CGMS-37 EUM-WP-26
v1, 2 October 2009
Prepared by EUMETSAT
Agenda Item: WG II/5
Discussed in WGII

# INTERNATIONAL OPERATIONAL AMV ALGORITHMS COMPARISON STUDY FINAL REPORT

In response to CGMS Action 36.18

This paper is the final report from the international operational AMV algorithms comparison study proposed at the 8th International Winds Workshop and formulated as Recommendation 34.15 at the 34th CGMS meeting, and as Action 36.18 at the 36th CGMS meeting. The Study is completed and the results are presented in this document. The Study suggests periodic operational AMV algorithm comparisons as a means of long-term AMV quality monitoring.

Recommendation proposed:

CGMS to consider periodic updates of this study as part of a long-term effort towards a consistent quality of AMVs from different providers of AMV products.

# International Operational AMV Algorithms Comparison Study

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## 1 INTRODUCTION

Atmospheric Motion Vectors (AMVs) have been assimilated routinely for years by many weather prediction centers. The AMV data disseminated by the producers undergo a number of quality control steps including: (i) quality indicator (QI) and/or recursive filter function (RFF) threshold-based AMV pre-selection, (ii) spatial blacklisting, (iii) spatial and temporal thinning and (iv) a check against model background. The lack of 1) in depth understanding of the impact of algorithm differences on AMV quality from different centers and 2) individual AMV error estimates from the producers was the motivating force for this first of its kind study. A prerequisite for the study were the multi-channel observations from MSG which provides a data set to test all existing operational height assignment methods.

Part 1 of the study (a.k.a. CGMS-1 Study) 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, firstly with the operationally used first guess forecast model, and secondly with the first guess forecast model from ECMWF.

Winds derived by the various producers from the 10.8 μm IR channel are inter-compared. Analysis focused on how the datasets compare in terms of coverage, speed, direction, height assignment and quality indicators. In addition the impact of the choice of first guess forecast initiating the AMV extraction was assessed. The aim is to identify best practice for the retrieval algorithm through identifying strengths and weaknesses of the existing approaches. This should lead to improved AMV data quality and reduced differences between derivation methods at different centres (preferable for NWP). The results were reported in "Global Atmospheric Motion Vector Inter-Comparison Study" by Iliana Genkova, Régis Borde, Johannes Schmetz, Kenneth Holmlund, Jaime Daniels, Chris Velden, 9th International Winds Workshop, Annapolis, Maryland, USA, April 2008, EUMETSAT P.51.

In Part 2 of the study (a.k.a. CGMS-2 Study) 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 will 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 of the study is using the AMVs produced during Part 1 for a further analysis of the links between AMV height assignment, AMV speed and the corresponding tracked cloud features. It additionally assesses the quality of each AMV data set through comparisons with (1) collocated RAOBs and (2) the ECMWF model forecast wind field.

## 2 RESULTS AND ANALYSIS

**Part 1. See** "Global Atmospheric Motion Vector Inter-Comparison Study" by Iliana Genkova, Régis Borde, Johannes Schmetz, Kenneth Holmlund, Jaime Daniels, Chris Velden, 9th International Winds Workshop, Annapolis, Maryland, USA, April 2008, EUMETSAT P.51.

**Part 2.**

In the second part of the global international operational AMV algorithms comparison study the producers used the same SEVIRI imagery as in Part 1, but applied their own operational wind retrieval algorithm using a target box size of 24x24 pixels and a search box size of 80x80 pixels. The aim was 1) to attempt to reconcile the differences in AMV height assignment and 2) to understand how consistent the QI implementation is when AMVs are derived on the same spatial grid. The AMVs were derived from the IR (10.8micron) spectral band using forecast model data from ECMWF. The 00:15 UTC image is used for AMV height assignment (when algorithm permits).

Table 1 presents the bulk statistics of each AMV data set from Part 2. Only winds with QI greater than or equal to 50 are included.

| IR-10.8 | EUM | NESDIS | Brazil | JMA | KMA |
|---|---|---|---|---|---|
| Total num AMV | 10775 | 4019 | 10128 | 10464 | 17082 |
| Winds QI>=50 | 7506 | 4019 | 5759 | 9786 | 12684 |
| Winds QI>=80 | 5099 | 2541 | 3869 | 6488 | 6037 |
| *****************For AMV with QI>=50 ***************************** | | | | | |
| SPD min | 2.50 | 4.00 | 3.04 | 2.5 | 2.61 |
| SPD max | 81.60 | 89.10 | 110.25 | 82.25 | 135.27 |
| SPD mean | 13.18 | 14.40 | 14.70 | 13.72 | 12.85 |
| P min | 102.17 | 137.00 | 105.00 | 129.18 | 20.00 |
| P max | 1008.5 | 925.00 | 900.00 | 996.28 | 999.00 |
| P mean | 669.27 | 537.7 | 612.17 | 724.81 | 650.64 |
| Low winds% | 57.73 | 43.15 | 47.54 | 74.45 | 55.18 |
| Mid winds% | 11.62 | 13.31 | 34.24 | 2.84 | 24.09 |
| High winds% | 30.66 | 43.54 | 18.21 | 22.71 | 20.73 |
| Low SPD min | 2.50 | 4.00 | 3.04 | 2.50 | 2.89 |
| Low SPD max | 50.59 | 26.50 | 97.92 | 52.33 | 91.85 |
| Low SPD mean | 8.09 | 8.53 | 9.12 | 8.96 | 8.76 |
| Low P min | 700.63 | 700.00 | 700.00 | 720.98 | 700.02 |
| Low P max | 1008.5 | 925.00 | 900.00 | 996.28 | 999.00 |
| Low P mean | 906.65 | 808.39 | 770.85 | 869.40 | 825.92 |
| Mid SPD min | 2.50 | 4.00 | 3.04 | 2.63 | 2.61 |
| Mid SPD max | 81.60 | 64.30 | 72.90 | 60.96 | 81.47 |
| Mid SPD mean | 15.53 | 13.67 | 15.74 | 18.07 | 16.93 |
| Mid P min | 400.13 | 412.00 | 401.00 | 400.44 | 400.18 |
| Mid P max | 698.77 | 687.00 | 699.00 | 697.26 | 699.99 |
| Mid P mean | 495.49 | 519.94 | 573.94 | 470.63 | 578.29 |
| High SPD min | 2.52 | 4.00 | 3.48 | 2.53 | 2.89 |
| High SPD max | 81.19 | 89.10 | 110.25 | 82.25 | 135.27 |
| High SPD mean | 21.88 | 20.43 | 27.07 | 28.79 | 18.97 |
| High P min | 102.17 | 137.00 | 105.00 | 129.18 | 20.00 |
| High P max | 399.93 | 400.00 | 400.00 | 399.25 | 399.81 |
| High P mean | 288.11 | 275.90 | 297.30 | 282.52 | 268.10 |

**Table 1.** Statistical summary of the AMV datasets with target/search box 24/80 pixels.

The statistics in Table 1 show that some outliers remain in the dataset even after a cut-off threshold of QI=50 is applied. For example, P min reported by KMA is 20 hPA, while all other producers P min values are around 100 hPa. KMA's data set has the highest SPD max, while it shows the slowest SPD max in study CGMS-1. Brazil and KMA report consistently extremely high Low level wind SPD max. KMA also reports a very high number of AMVs compared to the Part 1 study. JMA's amount of mid-level winds remains low compared to the other AMV producers. Finally, the NESDIS/CIMSS algorithm had to be altered in order to accommodate the larger target and search box sizes, as the correlation requirements during the tracking step are very strict.

When compared to the statistical summary from CGMS-1, the results from Table 1 imply that the operational algorithms are very finely tuned to one specific setup of tracer and search area size, and also probably to the imagery's spatial and temporal resolution (in the tracking routines). Because the target and search boxes are the same, we hypothesize that the difference in AMV heights are more related to differences in pixel selection for the height assignment and differences in the height assignment methods used. The pixel selection approaches are summarized in Table 2. The higher number of outliers in the datasets from study Part 2, and the reduced consistency across the AMV fields suggests that it is better to focus on the results from study Part 1, as they are extracted from the producers' algorithms at their best settings.

**Table 2.** Specifics of AMV retrieval schemes used by the various AMV producers

| 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. |

**Part 3.**
The datasets are collocated such that the distance between matched AMVs is equal or less than 0.5 deg in longitude and latitude, 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 JMA, our conclusions mainly pertain to low and high clouds. A map of the collocated AMVs is shown in Figure 1.

Similar to Figure 7 in the Status Report ("Global Atmospheric Motion Vector Inter-Comparison Study" by I. Genkova, R. Borde, J. Schmetz, K. Holmlund, J. Daniels, C. Velden, 9th International Winds Workshop, Annapolis, Maryland, USA, April 2008, EUMETSAT P.51, in Figure 2 we plot the speed, direction, height and quality indicator comparison for the collocated winds. They are plotted in increasing speed order, as this facilitates the recognition of a number of clusters in terms of AMV altitude. We will focus on each of them below.

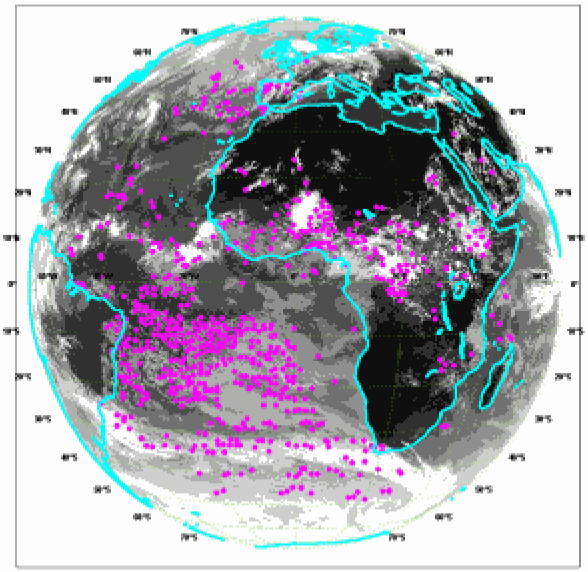


**Figure 1**. Map of the collocated AMVs retrieved by all producers

In KMA's and Brazil's data sets there are a number of AMVs with erroneous direction DIR=90deg. As most of the AMVs have properly assigned directions, we assume that this is an occasional numerical problem. The speed and the altitude for these winds are reasonable, so they are kept in the collocated dataset.

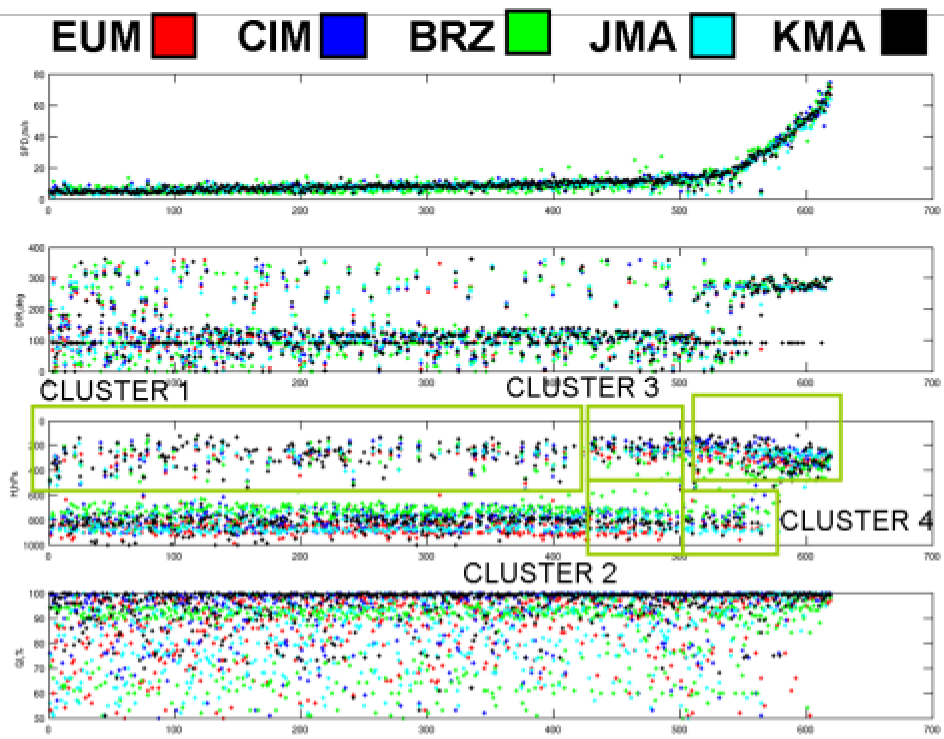
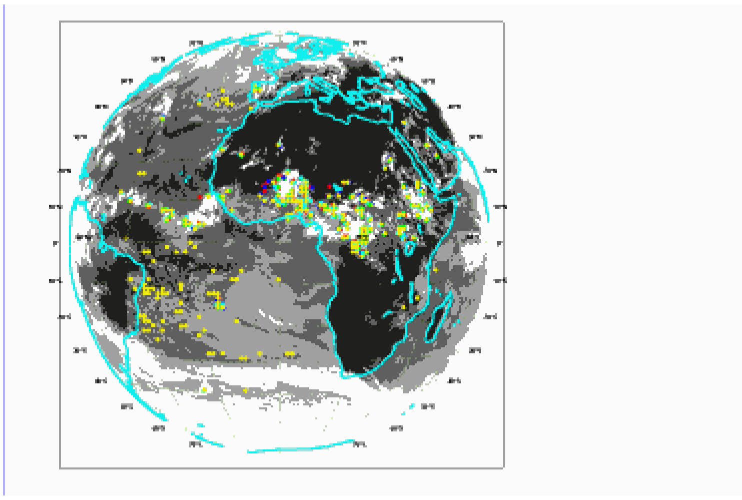
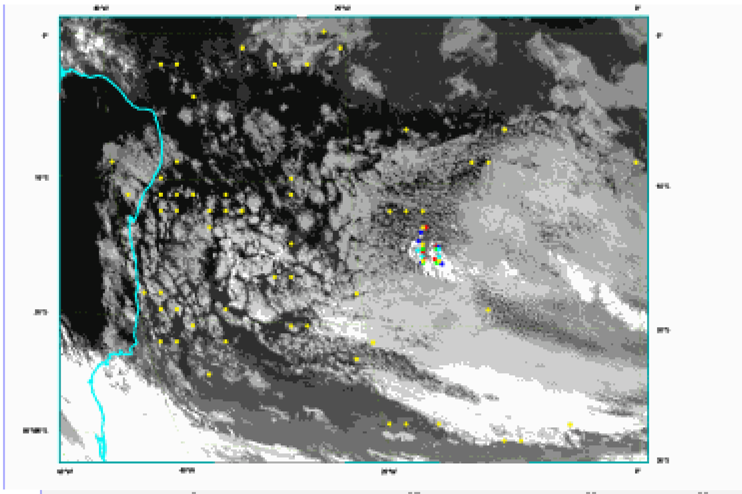


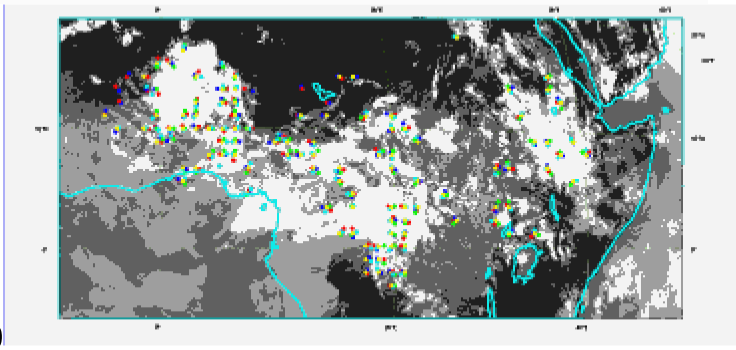

**Figure 2.** Speed, Direction, AMV height and QI for the collocated dataset of AMVs with QI≥50

Cluster 1 comprises of high level winds with speeds <15m/s. There is a large range in assigned pressures between centers. The map in Figure 3 (a) and the detailed maps in Figure 3 (b) and (c) illustrate the location of AMVs from this cluster.



(a)





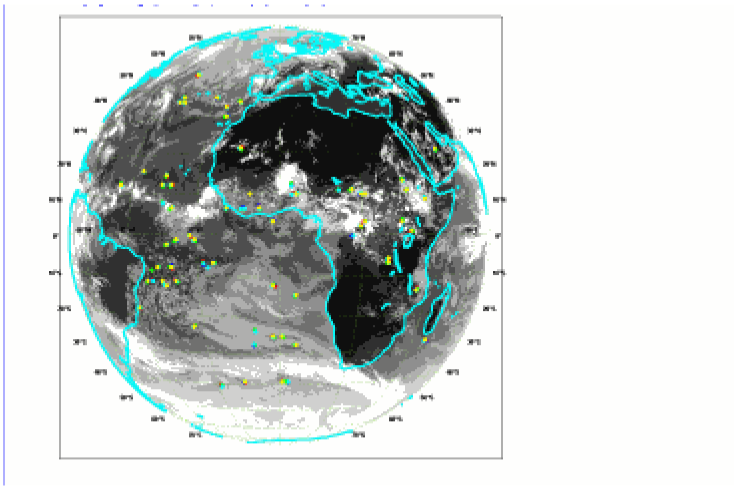
(b) (c)

**Figure 3.** Cluster 1 maps. The same colours are used as in Figure 2, with the exception of KMA, which is shown in yellow.

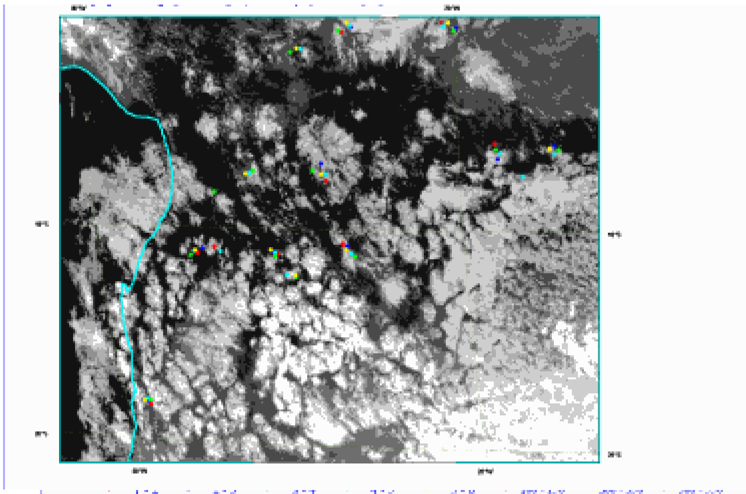
Figure 3(b) illustrates that some AMVs from Cluster 1 - mainly from KMA, are erroneously assigned to too high an altitude. Others, shown in Figure 3(c), appear to be placed well. These winds are extracted from tracking convective, vertically developed high cumulus in the equatorial belt. They may, however be from tracking the expansion/ growth of the clouds, thus the speed may not be representative of an air mass motion on a large scale.

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 on Figure 2).

The low level winds, Cluster 2, are mapped on Figure 4. They are derived either from tracking low marine cumulus, see Figure 4(b), or from the lower surroundings of growing or dissipating vertically developing cumulus - Figure 4(c). These winds are similar to the majority of the collocated winds which have speeds <20m/s, and are placed in the range 600-1000hPa. The altitude difference between 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.



(a)



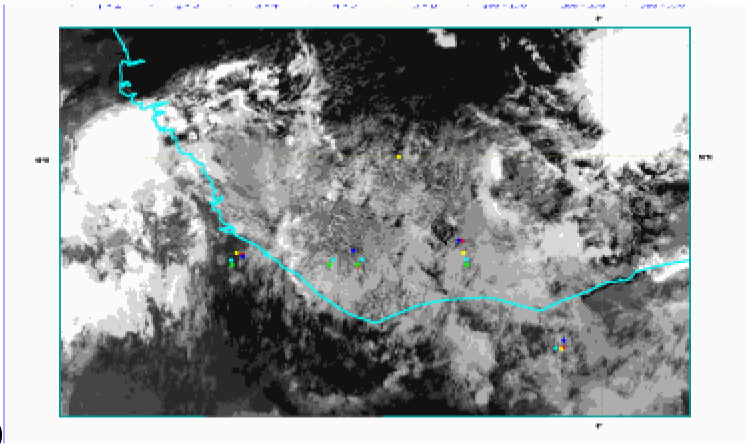
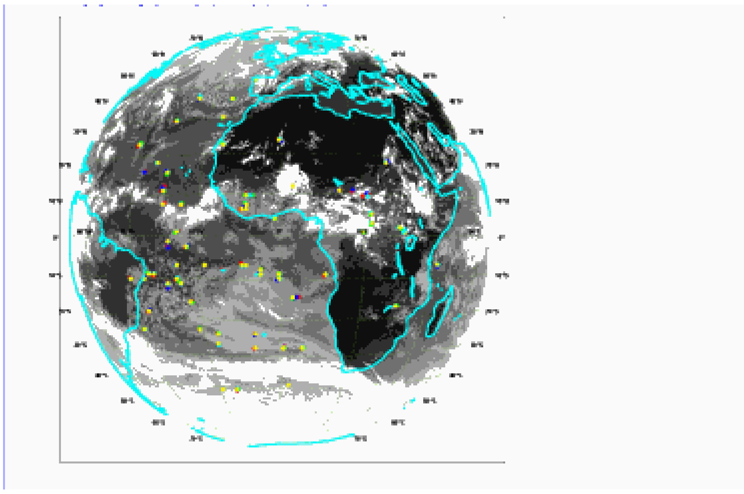
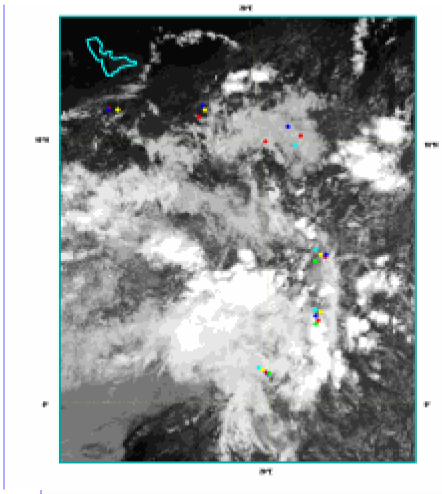
(b)  (c)

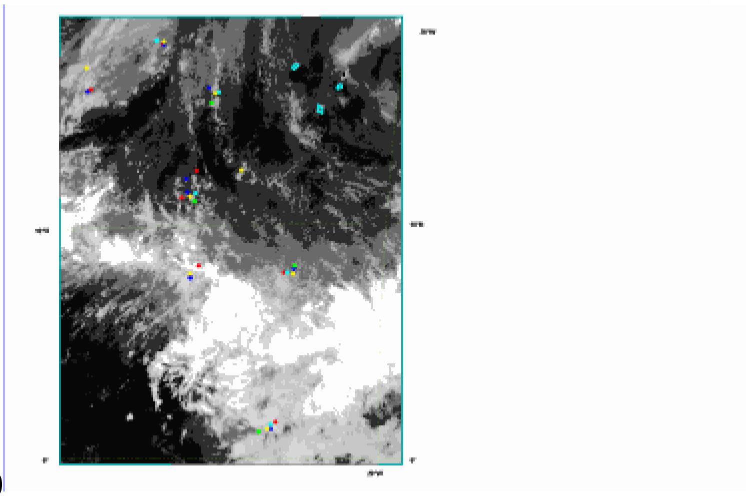
**Figure 4**. Cluster 2 maps. The same colours are used as in Figure 2, with the exception of KMA, which is shown in yellow

Cluster 3 includes winds from tracking a range of cloud type features, and as the map on Figure 5(a) shows there is no zonal preference.  Some winds come from tracking convective features similar to Cluster 1, thus, they are indeed high winds. Others - Figure 5 (b and c), seem to be lower in the atmosphere, but they are assigned as high winds. This could 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)

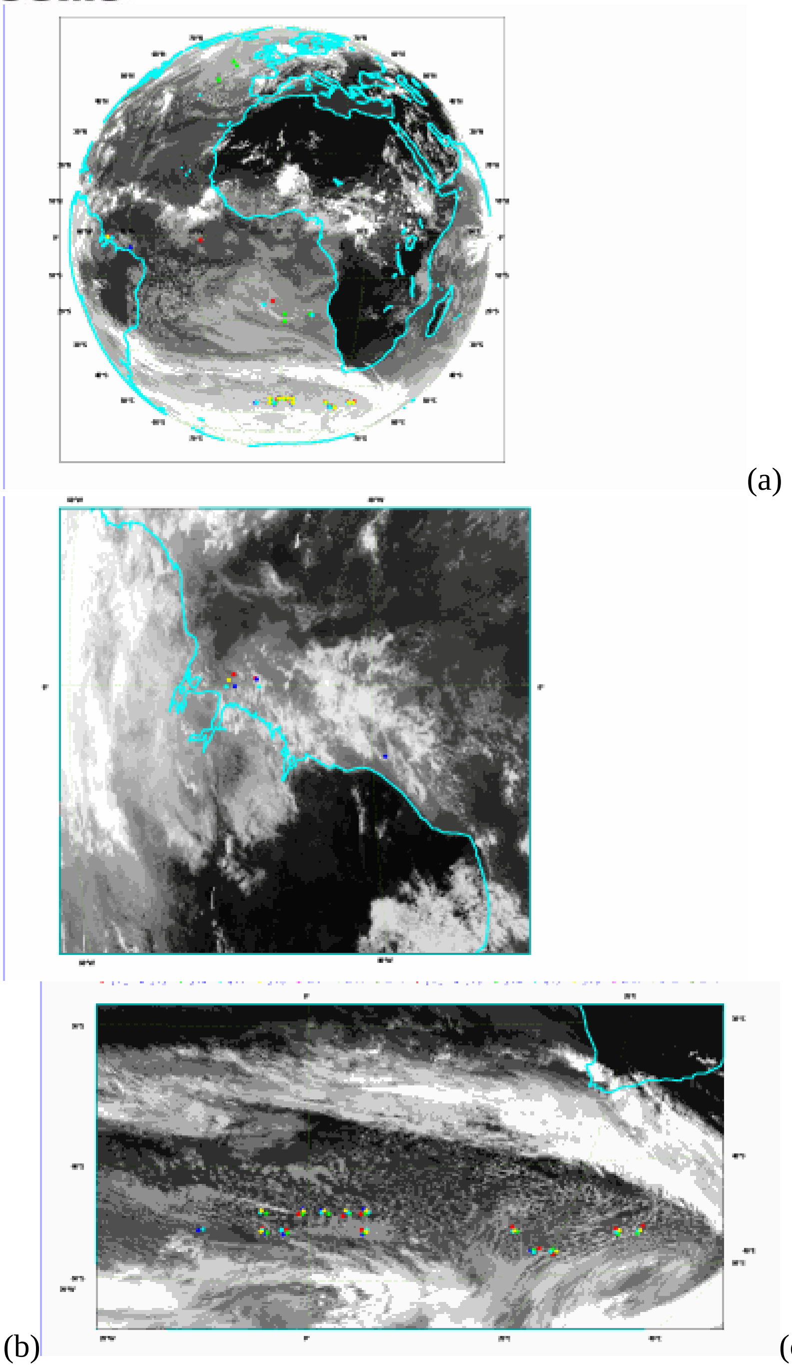




(b) (c)

**Figure 5**. Cluster 3 maps. The same colours are used as in Figure 2, with the exception of KMA, which is shown in yellow.

Cluster 4 includes faster (speeds > 20m/s) low clouds, as shown in Figure 6(a).
Their altitude appears reasonable. Figure 6(b) is an example of westerly trades and Figure 6(c) some faster moving marine cumulus, possibly part of a polar front.



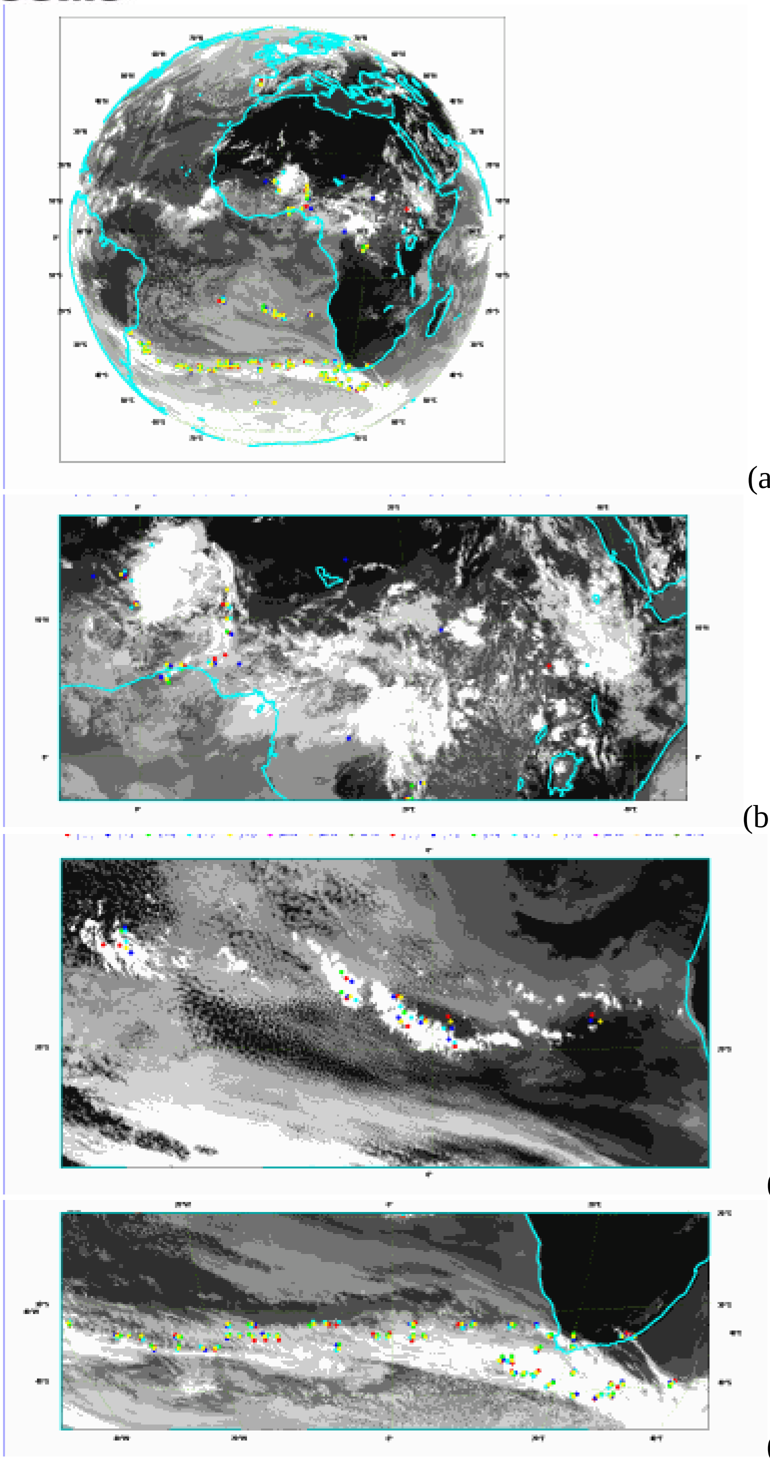
(a)

(b) (c)

**Figure 6.** Cluster 4 maps. The same colours are used as in Figure 2, with the exception of KMA, which is shown in yellow.

Cluster 5 includes winds with speeds larger than 20 m/s and placed by all producers as high. The agreement in terms of both speed and height is good. These winds are mapped on Figure 7(a). They are extracted from two different types of cloud feature. The ones shown on Figure 7(b) are high equatorial winds from tracking the top of well developed cumulus clouds. In comparison with Cluster 1 and 4, one may deduce that tracers in the tropics should be tracked only if they are part of a well developed cloud. Indicators for the latter could be homogeneity of the temperatures in the tracer box, or perhaps stricter correlation requirement during the tracking.

Figure 7(c) and 7(d) show that another reliable tracer is the edges of well developed cumulus clouds or optically thick cirrus features in polar fronts/cyclones.



(a)

(b)

(c)

(d)

**Figure 7.** Cluster 5 maps. The same colours are used as in Figure 2, with the exception of KMA, which is shown in yellow.

To better understand differences in the quality of the AMV datasets, they are first compared against collocated RAOBs. Table 3 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.

**Table 3.** Statistics from collocated RAOBs

| **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 |

The collocated datasets are additionally compared against ECMWF model first guess winds. To do so, it is assumed that the AMV heights are correct. The first guess speed departure results are presented in Table 4 for QI≥50, and in Table 5 for QI≥85.

**Table 4.** First Guess Departures statistics, QI≥50

| *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 | 19 | 413 |
| Mean | -0.51 | -2.39 | 0.83 | 0.27 |
| Median | -0.44 | -2.26 | 0.20 | -0.03 |
| Std | 4.07 | 5.11 | 5.80 | 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 5.** First Guess Departures statistics, QI≥85

| *QI≥85* | ALL | HIGH | MIDDLE | LOW |
|---|---|---|---|---|
| **EUMETSAT** | | | | |
| N | 439 | 136 | 10 | 293 |
| Mean | 0.27 | 0.75 | -2.27 | 0.13 |
| Median | 0.15 | 1.12 | -1.67 | 0.03 |
| Std | 2.66 | 4.08 | 3.07 | 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 | 7 | 227 |
| Mean | -0.46 | -2.30 | 0.04 | 0.59 |
| Median | -0.37 | -2.24 | -0.86 | 0.16 |
| Std | 4.39 | 5.38 | 7.00 | 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 |

For all height bands, EUMETSAT's AMVs show smallest standard deviations, although not always the smallest bias. It should, however, be emphasised that EUMETSAT have designed their system to work with SEVIRI imagery, so may have an advantage over the other centres.

## 3 FINAL 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 service, were compared. A statistical analysis of the differences between these various datasets showed median values for the differences 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. 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.

Datasets retrieved using common target and search box sizes revealed that is the different algorithms are finely tuned to 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.

First Guess departure analysis shows that EUMETSAT winds are superior at low levels, and the two datasets are more comparable at mid and high levels. JMA's FG departures mean and standard deviations are larger by 0.2m/s and 2m/s.

As a result of communicating the results from Part 1 Study with the producers, the following changes have been made:

- KMA improved AMV algorithm was presented at the 2008 EUMETSAT conference;
- JMA implemented new target and search box sizes, improved tracking, and a new pixel selection approach for the height assignment;
- NESDIS is revisiting the low level inversion correction;
- EUMETSAT is testing a new pixel selection approach for the height assignment and is developing a new cloud classification product.

It is recognised that we may benefit from repeating this study at intervals as a means to monitor developments to the AMV algorithms at different centers. As analysis approach and tools are already developed, it should be faster to conduct the study with new data. Should CGMS members encourage it, such a study could be repeated periodically (bi-annually) and serve as a means for long term global AMV quality monitoring.