GLOBAL ATMOSPHERIC MOTION VECTOR INTER-COMPARISON STUDY

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Abstract

Atmospheric Motion Vectors (AMVs) have been assimilated routinely for years by a number of weather prediction centers. The AMV data disseminated by the producers around the world undergo a thorough quality control including quality indicator (QI) (Holmlund, 1998) threshold-based AMV pre-selection, blacklisting, spatial and temporal thinning of the data, etc. The lack of 1) in depth understanding of the consistency of all the data sets in terms of algorithm set up with regard to AMVs quality, and 2) individual AMV uncertainty estimate (i.e. observation error) from the producers was the motivating force for performing an inter-comparison of AMVs derived by different producers from the same IR (10.8 μm) image triplet.

Part 1 of the study (a.k.a. CGMS-1 Study, Genkova et. al., 2008) included five AMV producers – EUMETSAT, NOAA-NESDIS, JMA, KMA, and the Brazilian Meteorological services. Each retrieved AMVs from one MSG-SEVIRI image triplet applying their own operational retrieval algorithm using first guess forecast model data from ECMWF. Winds derived by the various producers from the 10.8 μm IR channel are inter-compared. The analysis focused on spatial coherence, agreement in height assignment, and quality indicator consistency. For the height assignment routines some producers used WV imagery in addition to the IR imagery. EUMETSAT and NESDIS AMVs altitudes are thus retrieved with the IR channel method, CO_2 slicing method and Water Vapor-Infrared Window intercept method. JMA and KMA used the IR channel method and the Water Vapor-Infrared Window intercept method, and finally, Brazil's winds heights are assigned only with the IR channel method. In adition, EUMETSAT is employing a semi-transparency correction, and NESDIS is using cloud-base height assignment method for low winds over ocean surface. The limited count of collocated AMVs however does not allow for parsing the data by height assignment method.The study assessed how the various AMV producer's data inter-compare in terms of global coverage, speed and direction, what is the importance of the choice of first guess forecast initiating the AMV extraction.

In Part 2 of the study (a.k.a. CGMS-2 Study, Genkova et. al., 2008a) the AMV producers were requested to produce AMVs from the same SEVIRI images, but using consistent target and search box sizes. It was hoped that this would allow for a more meaningful comparison of target height assignments and target height estimation algorithms. It was found that each producer's algorithms is fine tuned to one specific setup of tracer and search area sizes, thus the resulting data sets were inconsistent with the ones from Study CGMS-1 and difficult to draw conclusions from.

Part 3 (final) of the study is using the AMVs produced during Part 1 for a further analysis of the links between the winds' vertical placements, the winds speed and the corresponding tracked cloud features. It assesses the quality of each AMV data set through collocated comparisons with RAOBs. As this study is aiming to improve the use of AMVs in NWP, it also reports on the agreement (in terms of speed) of the winds with the ECMWF model forecast.

RESULTS AND ANALYSIS

A summary of the differences in the AMV retrieval algorithm used by the various AMV producers is given in Table 1. They are the starting point for the qualitative analysis undertaken in Part 3 of the CGMS study. The datasets are collocated such that the distance between matched AMVs is equal to or less than 0.5 deg longitude- and latitude-wise, and all participating teams have retrieved a wind vector for the matched location. The collocated subset consists of 619 AMVs (number differs from

Study 1 due to removing a number of speed blunders). Because of the very few mid level winds from KMA, our conclusions mainly pertain to low and high clouds.

AMV Producer	EUMESAT	CIMSS/NESDIS	Brazil	JMA	KMA
Steps subsequence	target, track, height assign.	target, height assign., track	target, track, height assign.	target, track, height assign.	target, track, height assign.
Target box	24x24 pix	15x15 pix	32x32 pix	32x32 pix	32x32 pix
Search box	80x80 pix	21x37 pix	50x50 pix	64x64 pix	64x64 pix
Target selection	no threshold	7 bright. units	no threshold	no threshold	5 Kelvin
Height	coldest CTP peak, average interm. prod.	25% coldest pixels, middle image only	10% coldest pixels, average interm. prod.	highest CTP peak, second interm.prod.	15% coldest pixels, average interm. prod.
QI implementation	single band, average interm. prod	all bands, one final QI	single band, average interm. prod.	single band, second interm.prod.	single band, average interm. prod.

***Table 1:* Specifics of AMV retrieval schemes used by the various AMV producers**

Figure 1 shows the speed, direction, height and quality indicator comparison for the collocated winds. They are plotted in increasing speed order of the EUMETSAT winds, as this facilitates the recognition of a number of clusters in terms of AMV altitude. We will focus on each of them below. In the KMA's and Brazil's data sets there is a number of AMVs with erroneous direction DIR=90deg. As most of the AMVs have properly assigned directions, we assume that this is an ocasional numerical problem. The speed and the altitude for these winds are reasonable, so they are kept in the collocated dataset.

Cluster 1 comprises of winds with varying altitudes P<400hPa and consistent speed SPD<15m/s. At first, the ranging pressure appears a bit alarming. The map on Figure 2 (a) and the detailed maps on Figure 1 (b) and (c) illustrate the location of AMVs from this cluster.

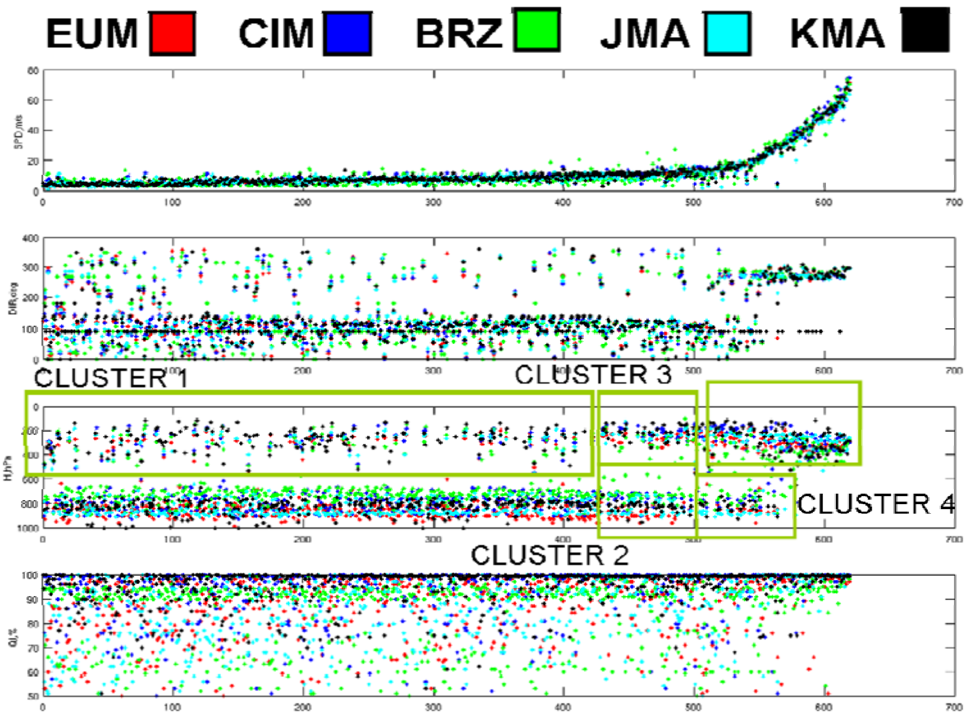


***Figure 1:* Speed (top panel), Direction (second panel), Height (third panel) and QI (bottom panel) for the collocated dataset of AMVs with QI≥50**

Figure 2(b) illustrates that some AMVs from Cluster 1 - mainly from the KMA dataset, are erroneously assigned a too high altitude (pressure). These winds are derived from tracking marine cumulus clouds which on average have top heights below 400hP. Others, shown in Figure 2(c), appear to be placed well. These winds are extracted from tracking convective, vertically developed high cumulus in the Equatorial belt. They may, however be from tracking the expansion/ growth of the clouds, thus the speed is not representative of an air mass motion on a large scale.

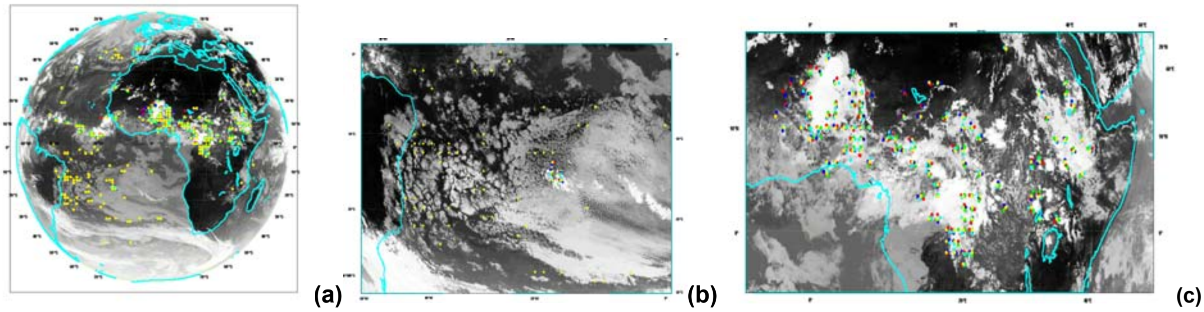


Figure 2: **Map of AMVs with speed below 12m/s and pressure less than 400hPa (Cluster 1) The colors indicate which producer derived the AMV: red - EUMETSAT, blue - NESDIS, green - Brazil, cyan - JMA and yellow - KMA, and the same apply to Figures 3-6**

Clusters 2 and 3 include AMVs with speed below 20m/s, but about equally distributed between the low and high level bins (x axis order indices from 450 to 500 in Figure 1).
The low level winds, Cluster 2, are mapped in Figure 3. They are derived either from tracking low marine cumulus, see Figure 3(b), or from the lower surroundings of growing or dissipating vertically developing cumulus - Figure 3(c). These winds are similar to the majority of the collocated winds which have speed <20m/s, and are placed in the range 600-1000hPa. Their altitude difference between the producers is not negligible, however it is consistent. Brazil's and KMA's AMVs are placed highest due to the lack of proper low level correction in their height assignment routines.

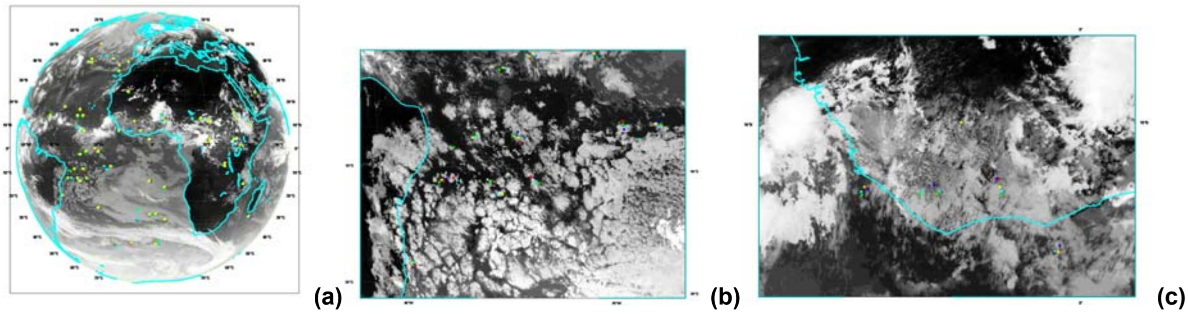
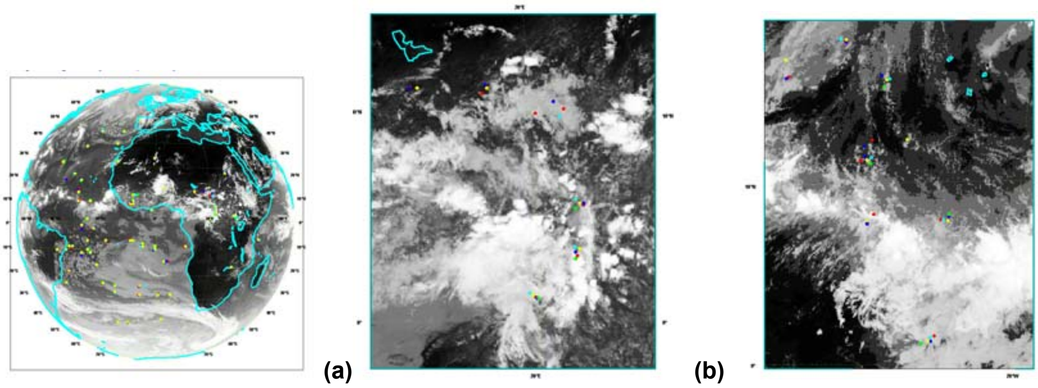


Figure 3: **Cluster 2 AMVs map**

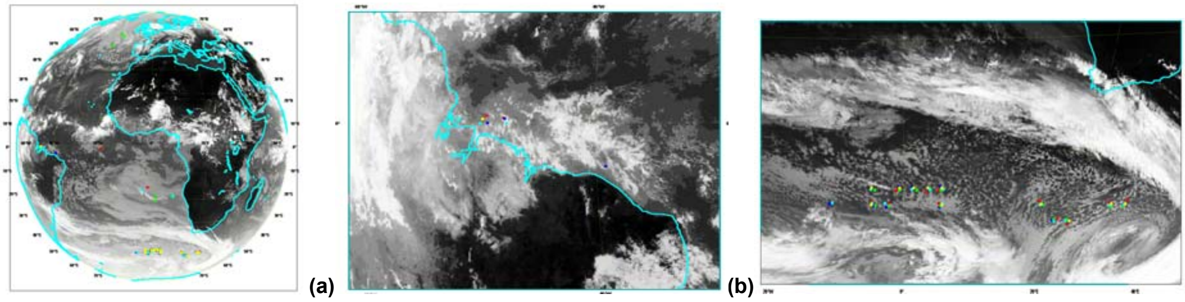
Cluster 3 includes winds from tracking a range of cloud type features, and as the map in Figure 4(a) shows there is no zonal preference. Some winds (Figure 4(b)) come from tracking convective features similar to Cluster 1, thus, they are indeed high winds. Others - Figure 4 (c), seem to be lower in the atmosphere, but they are assigned as high winds. This often happens when a very thin undetected cirrus layer is overlaying the tracked clouds, or it could also be due to tracking the warmer pixels and choosing the colder pixels from the tracer for height assignment. In some cases, there might be a sub-visible cirrus layer. There are also a number of winds which all other producers placed below 600hPa, but KMA assigned as high. It is not obvious what could cause that height assignment error.



(a) (b) (c)

Figure 4: **Cluster 3 AMVs map**

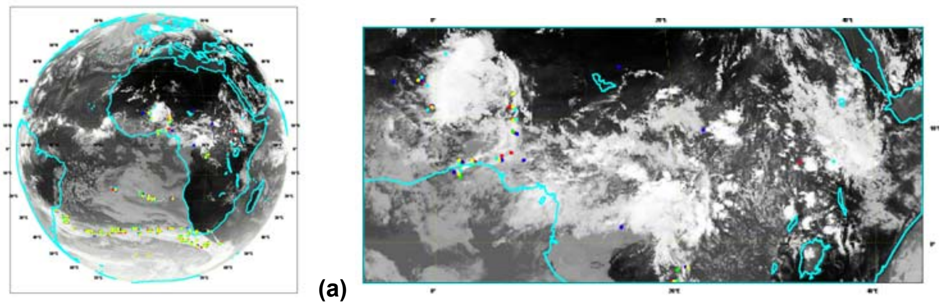
Cluster 4 includes faster (speed>20m/s) low clouds, as shown in - Figure 5(a). Their altitude appears reasonable. In Figure 5(b) is an example of west trades and in Figure 5(c) some faster moving marine cumulus, possibly part of a polar front.



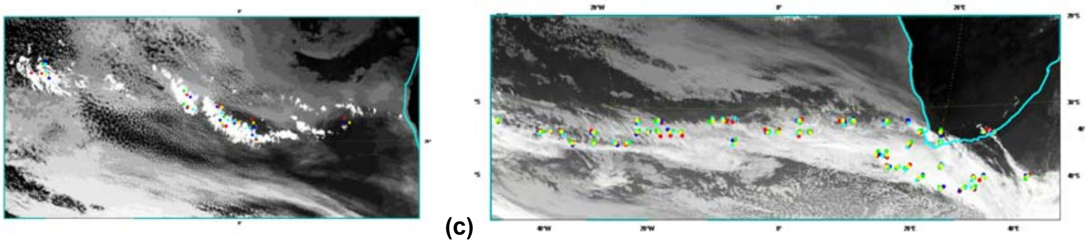
(a) (b) (c

Figure 5: **Cluster 4 AMVs map**

Cluster 5 is including winds with speeds larger than 20m/s and placed by all producers as high. The agreement in terms of both speed and height is good. These winds are mapped in Figure 6(a). They are extracted from two different types of cloud features. The ones shown in Figure 6(b) are high equatorial winds from tracking the top of the well developed cumulus clouds. In comparison with Cluster 1 and 4, one may deduct that tracers in the tropics should be tracked only if they are part of a well developed cloud. An indication for the latter could be the homogeneity of the temperatures in the tracer box, or perhaps a stricter correlation requirement during the tracking.
Figure 6(c) and 6(d) show that the edges of well developed cumulus clouds or optically thick cirrus features in polar fronts/cyclones are a tracer for which all processing schemes tend to retrieve similar results and correctly classify as high level winds.



(a) (b)



(c) (d)

***Figure 6*: Cluster 5 AMVs map**

Regardless of the cloud features leading to extracting the AMVs, all winds with QI≥50 are disseminated to the users. The quality of each data set is first assessed through collocation against RAOBs. Table 2 presents the results for winds with QI≥50 and QI≥80. Increasing the QI threshold leads to slightly better agreement in terms of speed and vector RMS between EUMETSAT and NESDIS. The KMA statistics indicate their algorithm needs some improvement.

QI≥50	Number	SPDbias	SPDrms	DIRbias	Vrms
EUM	322	-1.17	5.54	0.66	7.25
NESDIS	802	-0.42	4.53	0.35	6.63
JMA	541	-3.21	8.05	3.30	9.34
BRZ	287	-1.28	7.32	3.47	10.52
KMA	175	-3.03	8.42	-11.67	12.57
QI≥80	Number	SPDbias	SPDrms	DIRbias	Vrms
EUM	205	-0.53	4.57	0.84	6.16
NESDIS	653	-0.17	4.40	-0.57	6.62
JMA	291	-1.57	7.42	0.24	8.64
BRZ	119	-0.07	6.34	-1.93	8.65
KMA	140	-2.57	7.53	-9.87	12.05

***Table 2:* Statistics from collocated RAOBs**

Finally, First Guess departures are calculated for each collocated dataset in order to assess the quality of each product against independent data.
First Guess departures are defined as the speed difference between an AMV and the collocated ECMWF model forecast. The First Guess speed departure results are presented in Table 3 for QI≥50, and in Table 4 for QI≥85.

QI≥50	**ALL**	**HIGH**	**MIDDLE**	**LOW**
EUMETSAT				
N	619	202	26	391
Mean	0.09	0.04	-0.97	0.19
Median	0.03	0.58	-0.59	-0.04
Std	3.04	4.28	2.75	2.14
NESDIS				
N	**619**	**196**	**47**	**376**
Mean	**0.23**	**-0.88**	**0.82**	**0.74**
Median	**0.22**	**-0.40**	**0.58**	**0.44**
Std	**3.58**	**4.83**	**3.61**	**2.53**
JMA				
N	619	187		413
Mean	-0.51	-2.39		0.27
Median	-0.44	-2.26		-0.03
Std	4.07	5.11		3.04

Brazil				
N	619	144	152	323
Mean	0.49	0.40	2.05	-0.20
Median	-0.24	-0.12	0.19	-0.42
Std	5.58	5.95	7.65	3.86
KMA				
N	619	254	35	330
Mean	-0.57	-2.60	2.91	0.61
Median	-0.19	-2.12	2.60	0.34
Std	5.48	6.85	8.15	2.74

Table 3: **First Guess Departures statistics, QI≥50; entries with a sample of less than 20 winds have been omitted**

When assimilating winds at ECMWF, one of the first screenings is by QI. NESDIS winds are screened by QI≥50 and EUMETSAT and JMA winds are screened by QI≥85. The thresholds have been determined after monitoring the quality of each product. The rest of the quality control is using the First Guess departures. For an approximate sample of what would pass the initial screening for AMVs at ECMWF, it is best to compare the results for NESDIS from Table 3 and the results for EUMETSAT and JMA from Table 4. They are shown in bold font. For **all** winds, EUMETSAT's First Guess departures show best agreement with the model. EUMETSAT's **low-level** winds and NEDIS's **mid-level** winds show the smallest departures.

CONCLUSIONS AND OUTLOOK

AMVs generated from a common MSG-SEVIRI dataset (18 August 2006) by five AMV producers – EUMETSAT, NOAA-NESDIS, JMA, KMA, and the Brazilian Meteorological services, were inter-compared.

A statistical analysis of the differences between these various datasets showed median values for the difference in speed, direction and pressure to be 2.99m/s, 22 deg and 175 hPa, respectively. It is recognized that the process of target selection remains important for the quality of retrieved AMVs, including the size of the target and search box sizes. AMV height assignment differences between operational producers are driven by numerous differences in algorithms - target box size, pixel selection for height assignment, height assignment method. The quality indicator remains the simplest, but efficient measure to screen out bad quality AMVs and to indicate consistency in the remaining winds. However, it would be beneficial if its implementation is revisited and unified across the AMV producing centers.

Using a common model forecast (JMA used their own model forecast) eliminated height assignment discrepancies introduced by temperature to pressure conversion. Retrieving AMVs on the model forecast grid explains the lower number of winds from Brazil and KMA. It is hard to interpret the differences in the assigned AMV altitudes when various target sizes are used.
Winds data sets retrieved using common target and search box sizes revealed that each producer's algorithm is finely tuned to a specific imagery temporal and spatial resolution, as well as target and search box sizes. The importance of the selection of pixels for height assignment was highlighted. This data was not used for further analysis.

Collocation with RAOBs shows EUMETSAT and NESDIS winds to be of similar quality, while JMA's speed bias, rms and vector rms are about 1m/s, 3m/s and 2m/s worse, correspondingly. Comparisons against ECMWF's First Guess show that EUMETSAT winds are superior at low levels, whereas NESDIS winds are superior at middle levels, and the two data sets are comparable for high level winds. JMA's FG departures mean and standard deviations are larger by 0.2m/s and 2m/s correspondingly. As a result of communicating the results from Part 1 to the producers, the following changes have been made:
- KMA improved their AMV algorithm (Cho H-J. et.al, 2008, E-H. Sohn, personal communication);

- JMA implemented new target and search box sizes, improved tracking, and a new pixel selection approach for the height assignment (R.Oyama and K. Shimoji, personal communication);
- NESDIS is revisiting the low level inversion correction, but this will probably be implemented with the GOES-R algorithms;
- EUMETSAT is testing a new pixel selection approach for the height assignment and is developing a new cloud classification product.

QI≥85	**ALL**	**HIGH**	**MIDDLE**	**LOW**
EUMETSAT				
N	**439**	**136**		**293**
Mean	**0.27**	**0.75**		**0.13**
Median	**0.15**	**1.12**		**0.03**
Std	**2.66**	**4.08**		**1.52**
NESDIS				
N	516	164	30	322
Mean	0.53	-0.29	1.39	0.87
Median	0.57	0.08	1.43	0.60
Std	3.51	4.75	3.46	2.58
JMA				
N	**366**	**132**		**227**
Mean	**-0.46**	**-2.30**		**0.59**
Median	**-0.37**	**-2.24**		**0.16**
Std	**4.39**	**5.38**		**3.15**
Brazil				
N	425	93	99	233
Mean	0.57	0.89	2.93	-0.56
Median	-0.32	0.00	0.97	-0.71
Std	5.83	6.02	8.26	3.90
KMA				
N	552	229	25	298
Mean	-0.49	-2.37	2.68	0.67
Median	-0.14	-2.06	2.69	0.42
Std	5.33	6.88	7.27	2.69

Table 4: **First Guess Departures statistics, QI≥85; entries with a sample of less than 20 winds have been omitted**

Since some operational algorithms have changed during the course of the study, it will be beneficial if the study is repeated, and the results updated. As the analysis approach and tools are already developed, it should be faster to conduct the study with new data. Should the producers encourage it, such study could be repeated periodically (bi-annualy) and serve as a long term global AMV quality monitoring mean.

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