Reprocessing of Atmospheric Motion Vectors from Meteosat Image Data

Leo van de Berg, Jörgen Gustafsson and Ahmet Yildirim

EUMETSAT, Am Kavalleriesand 31, D-64295 Darmstadt Germany

Abstract

EUMETSAT has initiated a project to reprocess satellite image data from the preoperational satellites Meteosat-2 and Meteosat-3 in order to generate meteorological products with present day, state of the art algorithms. The objective of the EUMETSAT project is to support ECMWF's ERA-40 project. The emphasis of EUMETSAT's reprocessing lies on the extraction of atmospheric motion vectors (AMV's) and on the recalibration of both infra red channels for the period 1981 to 1990. Presently half a year of Meteosat-2 image data has been reprocessed. The differences between the reprocessed products and the historical AMV's will be discussed with regard to both the quality of the original and the present operational products. While the first comparison shows the impact of the improved algorithms, the second comparison is important identify a potential negative impact of the image data of the preoperational satellites. As the calibration of the infrared channels is inherently important for the quality of the reprocessed AMV products, these results will be discussed too.

1 Introduction

ECMWF started a project to derive a global analysis of the state of the atmosphere, land and surface conditions over the period 1957-2001 with present day algorithms. The analysis involves a comprehensive use of satellite data, starting from the early vertical temperature profile radiometer data in 1972, then later including TOVS, SSMI/I, ERS and ATOVS data. EUMETSAT supports the ERA-40 project by reprocessing the image data from the preoperational satellites (Meteosat-1, Meteosat-2 and Meteosat-3) to derive AMV's with state of the art algorithms. The operational retrieval of Meteosat AMV's was first performed within the Meteorological Information Extraction Centre (MIEC) of the European Space Operations Centre (ESOC) on behalf of the National Meteorological Services. Although the first operational products were already derived from 1981 onwards, there have been several improvements since. The result of the steady improvement of the AMV product quality was an increase in the use of these products within the analysis systems of numerical weather prediction models. While the early use of AMVs in the numerical weather prediction models had only a positive impact at low latitudes and Southern Hemisphere, (Kelly and Pailleux, 1989), more recent studies showed also a positive impact on Northern Hemisphere (Kalberg and Uppala 1998, Köpken, 2001). Hence, in order to support ECMWF's ERA-40 project, EUMETSAT has initiated a project to reprocess Meteosat-2 and Meteosat-3 image data using state of the art retrieval algorithms. A basic description of the reprocessing system is presented in Section 2. As the image data from the preoperational satellites differs substantially from the image data of the operational satellites, the major differences are described in Section 3. While Section 4 describes the major algorithm improvements, the first results of the reprocessing of Meteosat-2 data, covering the first six months of 1983, are presented in Section 5.

2 The reprocessing system

The operational Meteorological Product Extraction Facility (MPEF) accepts in near-real time image lines from the image processing system, which performs the geometrical correction on the images. The corrected image lines are send to the operational MPEF and blocks of 32 images lines are first analyzed using a multi-spectral histogram analysis method (Tomassini, 1981) and then processed to generate the various meteorological products (e.g. the AMV product). Hence, the processing speed of the MPEF is principally restricted by the scanning rate of the radiometer on board of the spacecraft. In addition to the image data input from sources external to EUMETSAT is required for the processing and verification of the meteorological products. Forecast data and sea surface temperatures are, for instance, used for the determination of the atmospheric absorption. While radiosonde observations of temperature, humidity and wind speed and direction are still used for product verification, their importance for the present operational products has diminished since the introduction of a new calibration method on 29th May 2000. This new method uses the black body calibration mechanism on board of Meteosat-7 together with a simple model for the front optics of the radiometer (which is not included in the optical path for the black body calibration) to determine a calibration for both infrared channels.

The largest difference of the reprocessing system (RMPEF) with respect to the operational system concerns the pre-processing of the image data and the required support data. The image data are first geometrically corrected within EUMETSAT's archive and then transferred to the RMPEF as complete images. Therefore the image processing within the RMPEF is completely data driven and only limited by its own CPU and IO-rates. Hence, it is possible to reprocess 7 to 10 days of image data within 24 hours (depending on the type and number of products to be processed). As in the operational MPEF the additional support data are required for determination of the atmospheric absorption, but instead of forecasts the RMPEF uses ECMWF analysis. In addition they are required for the vicarious calibration of the channel in the infrared window (IR). The radiosonde observations are not only required for product verification but also for the vicarious calibration of the channel in the water vapour absorption band (WV). All support data, covering the whole reprocessing period, have been retrieved from ECMWF's archive. All products derived by the RMPEF are transferred to EUMETSAT's archive.

3 The image data

The image data of the preoperational spacecraft differ quite substantially from the image data from the operational spacecraft (Meteosat-4 and following). First of all the image data in the visible and the WV channel are converted on board of the spacecraft to six bit data, while on the operational spacecraft these data are converted to eight bit data. For the channel in the atmospheric window (IR) the data are converted into eight bit data for both types of spacecraft.

Although the preoperational satellites had an IR, a WV and two VIS detectors (like the present Meteosat spacecraft), two different scanning patterns were used during daytime (06 to 18 UTC) due to memory restrictions on board of the spacecraft. For images, whose scan ended on the full hours (even slots: 24, 26, etc), the data from the IR, the WV and **one** VIS detector were disseminated to the Earth. However, for images, whose scan ended on the half-hour (uneven slots: 23, 25, etc), the data from IR and **both** VIS detectors were send to Earth. During nighttime the first scanning pattern was used all the time. Hence, during daytime every second WV image (uneven slots) is missing, and as a consequence AMV's from the WV imagery are only derived during nighttime. Consequently, only for those slots where the WV image was missing, a genuine high-resolution visible image (5000 x 5000 pixels) is available. Hence, in order to be able to generate a wind product from the high-resolution visible imagery (HRV product), the image lines for the even slots are duplicated to replace the missing image lines from the second VIS detector.

The WV imagery from the pre-operational satellites is very noisy, with respect to those from the operational satellites. As an example two WV images are presented in Figure 1 for Meteosat-7 and Figure 2 for Meteosat-2. In addition to the noise, there is a systematic difference in the occurrence of even and uneven counts, causing a problem for the histogram analysis scheme. To avoid the latter problem, within the reprocessing system the six bit WV images have been reduced to five bit data. Note that within the MIEC processing system both the VIS and the WV data were reduced to five bit data.

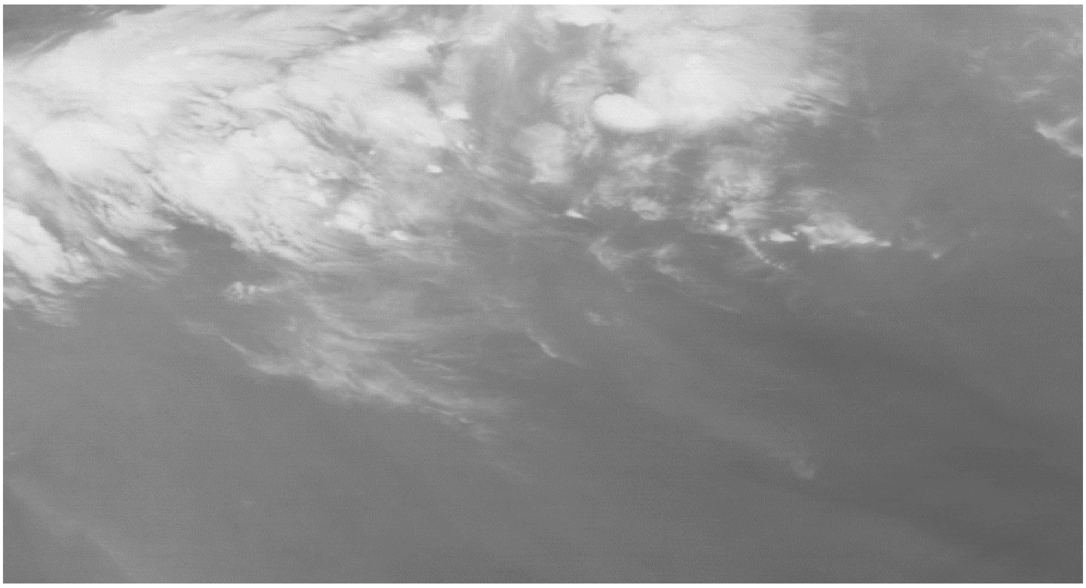

Figure 1: Example of the radiometric quality of a Meteosat-7 WV image.

Figure 2: Example of the radiometric quality of a Meteosat-2 WV image.

4 Major algorithm improvements

4.1 Calibration

In the last 15 years several improvements in the calibration of the infrared channels have been made, which of course impacted the meteorological product derivation. In September 1987 a major change was introduced for the calibration of the WV channel: before this date the difference between the satellite observed upper trophospheric humidity (UTH) and a UTH derived from radiosonde observations was forced to a zero bias by modifying the calibration coefficient. Hereafter the expected radiance at the top of the atmosphere is determined from the radiosonde observations using a radiative transfer model. The spacecraft observations (in counts) are used together with the expected radiances to derive the calibration coefficient (Schmetz, 1989). Another improvement was made by applying a more stringent quality control on the radiosonde observations (van de Berg et al., 1995). These changes in the WV calibration impacted the IR AMV's indirectly via the semi-transparency correction of transparent or broken clouds.

Within the early days of the MIEC system updates of both the IR and the WV calibration were performed manually. While the WV calibration was controlled by the above described forcing of a zero bias between the satellite UTH product and a radiosonde UTH product, the IR calibration was forced to a zero bias between the MIEC Sea Surface Temperature product and SHIP observations. Small corrections on the IR calibration were performed automatically in the MIEC system by using a Fine Adjustment of Gain (FAG). This method determined the variability in the IR detector by the looking at deviation of the IR black body observations, which were performed at an ambient temperature on board of the spacecraft, from the expected black body observation at a defined reference temperature.

4.2 AMV Product Generation

The most obvious change is the increased frequency of the AMV product generation and dissemination. While in the 1980's AMV products were disseminated three or four times a day at the main synoptic hours, presently an AMV product is disseminated every 1.5 hours. Additionally the present AMV product is derived for every available channel (and disseminated as such in the BUFR encoded product), while the historical product was derived from only the IR images.

Also the philosophy in the quality control of the AMV products has changed over the years. In the eighty's the user requirement concerning the product quality was quite passive: only the best AMV's should be disseminated. An automatic quality control system that checks on e.g. forecast and spatial consistency and an extensive manual quality control were used to reach this goal. Presently the user requires more data, but with a quality indicator for each observation. These quality indicators allow the users to develop their own data acceptance system for AMV's, where different limits and weights can be used by the individual users. Although the increase in AMV's per product (at least a factor of six) enfolds also the change in the dissemination philosophy, there is, on a daily basis, an enormous increase in the number of disseminated AMV's (at least a factor of 25).

Some of the improvements in the AMV algorithm are described in chronicle order in Schmetz et al. (1993). A simple image enhancement technique was introduced in March 1987: the radiance slicing technique for clouds above 400 hPa. The technique used the warm end of the high-level cloud scene as cutoff for masking background pixels. This simple technique was replaced in March 1990 by an image filtering that uses a spatial coherence method (Hoffman, 1990) to extract cloud pixels belonging to the highest cloud layer. The main advantage with respect to the slicing method is that the enhancement of high-level clouds improved, due to gradual screening of warmer pixel values.

The cloud tracking mechanism in an image triplet uses a cross correlation technique between the two pairs of images. In March 1989 the analysis of these correlation surfaces was changed. Before this date the search strategy started at the location of zero displacement and stopped at the first peak in the correlation surface (Bowen et al., 1979). Stopping at the first peak found, increased the tendency for a slow bias, as the correlation surfaces are generally multi-peaked (Schmetz and Nuret, 1987). To overcome this tendency, after March 1989 the correlation was calculated for a 35 x 35 pixel area around a displacement suggested by a wind forecast (Nuret and Schmetz, 1988). Using a large search area diminishes the potential problem that the AMV depends on the forecast.

Since 1997 Quality Indices (QI's) are determined for each AMV and they are disseminated as part of the BUFR products. The final QI for each AMV is determined from a series of tests, e.g. direction test between the two AMV components, speed test between the two AMV components, vector test between the two AMV components, spatial test, forecast test. For a full description of the tests and the derivation of the final QI the reader is referred to Holmlund et al. (2001) and Holmlund (1988). The introduction of these quality indices allowed the dissemination of AMV's with varying quality, from which any end user is then able to select only those AMV's that fulfill his own quality requirements.

5 First results

The operational reprocessing of Meteosat-2 image data started in September 2001, taking the 1st January 1983 as starting date. This date was chosen, as for the years 1981 and 1982 there are problems with the geometric correction of the images. Especially within the first few years of Meteosat operations, the formats of the files containing the uncorrected image data changed several times, and the documentation of these changes is incomplete or missing. Nevertheless attempts will be made to process these images and if possible the AMV reprocessing of those years will be performed at a later stage. The results of reprocessing the first six months of 1983 will be discussed within the following sections.

5.1 Calibration

5.1.1 IR Calibration

The MIEC calibration and the reprocessed IR calibration are shown in Figure 3. Clearly the manual updates of the MIEC IR calibration can be seen as the larger jumps of the calibration coefficient, while the effect of the FAG modulates the IR calibration. The reprocessed IR calibration is more stable, and can differ up to 3 % from the MIEC IR calibration.

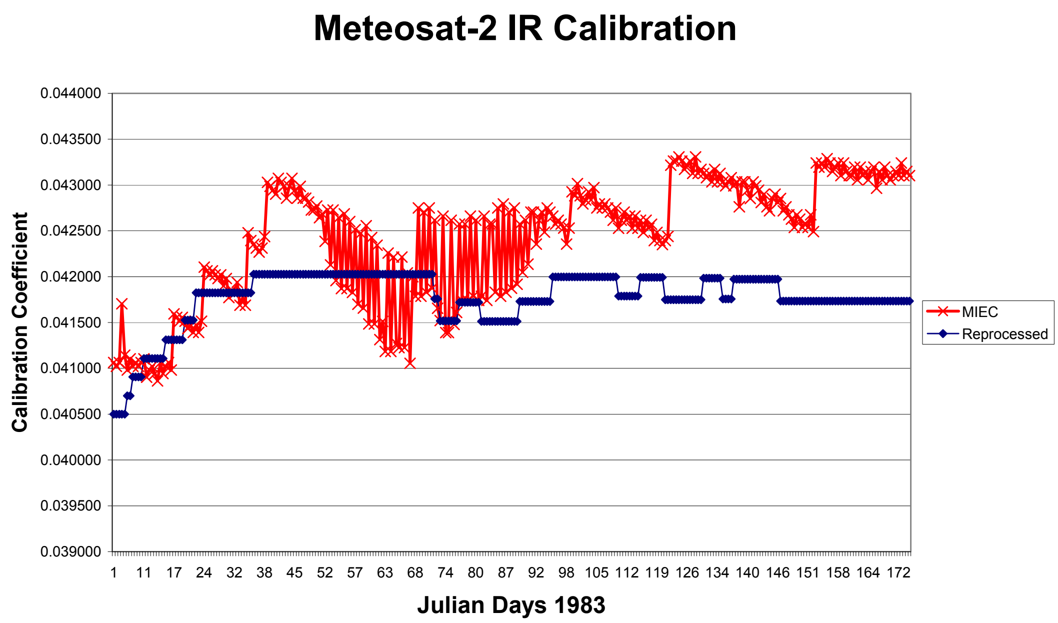

Figure 3: The Operational MIEC (red line) and the RMPEF (blue line) calibration of the IR channel for the first six months of 1983

5.1.2 WV Calibration

The MIEC WV calibration was very stable (see Figure 4). The only change within these six months is after the detector decontamination of Meteosat-2 in early January 1983 (not shown in Figure 4). The reprocessed WV calibration has a much larger variability due to the use of radiosonde observations for the calibration process. The basic reason is the variability in the number of radiosonde observations per given observation time and the difference in quality of the various radiosonde types. The calibration process only accepts radiosonde observations for areas that are free of clouds above 700 hPa, which makes the calibration process dependent on the meteorological conditions: changing conditions implicitly mean a changing geographical selection and a changing number of radiosonde observations (van de Berg et al., 1995). Assuming a linear trend within Figure 4, one observes an almost constant bias of about 3 % (the reprocessed calibration being higher).

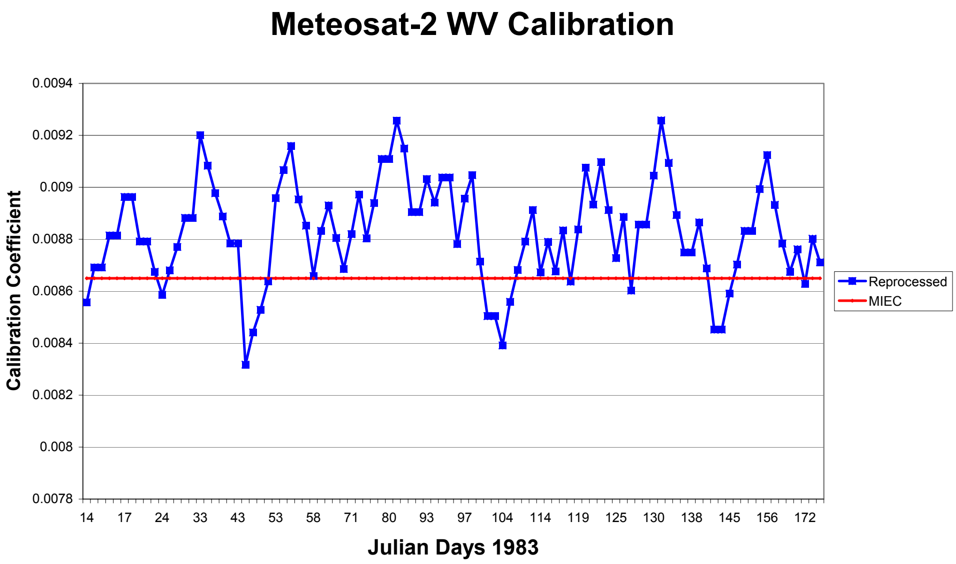

Figure 4: The Operational MIEC (red line) and the RMPEF (blue line) calibration of the WV channel for the first six months of 1983

5.2 AMV Products

Within the automatic quality control system the AMV's derived from the WV imagery are not automatically deleted. Nevertheless the low quality of the WV images reduces the number of reprocessed AMV's in the WV channel considerably. Hence, these AMV's will not be discussed in this paper.

The collocation of AMV's with radiosonde wind observations provides a powerful tool to estimate the quality of the AMV product. In this section the statistical analysis of these collocations from the reprocessed AMV products is compared both with the results from the MIEC AMV products as well as with the results from the present operational system. The latter comparison gives a clear indication on the performance of the AMV product derivation when used on Meteosat-2 image data. For this comparison radiosonde collocations for the months April to June (1983 and 2001) are used. The former comparison is presented for the full six month period and gives an indication of the expected quality improvement of the AMV products.

5.2.1 IR Wind Product

The normalized vector RMS (see Figure 5) of the collocations of the IR AMV's with the radiosonde observations is presented as function of the quality indicators. The used normalisation factor is the averaged radiosonde wind speed. The total number of collocations per quality class is shown in Figure 6. For both the 1983 and 2001 data the normalized vector RMS decreases with increasing quality indicator.

Though there are of course differences, due to the different meteorological conditions, it can be stated that the characteristics of both the present operational and the reprocessed data set are similar. Although on a first glance the quality of the reprocessed products seems to be slightly better than the quality of the operational prodoct (see Figure 5), this quality increase is accompanied by a lower amount of collocations in the highest quality class (see Figure 6). This behaviour is especially apparent for the AMV's above 400 hPa, and is likely caused by a fewer number of succesful semi-transparency corrections.

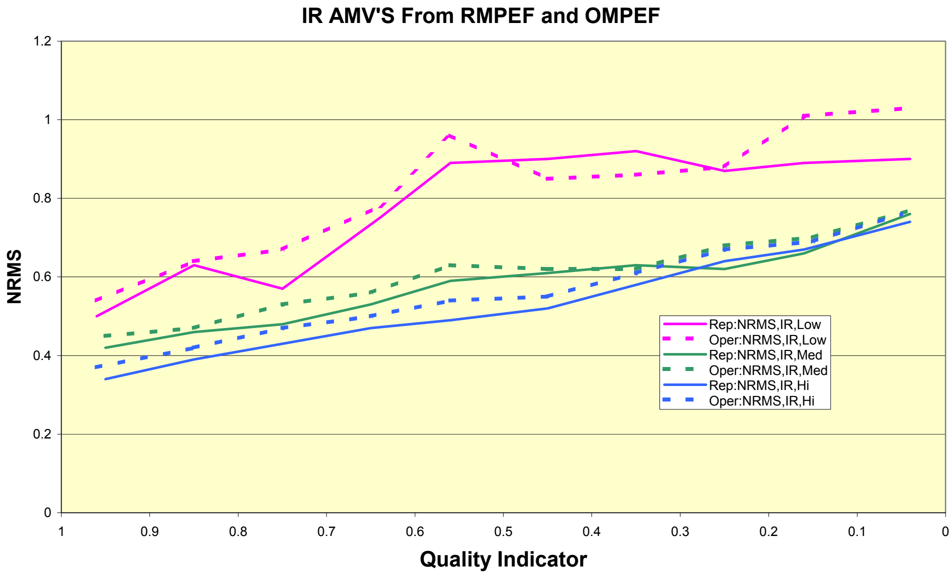

Figure 5: Normalised Vector RMS of the collocations of IR AMV's and radiosonde wind observations as function of the quality indicator. The periods used are April to June 1983 for the reprocessed products and April to June 2001 for the operational products.

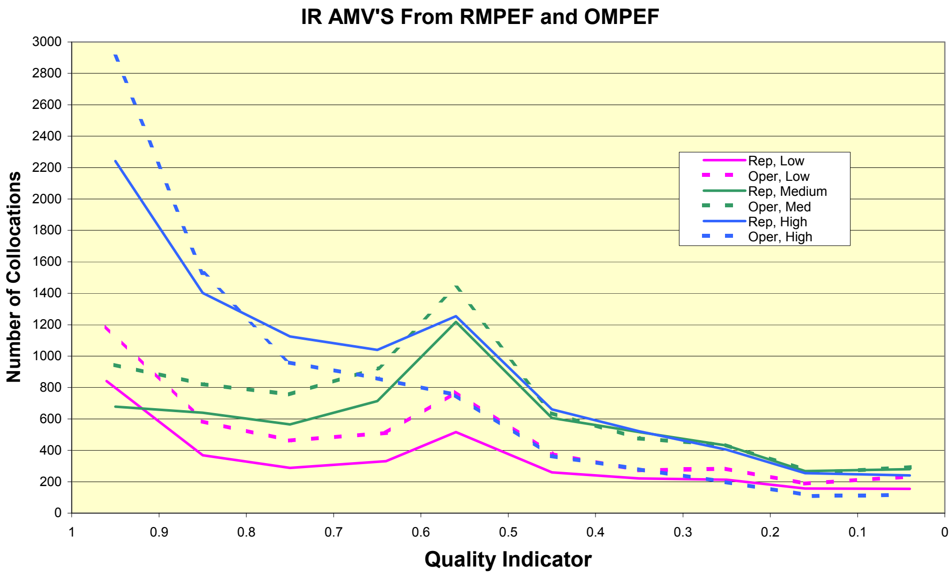

Figure 6: The total number of collocations of IR AMV's and radiosonde wind observations as function of the quality indicator. The periods used are April to June 1983 for the reprocessed products and April to June 2001 for the operational products.

When comparing the normalised vector RMS of the reprocessed IR AMV's and the historical MIEC IR AMV's with radiosonde wind observations, the results are similar for all three height levels (above 400 hPa, below 700 hPa, and between 700 and 400 hPa). Hence, only the results for the collocations of the high-level AMV's (above 400 hPa) are presented in Figure 7. Here it can be seen that the normalised vector RMS decreases in average with about 30 %, which is indicative for definite improvement in the product quality. As only the very best AMV's were disseminated and archived by MIEC, only reprocessed AMV's with a QI above 0.8 are used for the comparison presented in Figure 7. If all AMV's with a QI above 0.3 (the present operational threshold for dissemination) are used, then the normalised vector RMS of both products is very similar. Nevertheless, the final conclusion of the product quality improvement has to be demonstrated in special tests within the ERA-40 project, by looking to the difference in impact of the historical MIEC products and the reprocessed products.

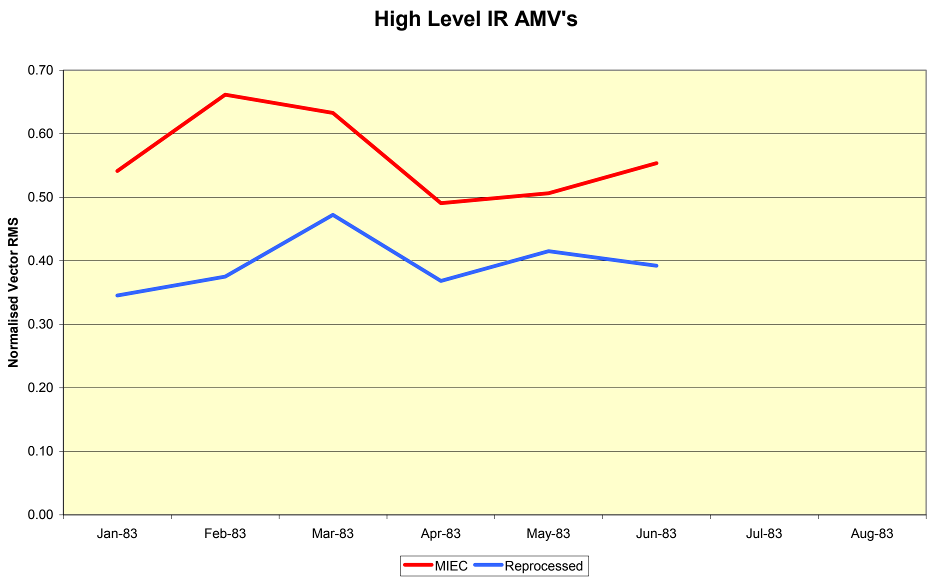

Figure 7: The variability of the normalised vector RMS of the collocations of IR AMV's and radiosonde wind observations over the first reprocessing period. The results of the historical MIEC products (red curve) and the reprocessed products (blue curve) are shown.

5.2.2 VIS Wind Product

Two types of VIS AMV's are being produced within the operational and reprocessing system. First the low-resolution VIS AMV's are produced, as part of the ELW product, from images having the same amount of pixels (2500 x 2500) as the IR images. These images are derived from the high-resolution images by sampling. The normalised vector RMS of the reprocessed and the operational low-resolution VIS AMV product are similar (see Figure 8), indicating a similar level of product quality.

In addition also from the high-resolution VIS images AMV's are derived. This high-resolution visible (HRV) wind product is a relatively new product (Ottenbacher et al., 1997). The reprocessed HRV product differs from the present operational product, due to the difference in the high-resolution visible imagery described in Section 3. The used duplication of image lines on image scans ending at the full hour will generate an error of maximally one VIS pixel in the tracking between two consecutive images. Nevertheless these differences, the quality of the reprocessed HRV products is similar to the quality of the operational HRV products (see Figure 8). The main difference is that the operational products are derived every three hours between 06 and 18 UTC, while the reprocessed products are derived every 1.5 hours in the same period.

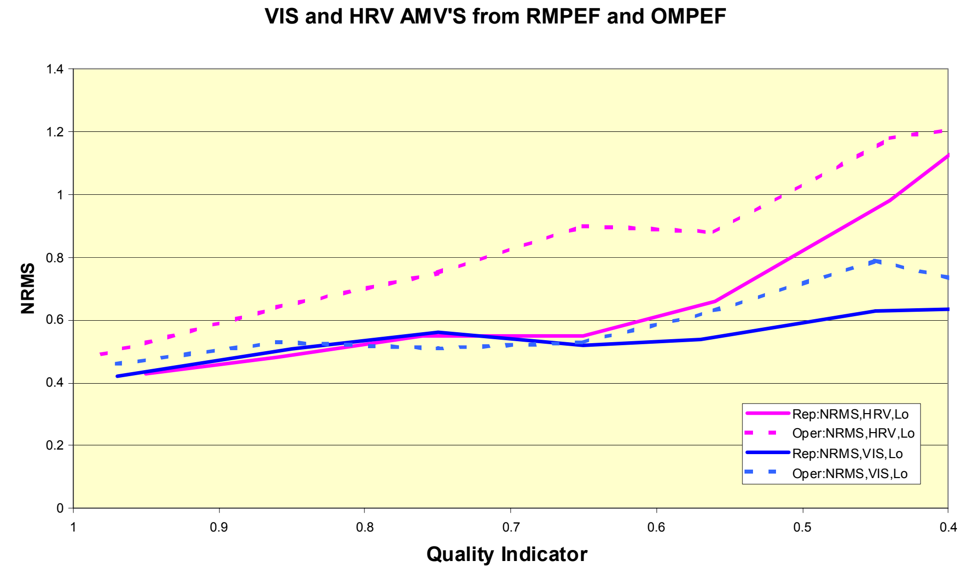

Figure 8: Normalised Vector RMS of the collocations of VIS AMV's and radiosonde wind observations as function of the quality indicator. The periods used are April to June 1983 for the reprocessed products and April to June 2001 for the operational products. The normalised vector RMS of both the low-resolution (pink curve) and the high-resolution (blue curve) products are displayed.

6 Conclusions

The image data of the preoperational spacecraft (Meteosat-1 through Meteosat-3) differ quite substantially from the image data from the operational spacecraft (Meteosat-4 and following). The lesser resolution and the larger noise of the WV imagery cause the reduced number of WV AMV's. The IR AMV's are indirectly impacted via a degraded performance of the semi-transparency correction.

The reprocessed WV calibration has, on average, a high bias with respect to the original calibration of about 3 %. However, the variability of the reprocessed WV calibration has increased with respect to the historical calibration: the instantaneous calibration data can vary up to 5 % from the longer-term average. This variability is a consequence of the use of radiosonde observations in the vicarious calibration method (van de Berg et al., 1995).

The number of AMV's per reprocessed product increased drastically with respect to the original MIEC products. The first reason for this increase is the use of all spectral channels for AMV derivation (MIEC only used the IR). The second reason is the changed dissemination strategy: while MIEC only disseminated the best winds, the operational MPEF, and the reprocessing system, disseminate all winds with a QI higher than 0.3. The quality of the reprocessed AMV products is similar to the quality of the operational products. With respect to the MIEC products there is a marked increase in quality, when comparing all reprocessed AMV's with a QI larger than 0.8 with the historical AMV's. A quality increase can still be seen in the normalized vector RMS if AMV's with a QI larger than 0.6 (ECMWF's present threshold for accepting Meteosat AMV's) are used in the comparison with the MIEC products.

In addition to the normal AMV products, we also derive AMV products from the high-resolution visible imagery. These HRV products have a quality almost similar to the present operational HRV products.

7 References

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