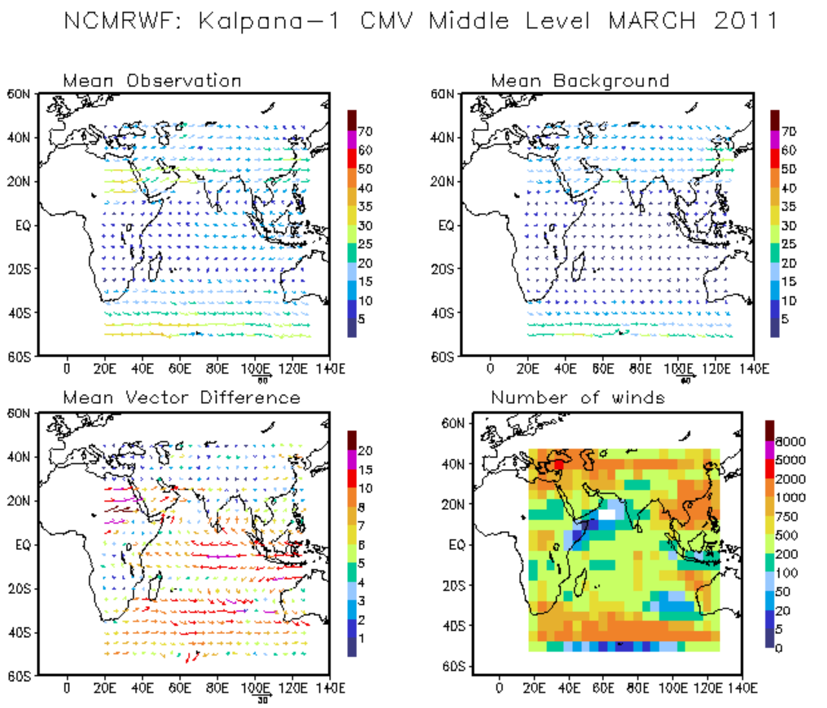

Figure 8: Vector plot for Kalpana-1 middle level CMV for March, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds

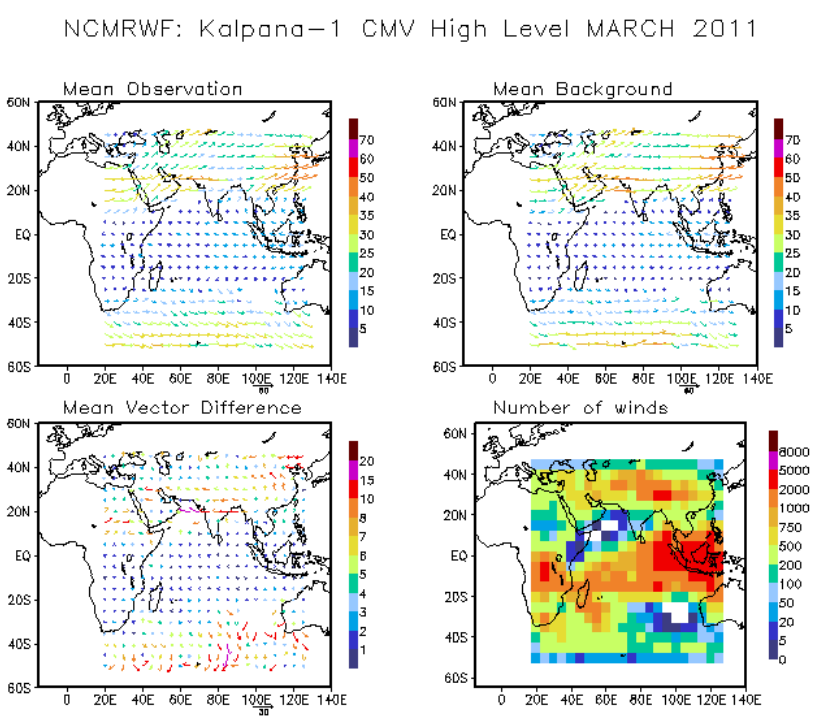

Figure 9: Vector plot for Kalpana-1 high level CMV for March, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds.

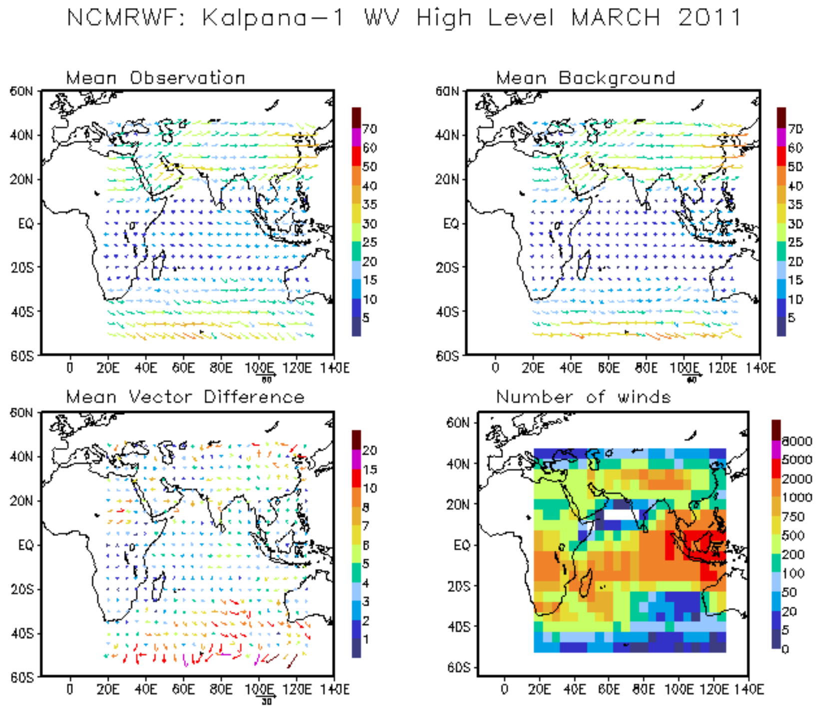

Figure 10: Vector plot for Kalpana-1 WVW for March, 2011. Mean AMV speed, Mean background speed, Mean Vector Difference and Number of collocated winds

Speed bias density plots for low, middle and high level CMVs and WVW are shown in figures 11.1, 11.2, 11.3 and 11.4 respectively. The low and middle level CMV in March, 2011 (figures 11.1 and 11.2) show high observed speed compared to the background speed as seen in January 2011 (figures (6.1 and 6.2). One can see from speed bias density plots for high level CMV and WVW (figures 11.3 and 11.4) for March 2011 better agreement between observed and background wind speed compared to that of January 2011 (figures 6.3 and 6.4), especially over Tropics and Southern Hemisphere. One limitation of Kalpana-1 WVW observed since March 2011 is that though in some cases the first guess exhibit high wind speed (> 45m/s), but the reported maximum wind speed is limited to 45m/s. This observation was reported to the Space Application Centre (SAC), Ahmedabad and based on our feedback SAC made required changes in the software and the same is operationally rectified at IMD from mid of June 2011.

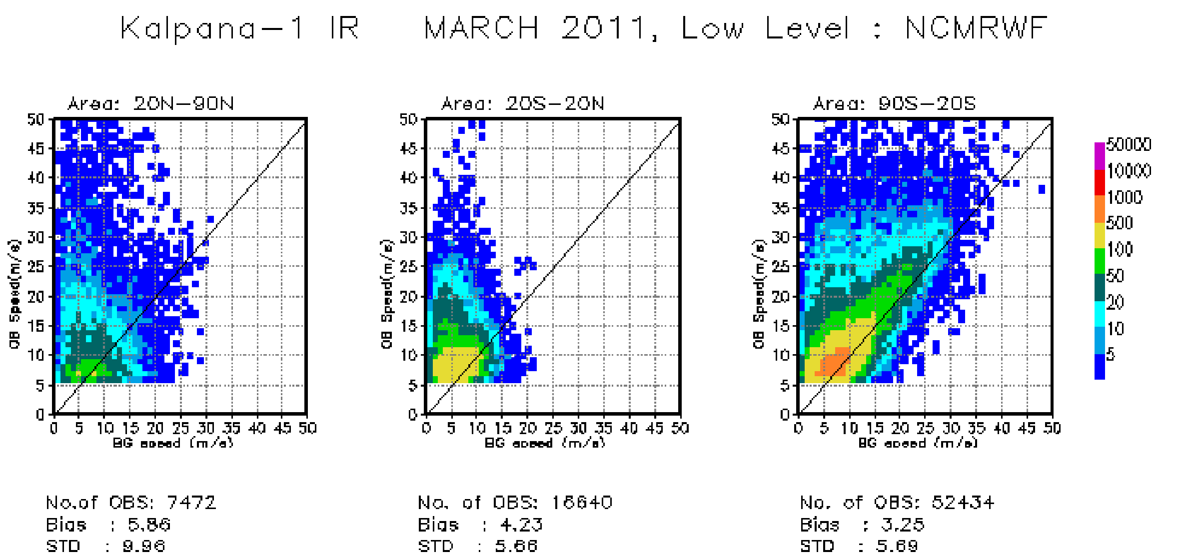

Figure 11.1: Speed Bias Density plots for Kalpana-1 low level CMV over Northern Hemisphere, Tropics and Southern Hemisphere for March 2011

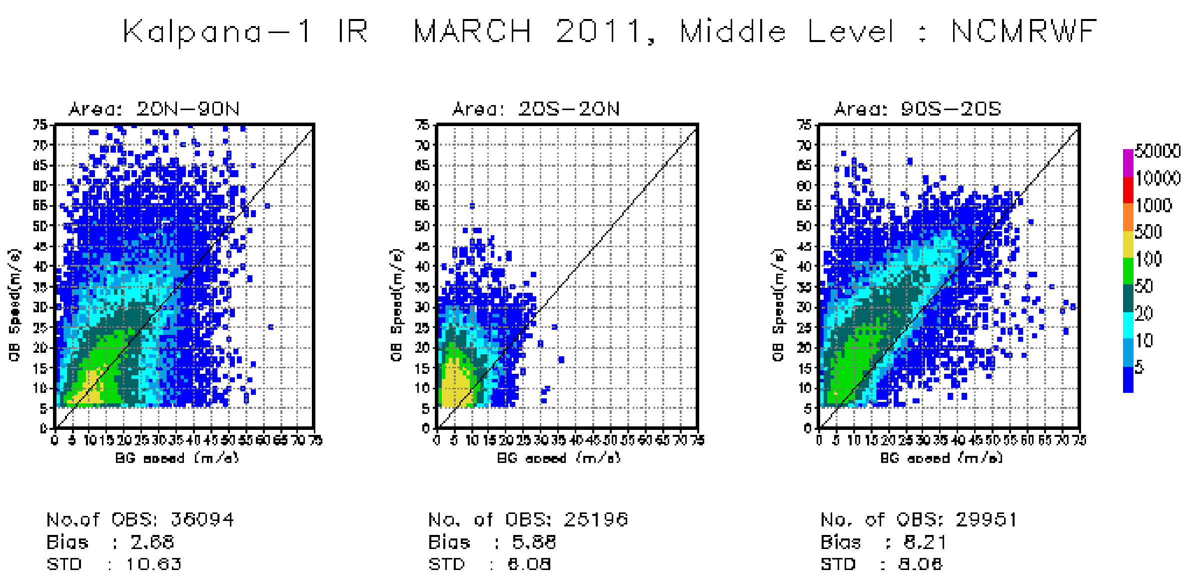

Figure 11.2: Speed Bias Density plots for Kalpana-1 middle level CMV over Northern Hemisphere, Tropics and Southern Hemisphere for March 2011

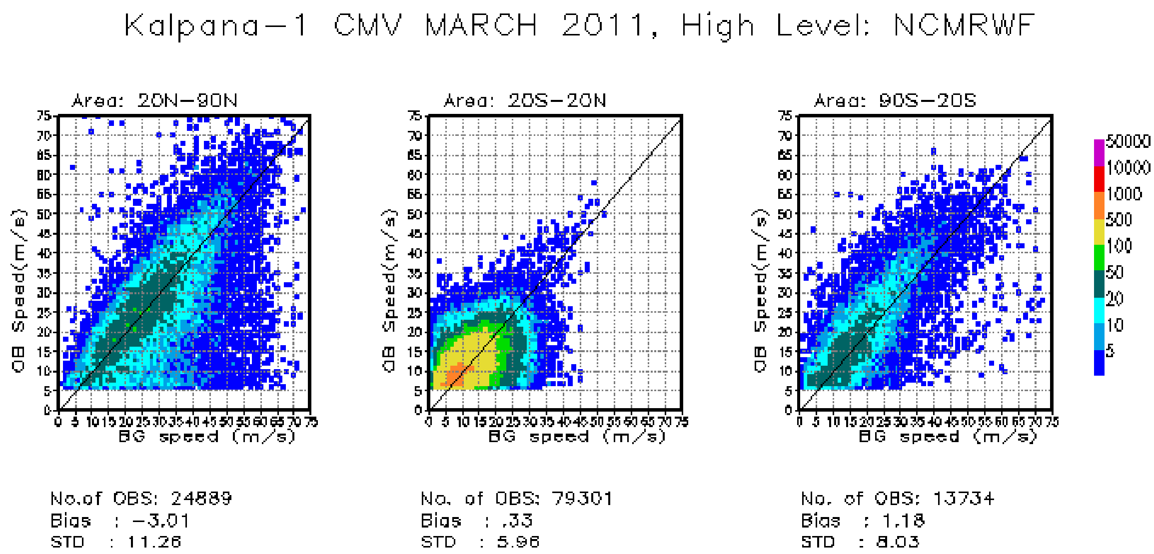

Figure 11.3: Speed Bias Density plots for Kalpana-1 high level CMV over Northern Hemisphere, Tropics and Southern Hemisphere for March 2011

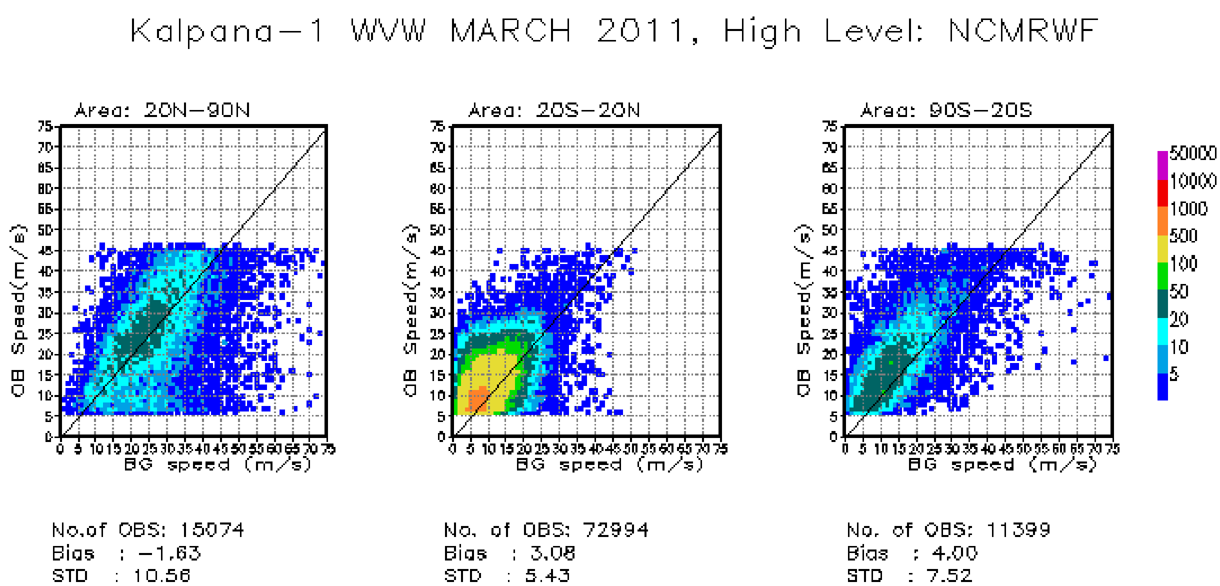

Figure 11.4: Speed Bias Density plots for Kalpana-1 WVW over Northern Hemisphere, Tropics and Southern Hemisphere for March 2011

Figure 12 depicts speed bias density plots for Kalpana-1 WVW over Northern Hemisphere, Tropics and Southern Hemisphere for July 2011. After the implementation of required changes in the software in IMD, the maximum speed limit of WVWs, discussed above has gone beyond 45 m/s from the mid of June 2011, and this is noticeable especially over Southern Hemisphere due to the presence of winter Jet stream at higher levels .

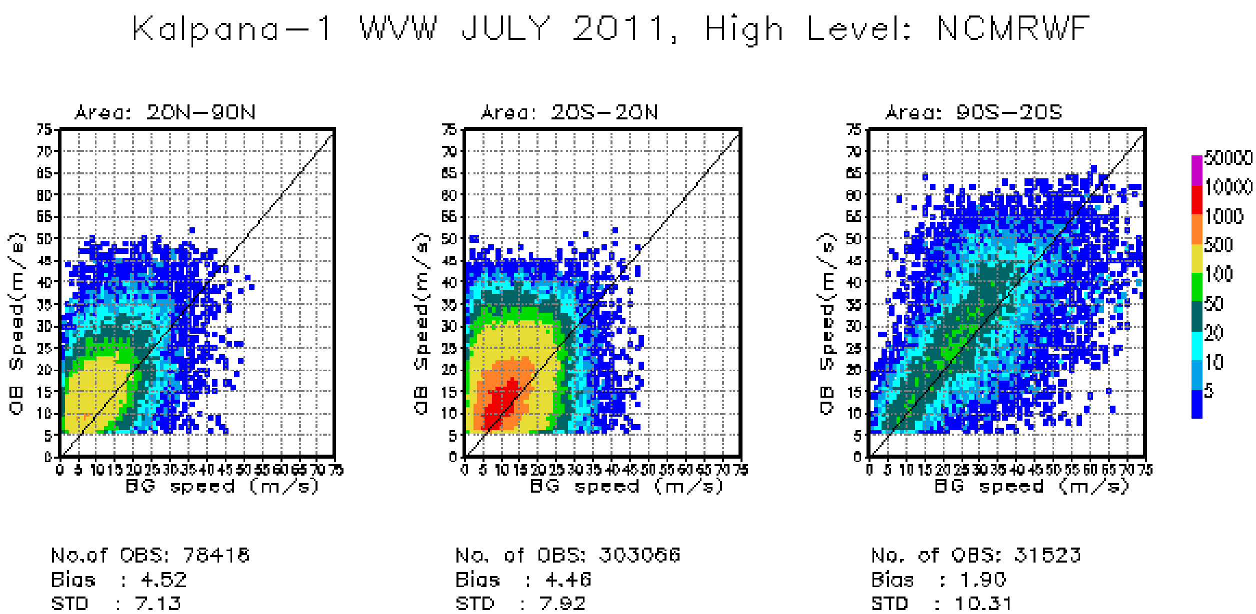

Figure 12: Speed Bias Density plots for Kalpana-1 WVW over Northern hemisphere, tropics and Southern Hemisphere for July 2011

Bias and standard deviation of Kalpana-1 high level CMV and WVW against NCMRWF's T382L64 first guess over different latitudinal regions from January to July 2011 are shown in Table 4. Both bias and standard deviation are reduced from January to March 2011 especially over Northern hemisphere and Tropics. Lower values of bias and standard deviation are seen since March 2011.

Table 4: Bias and standard deviation of Kalpana-1 high level CMV and WVW against T382L64 first guess for January and July 2011

Latitudinal Region	Month (2011)	Bias (m/s)		Standard Deviation	
		High Level CMV	WVW	High Level CMV	WVW
Northern Hemisphere	January	-5.50	-2.99	14.73	15.15
	February	-4.34	-2.39	11.36	11.75
	March	-3.01	-1.63	11.26	10.56
	April	-1.77	1.23	10.09	9.27
	May	0.30	2.47	8.62	7.75
	June	1.61	3.52	7.57	6.66
	July	1.73	4.52	7.50	7.13
Tropics	January	5.04	8.12	7.97	7.35
	February	3.22	5.61	7.92	7.12
	March	0.33	3.08	5.96	5.43
	April	0.96	3.18	5.75	5.54
	May	1.01	3.15	5.5	5.32
	June	0.72	4.44	7.39	6.99
	July	-0.17	4.46	8.42	7.92
Southern Hemisphere	January	4.19	5.48	9.63	11.72
	February	2.98	3.86	8.32	9.35
	March	1.18	4.00	8.03	7.52
	April	0.80	2.86	8.82	8.38
	May	-0.67	1.54	10.36	9.35
	June	-0.48	1.45	9.68	9.58
	July	-1.56	1.90	11.24	10.31

6. Conclusions

1. Validation of Kalpana-1 derived AMVs (CMV and WVW) is carried out against radiosonde winds and NCMRWF's T382L64 products for a period seven months from January to July 2011.

2. AMV validation against radiosonde winds showed that in January and February, the speed bias (SPDB) of Kalpana-1 AMVs was 7.5-14 m/s which reduced to below 5m/s since March 2011.

3. Root mean square vector difference (RMSVD) of Kalpana -1 AMV with respect to collocated radiosonde observations was quite high, 14m/s which reduced to 6-5m/s since March 2011 , which is comparable to that of other geostationary satellites, as discussed in section 1. Reduction of RMSVD is more noticeable in high level winds over Tropics (~ 5.5 m/s).

4. Validation against NCMRWF's T382L64 first guess is carried out using vector plots and speed bias density plots over different latitudinal regions and pressure levels. These plots also depicted the better match with first guess for high level Kalpana-1 winds; both CMV and WVW, over different latitudinal regions and pressure levels since March 2011.

5. Speed bias density plots are more scattered for January and February 2011, compared to that since March 2011. But at the same time it also has depicted a limitation of reported WVW speed (maximum is restricted to 45m/s) since March 2011, which was rectified by SAC from mid June 2011.

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References

1. Bedka, K., Velden, C. S., Petersen, R. A, Feltz, W. F., and Mecikalski, J. R., 2009: Comparisons of Satellite-Derived Atmospheric Motion Vectors, Rawinsondes and NOAA Wind Profiler Observations. *J. Appl. Meteor. Clim.,* **48**, 1542-1561.

2. De Smet, A., Genkova, I., Forsythe, M., and Bormann, N., 2010: The art of evaluating AMV algorithm changes. 10th International Winds Workshop, Tokyo, Japan, 22-26 february, 2010.

3. Deb S. K., C. M. Kishtawal, P. K. Pal, and P. C. Joshi, 2008: A modified Tracer Selection and Tracking Procedure to Derive Winds Using Water Vapor Images. *J. Appl. Meteor. Climatol.,* **47**, 3252-3263.

4. Fujita, T., 1968: Present status of cloud velocity computations from ATS-1 and ATS-3. COSPAR *Space Res*., **9,**557-570.

5. Forsythe, M. 2007: Atmospheric Motion Vectors: Past, Present and Future. *ECMWF Annual Seminar, September 2007.*

6. Hubert, L. F., and L. F. Whitney Jr., 1971: Wind estimation from geostationary satellite picture. *Mon. Wea. Rev.,* **99**, 665-672.

7. Kishtawal, C. M., S. K. Deb, P. K. Pal, and P. C. Joshi, 2009: Estimation of Atmospheric Motion Vectors from Kalpana-1 Images. *J. Appl. Meteor. Climatol.,* **48**, 2410-2421.

8. Leese, J. A., C. S. Novak, and B. B. Clark, 1971: An automated technique for obtaining cloud motion from geosynchronous satellite data using cross correlation. *J. Appl. Meteor.,* **10**, 118-132.

9. Le Marshall, J., G. Mills, N. Pescod, R. Seecamp, K. K. Puri, P. Stewart, L. M. Leslie, and A. Rea, 2002: The estimation of high density atmospheric motion vectors and their application to operational numerical weather prediction. *Aust. Met. Mag.,* **51**, 173-180.

10. Mitra, A. K., P. K. Kundu, A. K. Sharma and S. K. Roy Bhowmik, 2010: A quantitative aasessment of KALPANA-1 derived water vapour winds and their improvement from the use of NCEP first guess forecast fields. *Mousam,* **61**, 525-536.

11. Nieman, S. J., W. P. Menzel, C. M. Hayden, D. D. Gray, S. Wanzong, C. Velden and J. Daniels, 1997: Fully automated cloud-drift winds in NESDIS operations. *Bull. Amer. Meteor. Soc.,* **78**, 1121-1133.

12. Prasad, V. S., S. Mohandas, M. Das Gupta, E. N. Rajagopal and S. K. Dutta, 2011: Implementation of Upgraded Global Forecasting Systems (T382L64 and T574L64) at NCMRWF. NCMRWF/TR/5/2011. NCMRWF, A-50, Sector-62, Noida, (UP)-201307, India.

13. Rajagopal, E. N., M. Das Gupta, S. Mohandas, V. S. Prasad, J. P. George, G. R. Iyenkar and D. Preveen Kumar, 2007: Implementation of the T254L64 Global Forecast System at NCMRWF. *NMRF/TR/1/2007*. NCMRWF, A-50, Sector-62, Noida,(UP)-201307, India.

14. Schmetz, J., K. Holmlund, J. Hoffman, B. Strauss, B. Mason, V. Gaertner, A. Koch, and L. van de Berg, 1993: Operational cloud-motion winds from Meteosat infrared images. *J. Appl. Meteor.,* **32**, 1206-1225.

15. Tokuno, M., 1998: Collocation area for comparison of satellite winds and radiosondes. Proc. Fourth Int. Winds Workshop, EUM p24, Saanenmoser, Switzerland, EUMETSAT, 21-28.

16. Velden, C. S., and K. Bedka, 2008: Identifying the Uncertainty in determining Satellite derived Atmospheric Motion Vector Height Attribution, 9th International Winds Workshop, Annapolis, USA, 14-18 April 2008.

17. Young, M. T., 1975: The GOES wind operation. NOAA Tech. Memo. NESS 64 U. S. Dept. of Commerce, Springfield, VA, 111-121.