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Retrieval and validation of Atmospheric Motion Vectors from Indian National Satellite System KALPANA-1

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Working Paper Abstract

India Meteorological Department is processing 3 Channel Very High Resolution Radiometer (VHRR) data from KALPANA-1 and INSAT-3A Satellites since September, 2002 and April 2003 respectively. The retrieval of Atmospheric Motion Vectors using Infrared and Water vapor channels is one of the products derived from KALPANA-1 Satellite. Three consecutive images at 30-min intervals are used to determine the AMVs. The following steps are involved in this process: 1) image ‘‘thresholding,’’ 2) feature selection and tracking for CMV/WVW extraction, 3) use of image triplet and basic quality control, and 4) height assignment. An empirical height assignment technique based on a genetic algorithm is used to determine the height of cloud and water vapor tracers. The winds have been validated using 62 radio-sonde stations data according to the CGMS criterion. The validation procedure and results obtained for two years period, September, 2009 to August 2011 are presented in this paper. The results indicate that a) North of 20 deg. N, a definite seasonal variation is observed in the RMSE error and Bias values of the wind fields derived from the IR and WV channel data. The RMSE error values decrease in summer months, while the bias values become more negative as compared to winter months. The RMSE error and negative bias is generally high for low level winds. The RMSE error is less for middle and high level winds, and the positive bias is more and b) The seasonal effect on the error values is less pronounced south of 20 deg. N. Here too the error is high for low level winds. Positive bias is more in all months for high level winds, while negative bias is more for low and medium level winds. The overall improvement in the error values, especially in high level winds over the period indicates that the data is suitable for assimilation into NWP models as well as input for synoptic forecasting.

1.0 Introduction:

India Meteorological Department (IMD) started producing the Cloud Motion Vectors (CMV) Operationally since 1984 with two channel imager payload, Very High Resolution Radiometer (VHRR) on board INSAT-1 series of satellites. With the availability of Water Vapour channel on the second generation INSAT-2E satellite, IMD started producing Water Vapour Winds (WVW) also. The current operational Indian National Satellite System; KALPANA-1 which is launched in September, 2002 having 3 channel imager payload with Visible (0.55-0.75µm), Infrared (10.5-12.5 µm) and Water Vapour (5.1-7.1 µm) channels. Using three consecutive half-hourly images, the Cloud Motion Vectors (CMV) from 900-100hpa and Water Vapour Winds (WVW) from 600-100hpa are being generated using Infrared and Water vapour Channels respectively. The retrieved vectors have been validated against the co-located radiosonde data and statistics like Mean Vector Difference (MVD), Root Mean Square Error (RMSE), BIAS are estimated as guided by CGMS at the end of each calendar month.

2.0 Brief description on the retrieval of Atmospheric Motion Vectors (AMV):

2.1 Retrieval of Cloud Motion Vectors (CMV):

Derivation of Cloud Motion Vectors involves following four steps.

a) **Image Thresholding**: Based on the histogram analysis of a large number of images (Prasad et al. 2004), thresholds of gray counts of low (900-700hpa) and high (300-100) clouds are predetermined. If 521 $\leq$ Gray value $\leq$ 640 then it is low clouds and if 641 $\leq$ Gray value $\leq$ 880 then it is high clouds

b) **Feature selection and Tracking for CMV extraction**:
The spatial resolution of the Infrared channel of KALPANA-1 is 8km, a template window of 20 x 20 has been used to identify features in Kalpana-1 images. The maximum and average Gray value of a template are used to determine the type of the cloud (low or high). If the distribution of gray value is coherent within a template, it is assumed that there is no traceable feature in that template and excluded derivation of vectors. If a feature is found in the first image, the match will be searched in the second image within 64 x 64 pixels search window. The match is done using cross-correlation (CC) method given by Schmetz et al 1993. The tracers with cross correlation less than 0.8 are rejected. The centre of template with maximum CC is considered to be the location of the feature in the second image. Then the template is shifted in the x & y directions and the vectors are determined.

c) **Use of triplet and basic quality control**:
The step (b) is repeated for the second and third images and second set of vectors is generated. In the both sets there will be several spurious vectors which are to be eliminated using some basic quality controls. Vectors that

show unrealistic retrievals or speed and directional deviations with respect to surroundings greater than a certain threshold value are rejected. The technique employed the automatic quality control procedure used at EUMETSAT (Holmlund 1998)

d) **Height assignment**: An empirically derived height assignment technique based on a genetic algorithm is being used to assign the height for the final vectors. The genetic algorithm is an automatic method that determines the most fitting relationship between dependent and independent fields. Brief description on the Genetic algorithm is given by Kishtawal et al 2009.

2.2 Retrieval of Water Vapour Winds (WVW): The following three steps involved in the derivation of Water Vapour Winds

a) **Tracer selection and tracking for WVW extraction**:
The tracers are selected by computing the local image anomaly in a 20 x 20 template window. The local image anomaly is calculated using the formula:

$$a(I,j) = \sum_{i} \sum_{i} [\, I(I,j) - \bar{I} \,]$$

where I(I,j) represents the gray values for the (I,j) pixel of a template window and the bar indicates the mean of gray values in that template.
For tracking the tracer between two successive images is done by measuring the degrees of matching by Nash-Sutcliffe model efficiency coefficient E.

$$E = 1 - \frac{\sum_{i=1}^{n} (I_t - I_s)^2}{\sum_{i=1}^{n} (I_t - \bar{I}_t)^2}$$

where I_t & I_s are the variance of the gray value for the template and search window and I_t is the average of variance of the template window. The coefficient E is normalized to values between $-\infty$ and + 1. An efficiency E=1 means a perfect match; E = 0 means that the search window is as accurate as the mean of the template window, and E < 0 implies a lack of matching. The closer the efficiency is to 1, the more accurate is the matching between the template and search window.

b) Use of image triplet and basic quality control
The step (a) is repeated for second and third images and a second set of vectors is generated. For the quality control same method is followed as in the case of Cloud Motion Vectors (CMV).

c) **Height assignment**: An empirically derived height assignment technique based on a genetic algorithm is being used to assign the height for the final vectors. The genetic algorithm is an automatic method that determines the most fitting relationship between dependent and independent fields. Brief description on the Genetic algorithm is given by Kishtawal et al 2009.

3.0 Validation of Atmospheric Motion vectors with radiosonde observations

The validation of Atmospheric Motion Vectors (AMV) which includes both Cloud Motion vectors (CMV) and Water Vapour Winds (WVW) for a two years period from september, 2009 to August 2011 using radio-sonde data from 62 stations (locations of the stations shown in fig.1) as per the CGMS guidelines.

At the CGMS XXIII the Working Group on Satellite Tracked Winds recommended that evaluation of operational wind production quality should be accomplished with a new standardized reporting method. They recommended three parts to the report. (1) Monthly means of speed bias and rms vector difference between radiosondes and satellite winds for low (>700 hPa), medium (700-400 hPa), and high (< 400 hPa) levels together with the radiosonde mean wind speed. This should be done for three latitude bands : north of 20 N, the tropical belt (20 N to 20 S), and south of 20 S. (2) Trends of the evaluation statistics for the monthly cloud motion vectors and water vapor motion vectors through the last 12 months. (3) Information on recent significant changes in the wind retrieval algorithm.

In accordance with the CGMS guidelines, the authors computed the monthly means of speed bias and rms vector difference between radiosondes and satellite winds for low (>700 hPa), medium (700-300 hPa), and high (< 300 hPa) levels together with the radiosonde mean wind speed for the above mentioned period. These computations were carried out separately from
(i) CMV derived from Infrared channel (ii) WVW derived from Water Vapour Channel (iii) combination of both (CMV and WVW) for the following two regions:

(i) **Region 1** : North of 20 deg. N
(ii) **Region 2** : South of 20 deg. N

Since very few data are obtained south of 20 deg. S, a separate region was not defined for validation.

4.0 Results & Discussions:

RMSE:

IR Winds (above 20º North): RMSE has decreased in the summer months compared to wintertime values (Fig.2a) The decrease is more significant for the high level winds (2-3 m/s less compared to the same time in 2010).
IR Winds (below 20º North): RMSE is mostly in the range of 10-15 m/sec throughout the period (fig.2b). The error does not show seasonal variation. However, error is maximum for low-level winds (upto 20 m/s for June, 2011).

WV Winds (above 20º North): There is a significant decrease in the RMSE error, especially of the high level winds (above 400 hPa) for the summer months (May, June and July, 2011) compared to the preceding months (fig. 2c). This is in line with previous observation of the cyclic nature of error over the region, with maximum error occurring in winter months and minimum in summer months. However, the decrease in error of high level winds is especially significant compared to previous years.
WV Winds (below 20º North): RMSE has decreased in the summer months compared to wintertime values (Fig.2d). The decrease is more significant for the high level winds (2-3 m/s less compared to the same time in 2010.

BIAS :

IR Winds (above 20º North): Negative bias in the wind speed increases during summer months and decreases(positive bias increases) during winter months (Fig.3a). Negative bias is most for low level winds , positive bias is more for high level winds. Bias values have decreased during the past 3-4 months (April to July, 2011).
IR Winds (below 20º North): No significant change in bias values (Fig.3b). Positive bias is more in all months for high level winds, while negative bias is more for low and medium level winds.

WV Winds (above 20º North): Negative bias increases during summer months and positive bias increase during winter months (Fig.3c). The positive bias values are more for high level winds. It is abnormally high in the winter months of 2011 (January and February, 2011.)
WV Winds (below 20º North): Negative bias has increased in the high level winds in the last few months (Fig.3d).

5.0 Conclusions:

a) North of 20º North, a definite seasonal variation is observed in the RMSE error and Bias values of the wind fields derived from the IR and WV channel data. The RMSE error values decrease in summer months, while the bias values become more negative as compared to winter months. The RMSE error and negative bias is generally high for low level winds. The RMSE error is less for middle and high level winds, and the positive bias is more.

b) The seasonal effect on the error values is less pronounced south of 20º North. Here too the error is high for low level winds. Positive bias is more in all months for high level winds, while negative bias is more for low and medium level winds.

c) The overall improvement in the error values, especially of high level winds over the period indicates that the data is suitable for assimilation into NWP models as well as input for synoptic forecasting.

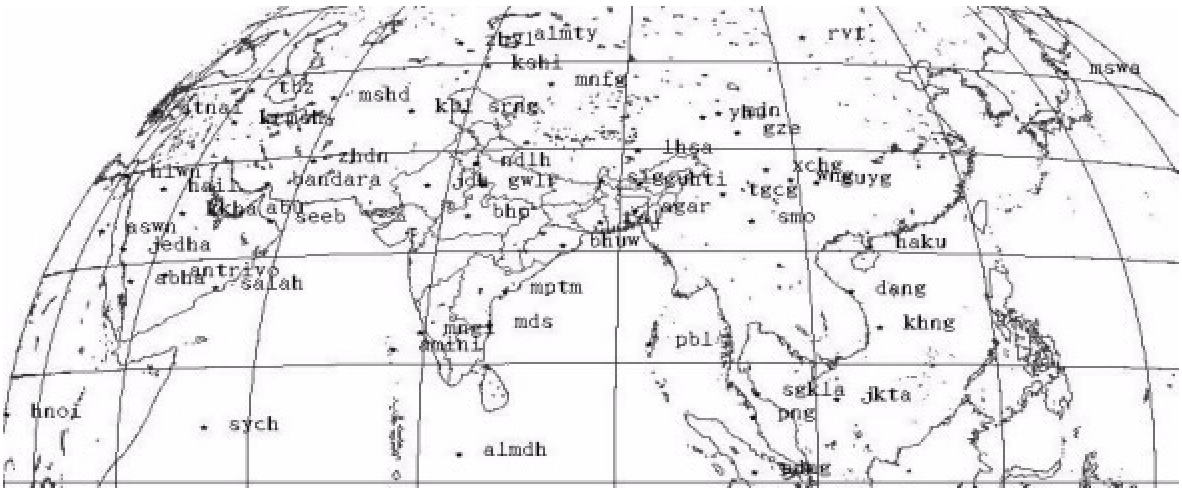

Fig.1 Location of Radiosonde Stations

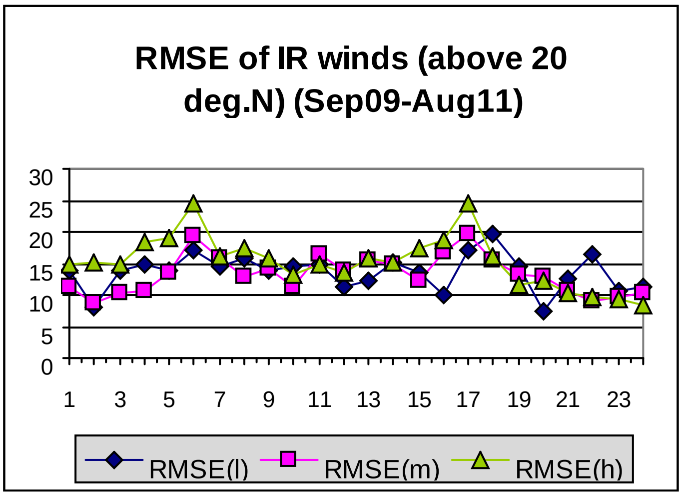

Fig. 2a RMSE of IR winds above 20º N

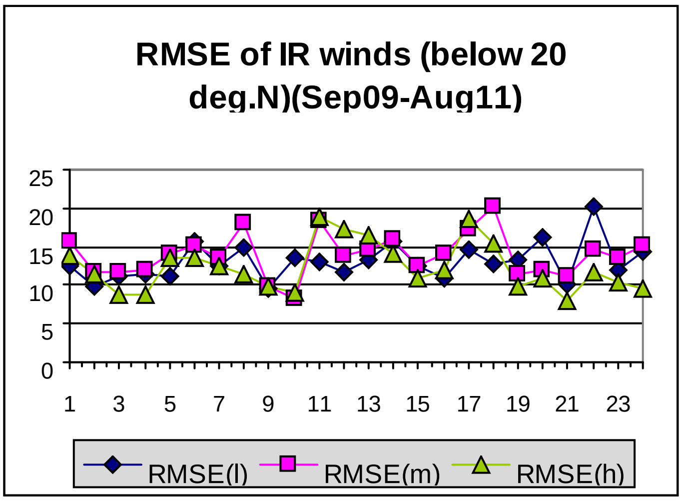

Fig. 2b RMSE of IR winds below 20º N

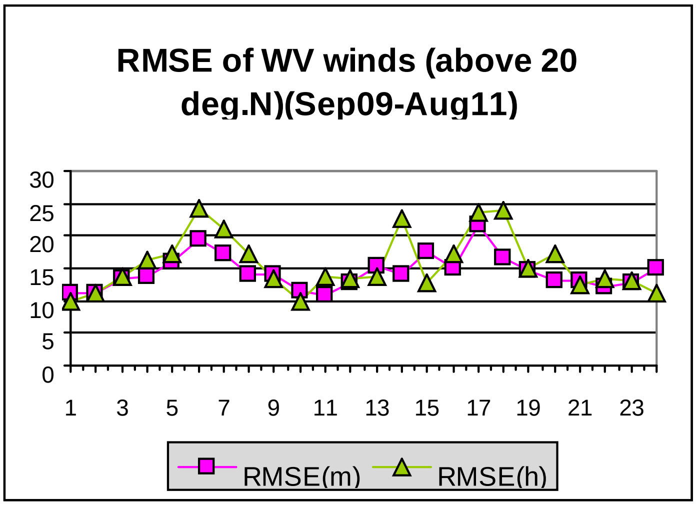

Fig. 2c RMSE of WV winds above 20º N

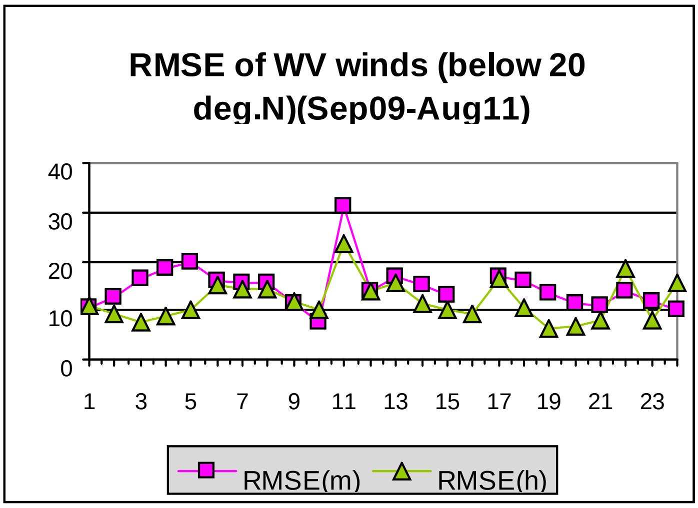

Fig. 2d RMSE of WV winds below 20º N

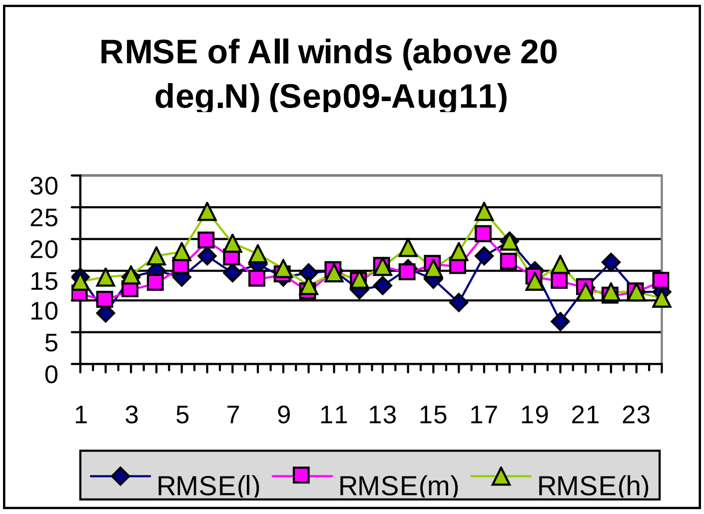

Fig. 2e RMSE of All winds above 20º N

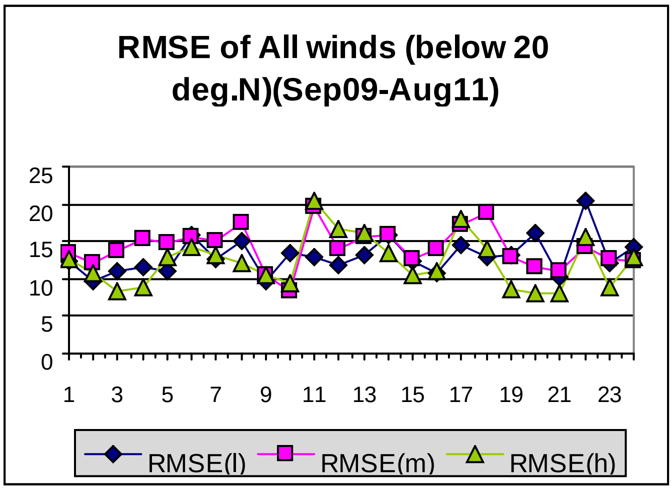

Fig. 2f RMSE of All winds below 20º N

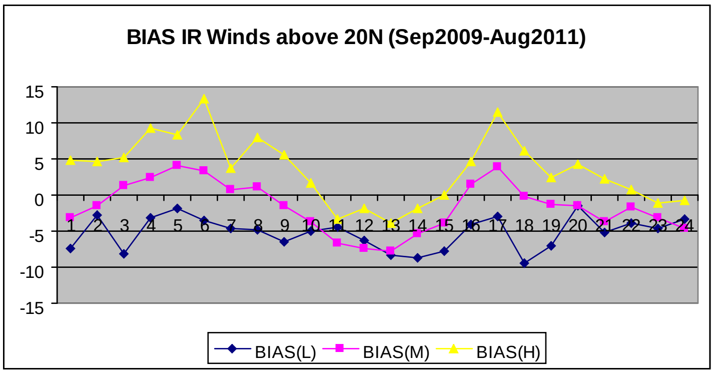

Fig. 3a BIAS of IR Winds above 20º N

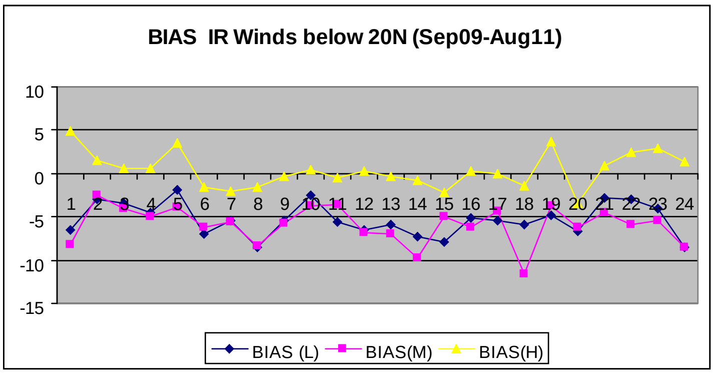

Fig. 3a BIAS of IR Winds below 20º N

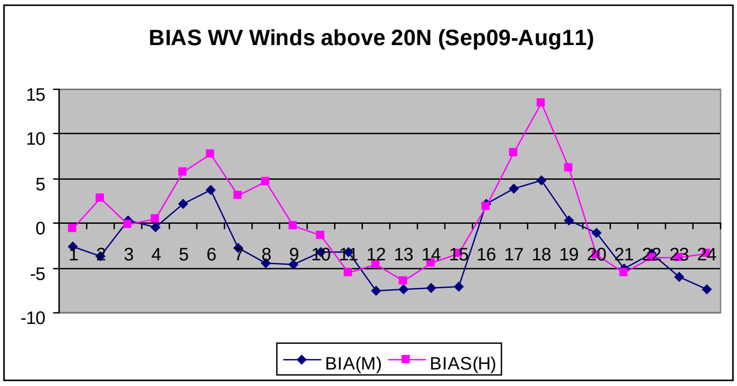

Fig. 3c BIAS of WV Winds above 20º N

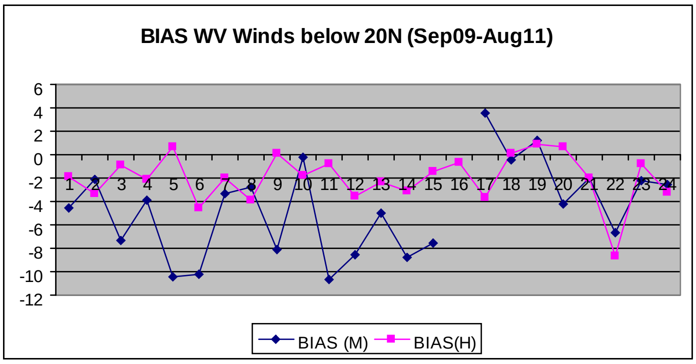

Fig. 3d BIAS of WV Winds below 20º N

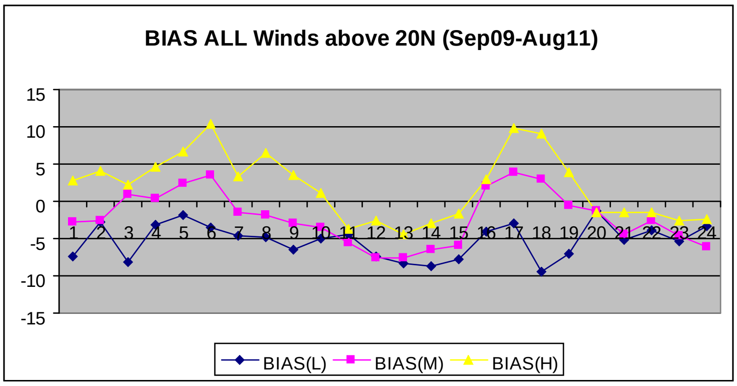

Fig. 3e BIAS of ALL Winds above 20º N

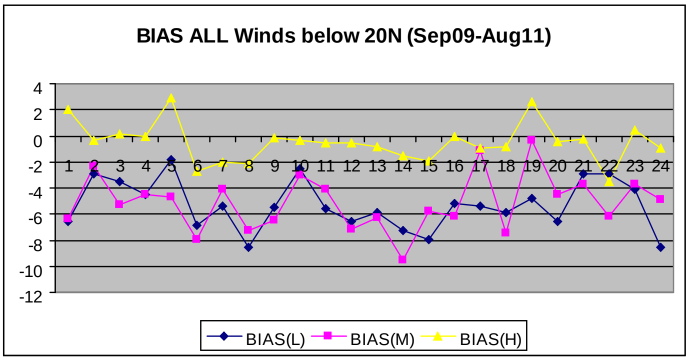

Fig. 3f BIAS of ALL Winds below 20º N

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Formulae used to compute speed bias, Mean Vector Difference and Root Mean Square Error as per CGMS guidelines

The speed bias (BIAS) is calculated as

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

The mean vector difference (MVD) is calculated as

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

The root mean square error (RMSE) is calculated as

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

where subscripts ‘ i ’ and ‘ r ‘ are for individual wind and collocated radiosonde wind respectively.