# GLOBAL ATMOSPHERIC MOTION VECTOR INTER-COMPARISON STUDY

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**Abstract**

Atmospheric Motion Vectors (AMVs) are amongst the data assimilated routinely by a number of weather prediction centres. The raw AMV data sets undergo various thinning, quality indicator (QI) and/or recursive filter function (RFF) threshold-based AMV pre-selection or a similar quality control routine. Until now all AMV producers disseminate their data without an in depth understanding of how consistent all the data sets are, how algorithm tuning impact the results, are the quality indicator routines implemented in a consistent fashion etc. Some of these issues will be addressed in our study.

Five AMV producers retrieved AMVs from one MSG-SEVIRI image triplet applying their own retrieval algorithm as it is used in operations and the same first guess forecast model from ECMWF is employed. Winds from the 10.8 μm IR channel are inter-compared with regard to spatial coherence, agreement in height assignment, quality indicator agreement. With this study we hope to assess how the various AMV producer's data inter-compare, recognize the strengths and weaknesses of each retrieval algorithm, and suggest how to better interpret the winds sets prior and during their assimilation into NWP models.

## MOTIVATION AND STUDY SETUP

A number of meteorological centers have been retrieving Atmospheric Motion Vectors for years (Velden et. al., 2005). To this date, their products have not been juxtaposed in a coordinated study and on a global scale. From the various recommendations formulated during the 8th International Winds Workshop (April 2006, Beijing, China), the CGMS-34 concluded and formulated the following action: *"Recommendation 34.15: There should be a comparison of the operational algorithms of all satellite wind producers for the height assignment of AMVs from clouds using a common data set from SEVIRI on MSG, and the same ancillary data."* To address the quoted recommendations, the IWW community invited all AMV producers to participate in a Global atmospheric motion vector inter-comparison study.

For the study a triplet of SEVIRI images (18 August 2006, 12UTC - 13 UTC) and the corresponding ECMWF model forecast were provided to the AMV producers to apply their own AMV retrieval algorithms, with their own operational settings, using VIS (0.8μm), IR (10.8μm), IR (13.4μm), WV (6.2μm) and WV (7.3μm) spectral bands. One of the triplet images is shown on Figure 1. It is a SEVIRI full disk image from 18 August 2006, 12:15 UTC, band 9 = 10.8μm. This full disk image shows a typical cloud coverage over Europe and Africa – mostly convective development and anvil Ci over the tropics, low level marine cumulus over the ocean, and a variety of clouds are observed in the mid to high latitudes. Producers first used the provided by EUMETSAT forecast model data from ECMWF to derive AMVs. The resulting winds datasets were collected from six AMV producers – EUMETSAT, NESDIS/CIMSS, Brazilian Meteorological services, Japanese Meteorological Agency (JMA), Korean Meteorological Agency (KMA) and Spanish Meteorological services. From all proposed spectral bands, only 10.8μm and 6.2μm were derived by all producers excluding Spain. Thus, in this paper we will focus and report results from the analysis of the 10.8μm winds. Future work will analyse the winds from 6.2μm band imagery as well and the high resolution visible band 12.

## RESULTS AND ANALYSIS

All AMV producing centres participating in the study - EUMETSAT, CIMSS/NESDIS, Brazil, JMA and KMA, submitted for each wind vector derived from the 10.8μm imagery: latitudinal and longitudinal location, the algorithms target and search box sizes in pixels, AMV speed and direction, brightness temperature, assigned altitude (pressure), corresponding guess speed and direction, height assignment method, and forecast independent quality indicator (QI).

Operational AMV extraction schemes usually track cloud or water vapour features in subsequent images. Despite that commonality, the individual AMV producer centres retrieval algorithms are different in many aspects. A summary of the differences is presented in Table 1. The major differences are first, in the order of performing target selection, tracking and height assignment, and second, in the selection of pixels from the target for AMV height assignment. NESDIS/CIMSS is the only team that assigns a height to a target from the second image in the triplet and then performs the tracking step. The other teams select a target form the first image in the triplet, track it through the sequence and then assign height to it. At the height assignment step, EUMETSAT (at the time of the study runs) builds a histogram of the target pixels CTP and selects the coldest peak of the distribution to be AMV height. Such heights are calculated for the two intermediate products and then an average of the two is assigned to the final AMV. NESDIS/CIMSS uses the second image in the triplet for height assignment. The 25% coldest pixels are used to calculate a mean radiance and retrieve an effective altitude for the AMV. Brazil and KMA follow the approach adopted by NESDIS/CIMSS, however they use 10% and 15% of the coldest pixels, correspondingly. JMA has adopted the EUMETSAT retrieval steps order; however for the height assignment they use the most frequent of the target pixels cloud top heights.

Another important difference among the inter-compared retrievals is the implementation of the QI. NESDIS and CIMSS in general calculate the QI after winds from all spectral bands are extracted. Thus there is a denser AMV coverage to look for buddies from. Intermediate wind vector QI is not calculated. EUMETSAT, KMA, Brazil and JMA calculate QI for the intermediate products, and aside from JMA, which uses second intermediate vector and its QI only, they do averaging of the intermediate vectors and QIs.

***Table 1*. AMV retrieval schemes specifics**

| 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. |

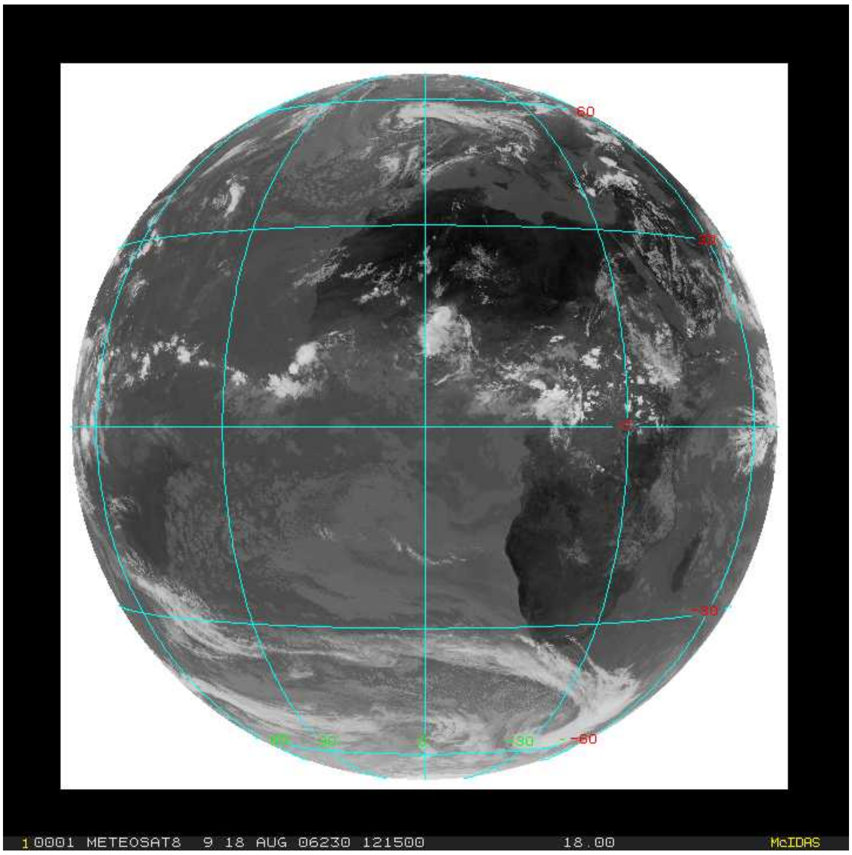



***Figure 1.*** **MSG SEVIRI full disk image, 18 August 2006, 12:15 UTC, band 9 (10.8μm)**

Figures 2-6 illustrate each data sets' spatial distribution of vectors of all qualities, as well as the frequency distribution for the quality indicator (QI), speed (SPD), direction (DIR), height (H) and heights assignment method (HAM). Employed are the following height assignment methods: 0= EBBT (i.e. IR channel method), 1=CO2 slicing, 2=STC/IR rationing method, 3=Other method. Table 2 offers a statistical representation of the inter-compared winds datasets. In general, the data sets exhibit similar histogram shapes, number and location of maxima. Bulk statistics (see Table 2) support this observation. CIMSS QI have significantly higher values than the rest, due to fact that target do not follow a model grid distribution, thus the distance check component from QI is contributing more as the distances at non-gridded AMV locations are shorter. Also, CIMSS/NESDIS pre-screen targets, thus only high contrast targets (more than 7 brightness units) are processed; hence winds are expected to be better due to algorithm specifics.

KMA's number of winds is significantly lower. Most probably, this is associated with threshold requirement for selecting a target and following a model grid for target's location. It is also interesting that KMA reports a significantly lower amount of mid level clouds. This may be due to erroneous high assignment. Brazil's lower value for low winds Pmean is due to not applying a low level inversion correction. Similar explanation could be attributed to CIMSS slightly higher low level winds mean altitude. Every data set has its own low limit for reliable speed retrieval, and this governs the slight differences in mean speed. The noticeably high speed retrieved for low level winds is obviously unrealistic and evidence for wrong height assignments in situations such as thin cirrus clouds over lower cloud decks, when the fast speed of the cirrus is assigned to a low warm cloud dominating the value of the brightness temperature. CIMSS/NESDISS and EUMETSAT retrievals seem to handle best such cases thanks to adopting algorithm checks for multilayer scenes.

The statistics shown in Table 2 are calculated for winds with QI equal or greater than 50.

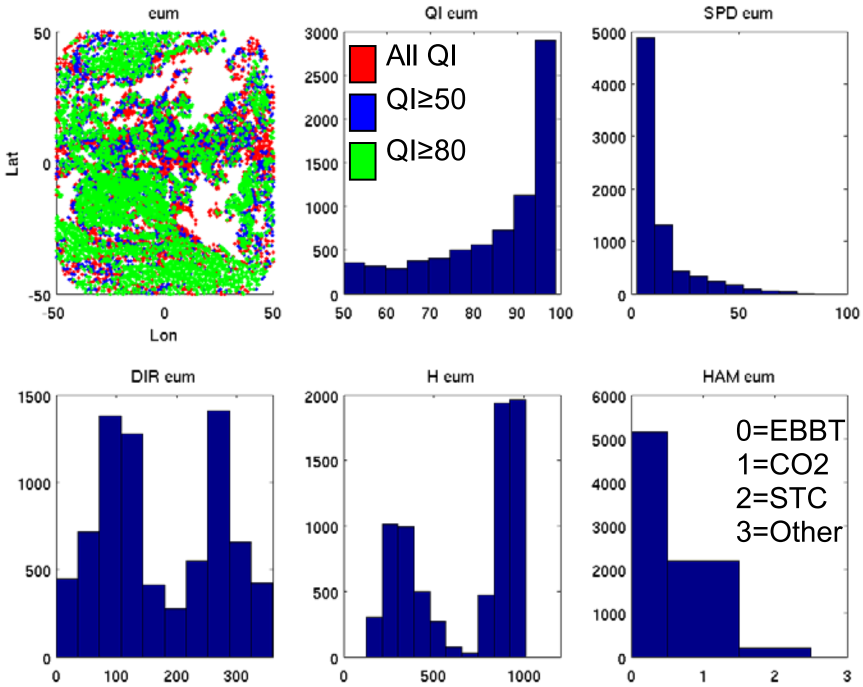



***Figure 2.*** **Spatial distribution of all AMVs (red), AMVs with QI≥50 (blue) and AMVs with QI≥80 (green) (top left panel); QI distribution (top middle panel); Speed (m/s) distribution (top right panel); Direction (deg) distribution (bottom left panel); AMV Pressure (hPa) (bottom middle panel) and Height Assignment Method (HAM) (bottom right panel) for EUMETSAT's IR10.8 winds from 18 August 2006, 12:15 UTC.**

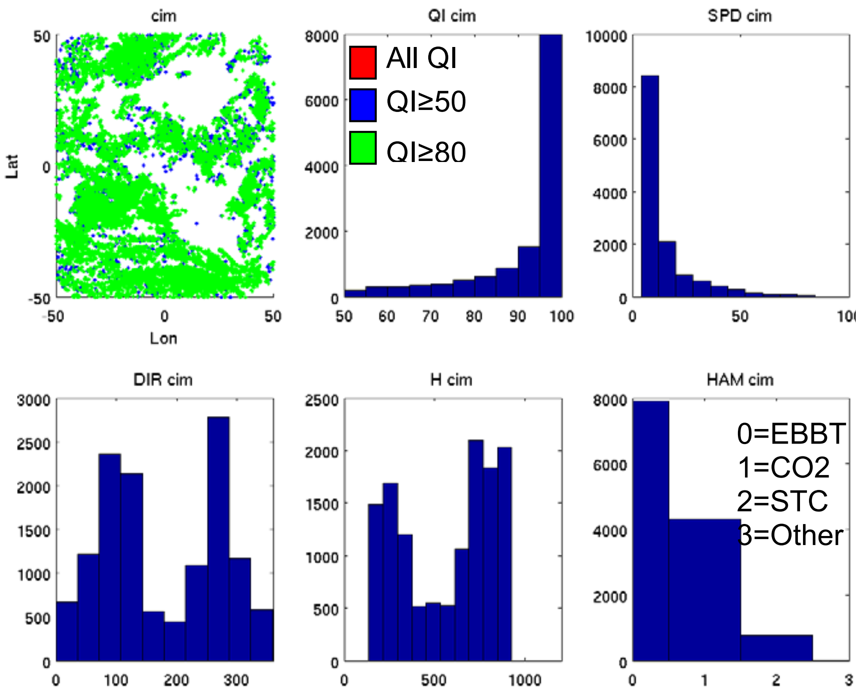



***Figure 3.*** **Same as Figure 2, but for NESDIS/CIMSS winds dataset**

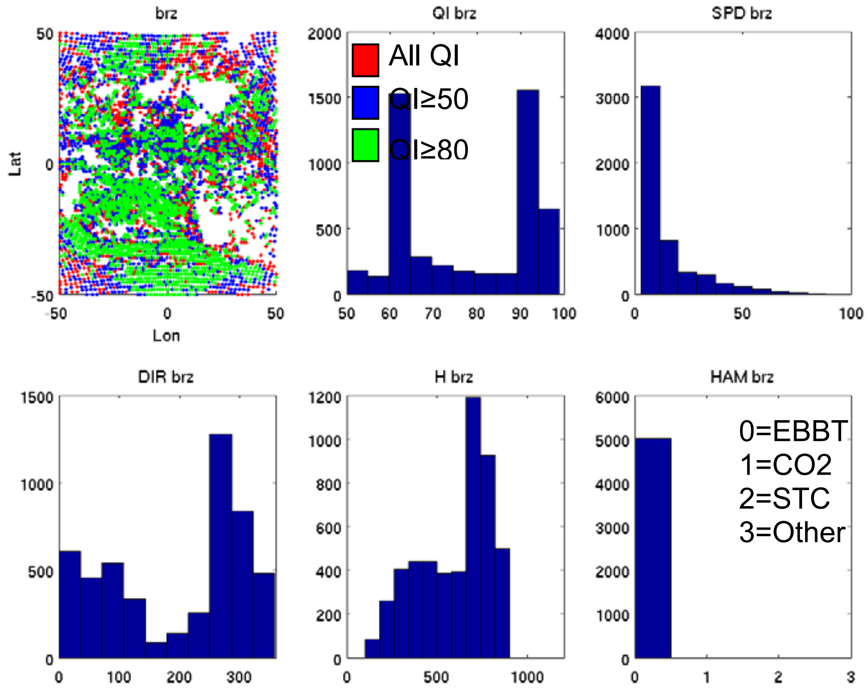



***Figure 4.*** **Same as Figure 2, but for Brazil winds dataset**

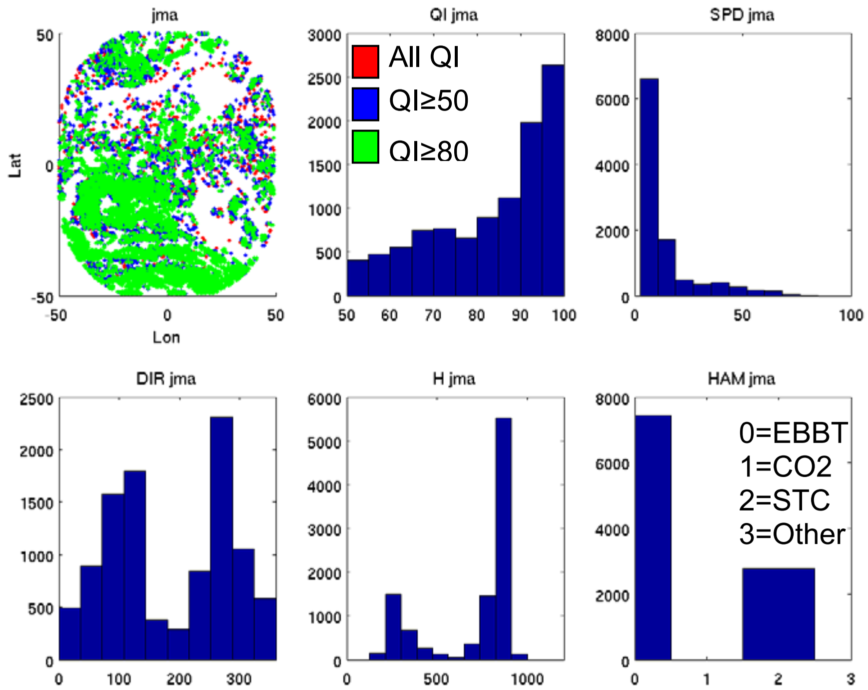



***Figure 5.*** **Same as Figure 2, but for JMA winds dataset**

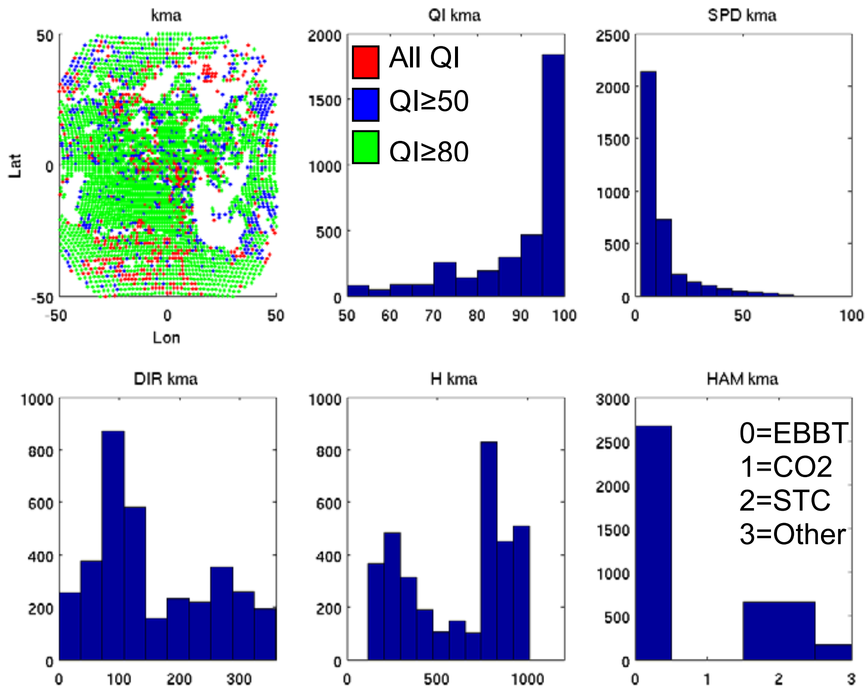



***Figure 6.*** **Same as Figure 2, but for KMA winds dataset**

Next, the datasets are collocated such that the distance between matched AMVs is equal 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 647 AMVs. Note that because of the very few mid level winds from KMA, our conclusions from here on will pertain mostly to low and highs clouds. Figure 7 depicts the speed, direction, height and quality indicator comparison for the collocated winds.

Best agreement is observed for the speed, with increasing divergence for faster winds. The difference in speeds retrieved by all producers for a single AMV match could vary from 0 and 25.34 m/s, and the median value is 2.99m/s. The median directional difference is 22.6 deg. However it is worth noticing that KMA is contributing most to it, due to an unexplained high number of winds with 90 degree direction. This will be investigated further. The winds altitude comparison on Figure 7 shows as mentioned earlier that EUMETESAT heights for low clouds have the lowest values due to low level correction applied to all AMVs. JMA is implementing a low level correction as well. The rest of the teams are advised to reconsider adding such a routine to their retrievals or revise their current implementation in order to conduct a fairer comparison of the low level wind heights. For high clouds the pressure spread is larger, but no tendencies are observed. Height discrepancies are as little as 20hPa and as large as 747 hPa, and the median value is 175 hPa.

A valuable, but surprising finding of this comparison is the large spread of QI values for each matched wind despite the reasonable agreement in speed, direction and height. Thus, using QI for data thinning and screening prior to data assimilation is probably not very efficient, as it will include winds of different quality. Despite all teams have followed Holmlund, 1998 paper to code their QI schemas, the particular implementation are different, see table 1. Thus, one major recommendation from this study is to review the QI implementation. Further more thorough investigation will guide the teams to reconcile the QI differences.

***Table 2*. Statistical depiction of the AMV datasets**

| | EUMETSAT | CIMSS/NESDIS | Brazil | JMA | KMA |
|---|---|---|---|---|---|
| Totalnumber AMV | 10775 | 13003 | 7051 | 11006 | 4072 |
| Winds QI>=50 | 7506 | 13003 | 5017 | 10216 | 3501 |
| Winds QI>=80 | 5099 | 11081 | 2503 | 6805 | 2819 |
| *For AMV with QI>=50* | | | | | |
| SPDmin | 2.50 | 4.00 | 3.04 | 2.5 | 2.51 |
| SPDmax | 81.60 | 84.20 | 88.50 | 84.66 | 73.30 |
| SPDmean | 13.18 | 14.41 | 14.19 | 13.79 | 12.08 |
| Pmin | 102.17 | 137.00 | 101.00 | 125.96 | 115.00 |
| Pmax | 1008.59 | 925.00 | 900.00 | 997.70 | 1009.98 |
| Pmean | 669.27 | 566.49 | 598.04 | 704.34 | 609.20 |
| Low winds (%) | 57.73 | 45.87 | 42.58 | 72.18 | 53.61 |
| Mid winds (%) | 11.62 | 18.81 | 36.14 | 4.33 | 12.11 |
| High winds (%) | 30.66 | 35.32 | 21.29 | 23.49 | 34.28 |
| LowSPDmin | 2.50 | 4.00 | 3.12 | 2.50 | 2.56 |
| LowSPDmax | 50.59 | 43.40 | 88.50 | 82.78 | 70.16 |
| LowSPDmean | 8.09 | 9.10 | 8.78 | 8.73 | 9.39 |
| LowPmin | 700.63 | 700.00 | 700.00 | 701.24 | 700.56 |
| LowPmax | 1008.59 | 925.00 | 900.00 | 997.70 | 1009.98 |
| LowPmean | 906.65 | 801.76 | 777.30 | 850.93 | 859.94 |
| MidSPDmin | 2.50 | 4.00 | 3.04 | 2.54 | 2.51 |
| MidSPDmax | 81.60 | 59.40 | 87.54 | 62.55 | 63.66 |
| MidSPDmean | 15.53 | 14.27 | 15.29 | 15.42 | 15.36 |
| MidPmin | 400.13 | 412.00 | 401.00 | 400.57 | 400.02 |
| MidPmax | 698.77 | 687.00 | 699.00 | 699.84 | 698.11 |
| MidPmean | 495.49 | 574.75 | 567.38 | 515.72 | 521.88 |
| HighSPDmin | 2.52 | 4.00 | 3.48 | 2.53 | 2.61 |
| HighSPDmax | 81.19 | 84.20 | 83.70 | 84.66 | 73.30 |
| HighSPDmean | 21.88 | 21.37 | 23.12 | 29.01 | 15.12 |
| HighPmin | 102.17 | 137.00 | 101.00 | 125.96 | 115.00 |
| HighPmax | 399.93 | 400.00 | 400.00 | 399.89 | 399.77 |
| HighPmean | 288.11 | 256.58 | 291.54 | 288.69 | 247.85 |

The last component of this study is to investigate how the winds heights intercompare. On Figure 8 the CIMSS/NESDIS, Brazil, JMA and KMA winds altitudes are plotted against the EUMETSAT heights shown on the x axis. For high clouds the linear correlation is quite good, except for a few outliers. For low clouds however, there is a significant amount of winds, derived by KMA, placed too high in the atmosphere. They are circled in a crossed red oval curve. Their locations on the full disk image are shown on Figure 9(a), thus illustrating what conditions are driving this strong disagreement. It is evident that over ocean areas the low clouds are assigned wrong heights. The reasons for this phenomenon will be investigated. Since there is a consistent cloud situation that is causing these wrong height assignments, we hope it could be addressed in further KMA HA version, and for this study we will exclude these data from the statistical analysis. The other distinct group of problematic cases is on the top left part of the plot and circled in red. Brazil, JMA and KMA have assigned mid level to low heights instead of high heights as EUMETSAT and CIMSS did. The spatial distribution on Figure 9(b) however shows that there are many and various condition causing this - broken clouds, cirrus clouds, convective regions, cloud edges, etc., thus it would probably be more difficult to address all these issues at once, so we will leave these data point as is. Finally, plotting a linear fit for each data set against the EUMETSAT winds derives the following fit equations:

| | |
|---|---|
| CIMSS | Y=0.8*x+34.1 |
| BRAZIL | Y=0.6*x+196.8 |
| JMA | Y=0.8*x+53.7 |
| KMA | Y=0.8*x+21.4 |

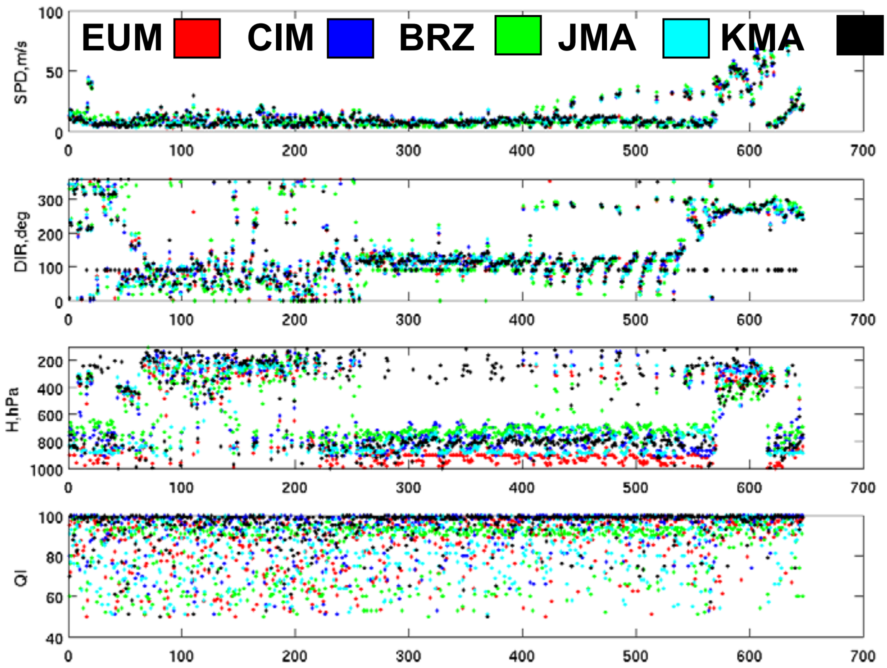



***Figure7***. **Speed, Direction, AMV Height and QI for the collocated dataset – only AMV with QI≥50 are used**

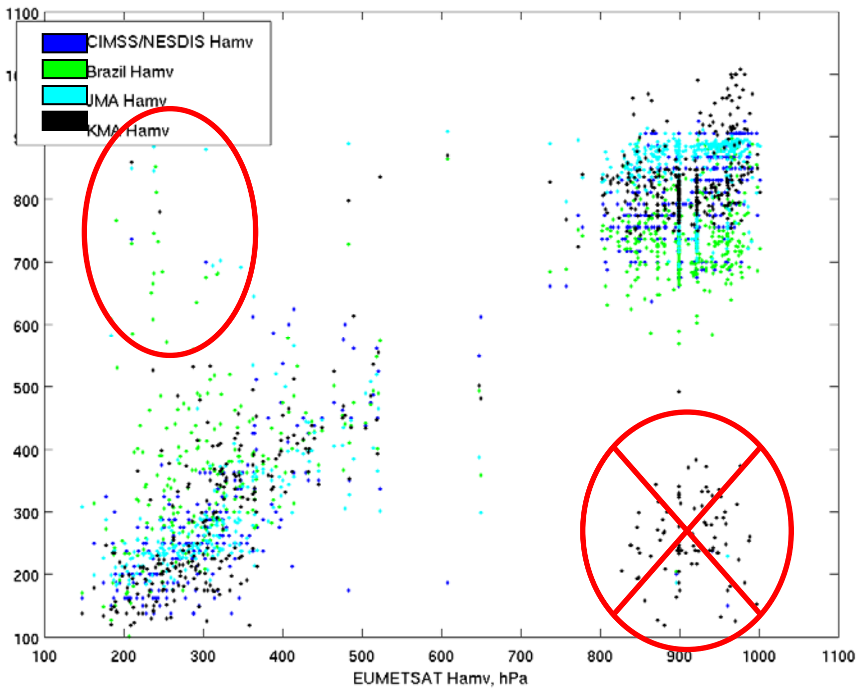
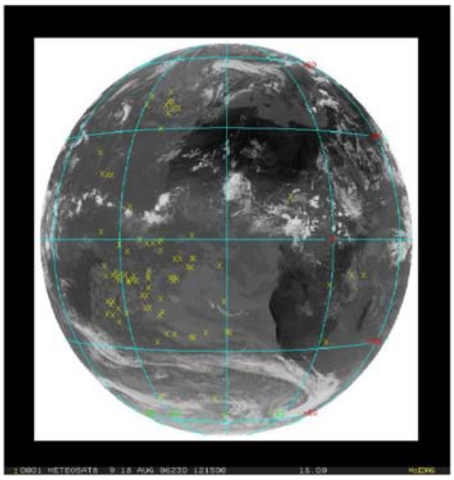
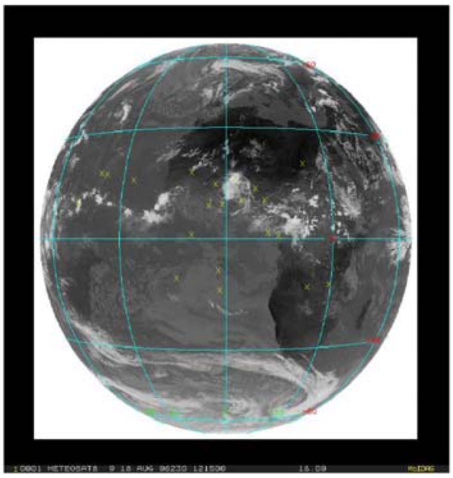



***Figure 8***. **AMV heights inter-comparison**



a.



b.

***Figure 9.*** **(a) location of AMVs with low bias from KMA; (b) location of AMVs with high bias from Brazil, JMA and KMA**

## CONCLUSIONS AND FUTURE WORK

Preliminary investigation of the AMVs data sets derived from one MSG - SEVIRI full disk image triplet from 18 August 2006 reports median values for the difference in Speed, Direction and Pressure to be 2.99m/s, 22 deg and 175 hPa, correspondingly. 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, image used for the assignment. Quality indicator remains the simplest, yet efficient measure of the AMV quality. However, its implementation needs to be 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 size is used.

Limited to the findings from this case study, a few further study components are recommended:
- KMA could investigate the reasons for too few mid-level AMVs;
- JMA - height assignment for low broken clouds over ocean; slower mean speeds;
- All teams could review their low level inversion correction;
- CIMSS could increase the size of the target and search box sizes;
- Repeat the study, asking JMA to use the ECMWF forecast, and all producers apply same size target and search box sizes.
- Independently evaluate the quality of each data sets through comparisons to RAOBS and ECMWF model U-V wind fields.

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Holmlund, K., (1998) The utilization of statistical properties of satellite−derived atmospheric motion vectors to derive quality indicators. Wea. Forecasting, **12**, 1093−1103.