REPROCESSING OF ATMOSPHERIC MOTION VECTORS FROM METEOSAT IMAGE DATA

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ABSTRACT

EUMETSAT is supporting ECMWF's ERA-40 project by reprocessing satellite images from the preoperational satellites Meteosat-2 and Meteosat-3, using present algorithms and systems within the Meteorological Product Extraction Facility (MPEF). The emphasis lies on the extraction of Atmospheric Motion Vectors (AMV), although Clear Sky Radiances and recalibration of the IR- and WV-channels are essential parts of the project. Presently (April 2002) the period May 1982 - December 1985 is reprocessed

The regularity and quality of the Meteosat-2 images is periodically low, especially for the WV channel. Nevertheless, compared to the original MIEC AMV products, a drastic increase in the number of extracted winds together with a better quality is experienced. The quality is close to the present operational product quality. Initial ECMWF assimilation impact experiments with the reprocessed AMVs indicate a positive forecast impact over the extra-tropics compared to using the original MIEC product.

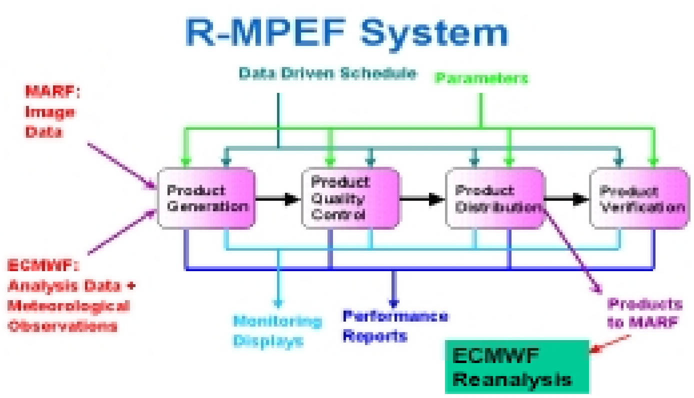
1 Introduction

The new ECMWF reanalysis project ERA-40 will cover the period from mid-1957 to 2001 overlapping the earlier ECMWF reanalysis ERA-15 (1979-1993). The main objective is to promote the use of global analyses of the state of the atmosphere, land and surface conditions over the period. It will use an advanced and operationally tested variational data assimilation system with a refined numerical model, and will be innovative in its use of satellite data. As ECMWF analysis has provided evidence of a significant improvement in the quality of cloud-wind products from geostationary satellites throughout the 1980s (Uppala, 1997) EUMETSAT supports the ERA-40 project by reprocessing the image data from the pre-operational satellites Meteosat-2 and Meteosat-3.

The operational retrieval of Meteosat AMVs was first performed within the Meteorological Information Extraction Center (MIEC) of the European Space Operations Center (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 then. The steady improvement of the AMV product increased the use of these products in the data assimilation 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 the Southern Hemisphere, (Kelly and Pailleux, 1989), more recent studies showed also a small positive impact on the Northern Hemisphere (e.g., Kelly et al. 1998). A basic description of the reprocessing system is presented in Section 2. As the image data from the pre-operational satellites differs 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 period 1982 - 1985 are presented in Section 5. A validation dataset for the period 1 July - 10 August 1988, has been used by ECMWF for data assimilation and forecast impact experiments, and some of the results are presented in section 6.

2 The Reprocessing System

The operational Meteorological Product Extraction Facility (MPEF) accepts in near-real time geometrically corrected image lines from the image processing system. Blocks of 32 image 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 external sources is required for the processing and verification of the meteorological products. Forecast data is, for instance, used for the determination of the atmospheric absorption. While radiosonde observations are still used for product verification, their importance for the present operational products has diminished since the introduction of a new calibration method in May 2000. This new method uses the black body calibration mechanism on board of Meteosat-7 to determine a calibration for both infrared channels (IR and WV).



The Reprocessing MPEF (RMPEF) is different compared to the operational system concerning all input data, both the pre-processing of the image data and the required support data (Figure 1). The image data is first geometrically corrected within the 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 about 10 days of image data within 24 hours. As in the operational MPEF the additional support data is required for determination of the atmospheric absorption, but instead of forecasts the RMPEF uses ECMWF analysis from the ERA15 project. Since no blackbody information is available from the Meteosat 2 and 3, RMPEF uses the old vicarious calibration method, i. e. comparisons with sea surface temperatures for the IR calibration and radiosonde humidity observations for the WV channel. All support data, covering the whole reprocessing period, have been retrieved from the ECMWF archive. All products derived by the RMPEF are transferred to EUMETSAT's archive, and stored in binary (BUFR) format.

3 The Image Data

The image data of the pre-operational spacecrafts (Meteosat1 - Meteosat3) differ quite substantially from the image data of the operational spacecrafts. First of all the image data in the VIS and WV channels are converted on board of the spacecraft to six bit data, while on the operational spacecraft these data are converted to eight bit data. The IR channel is converted into eight bit data for both types of spacecraft. The WV imagery from the pre-operational satellites is very noisy. 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, while for technical reasons the VIS images has been converted to eight bits by adding two random bits in the least significant end. Note that within the MIEC processing system both the VIS and the WV data were reduced to five bit data.

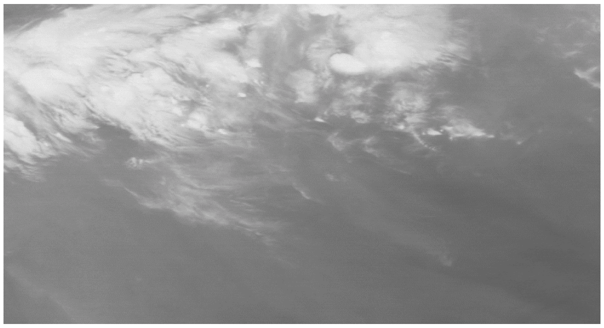


Figure 2: Example of Meteosat-7 WV image.

Figure 3: Example of Meteosat-2 WV image.

Although the pre-operational satellites had an IR, a WV and two VIS detectors (as the present Meteosat spacecrafts), 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 AMVs from the WV imagery are only derived during nighttime. Consequently, semi-transparency correction is not applied on every second AMV product (uneven slots) during daytime, which has a direct impact on both quality and number of extracted high level IR winds.

Also, only for those slots where the WV image was missing, a genuine high-resolution visible image (5000 x 5000 pixels) is available, and therefore the High Resolution Visual wind product (HRV) is for every second image actually using a low resolution image where the image lines are duplicated to replace the missing image lines from the second VIS detector. The quality of the HRV product is therefore not directly comparable to the operational HRV.

The reprocessing success rate, in terms of available AMV products is presented in Figure 4, where 100% equals the expected 16 AMV products per day, without any compensation for eclipse image losses. The black line indicates the initial success rate, i.e. only depending on image availability, the red line indicates the success rate for AMV products fulfilling a minimum criteria for size and quality and the blue line indicates products of normal size and quality. The two most common reasons for the difference between the red and the blue lines are bad image rectification and/or lost image lines.

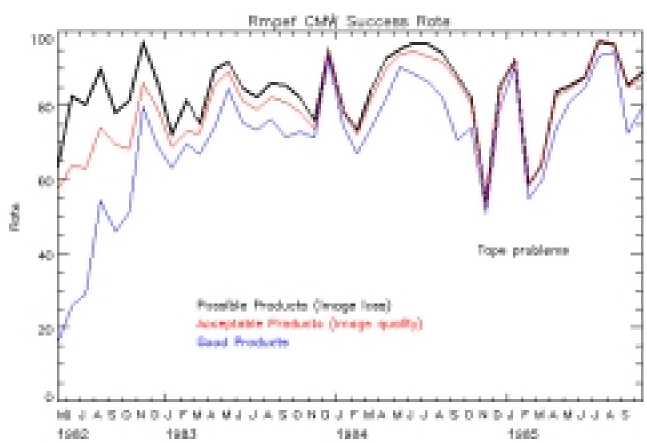


Figure 4: RMPEF success rate

4 Major AMV Algorithm Improvements

The most obvious change is the increased frequency of the AMV product generation and dissemination. While in the 1980's AMV products were disseminated two to 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.

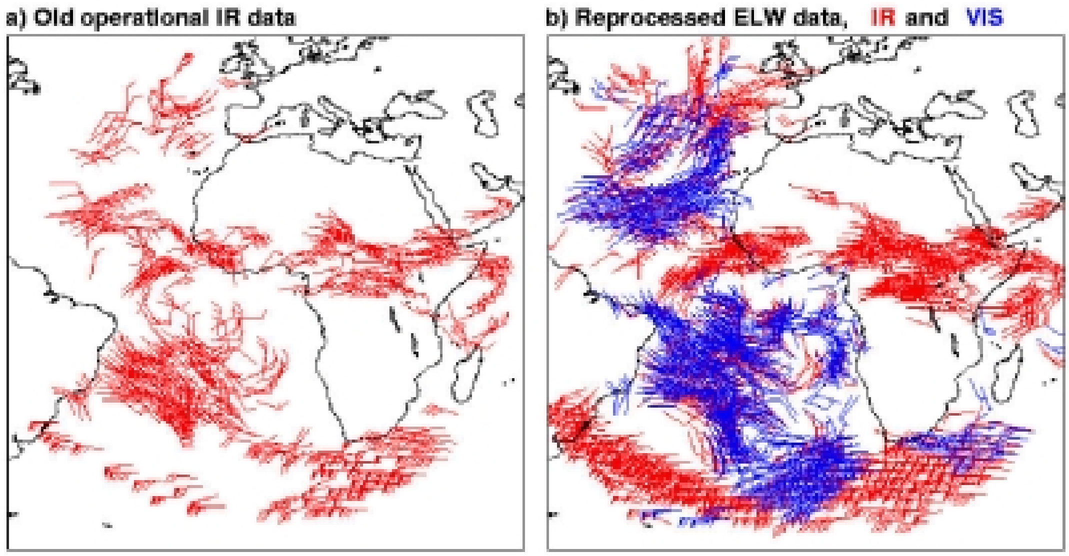


Figure 5. Typical AMV coverage for 1st of August 1988 12z +/- 3h, after applying ECMWF's blacklisting based on the quality indicator (e.g., Rohn et al. 2001). MIEC 513 IR winds, RMPEF 2301 IR and 1525 VIS winds.

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 AMVs should be disseminated. First an automatic quality control system based on internal tests filtered the AMVs, then another check marked AMVs differing too much from the forecast as rejected. Finally an extensive manual quality control were used to reach the goal of a high quality product. Presently the users requires all data, relaying on their own assimilation scheme for quality control, and almost all data is today disseminated but with a quality indicator for each observation. These quality indicators allow the users to develop their own data acceptance system for AMVs, where different limits and weights can be used by the individual users.

Some of the improvements in the AMV algorithm are described in chronicle order in Schmetz et al. (1993). An 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 cut-off for masking background pixels. This 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 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., 1989). 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 a weighted mean from a series of tests, e.g. checking direction/speed/vector consistencies between the two AMV components, a spatial test checking the consistency with neighbouring vectors, and finally a forecast test checking the consistency with the used forecast. Since June 2001 an additional final QI is disseminated in the BUFR coded operational AMV product, not containing the forecast check. This change is not applied in RMPEF. 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 AMVs with varying quality, from which any end user can select only those AMVs that fulfil his own quality requirements.

5 Results

The operational reprocessing of Meteosat-2 image data started in September 2001, beginning with the 1st of January 1983. This date was chosen, as for the years 1981 and 1982 there are problems with the geometric correction of the images. Within the first 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. Later it was found that a large part of 1982 could be used, and the period May - December 1982 was reprocessed during March 2002. The results of reprocessing the period May 1982 to September 1985 will be discussed within the following sections.

5.1 Calibration

The MIEC and the RMPEF calibrations are shown below. Clearly the manual updates of the early MIEC IR calibration can be seen as the larger jumps of the calibration coefficient. The reprocessed IR calibration is more stable, and can differ up to 3% from the MIEC IR calibration

The MIEC WV calibration was very stable. 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).

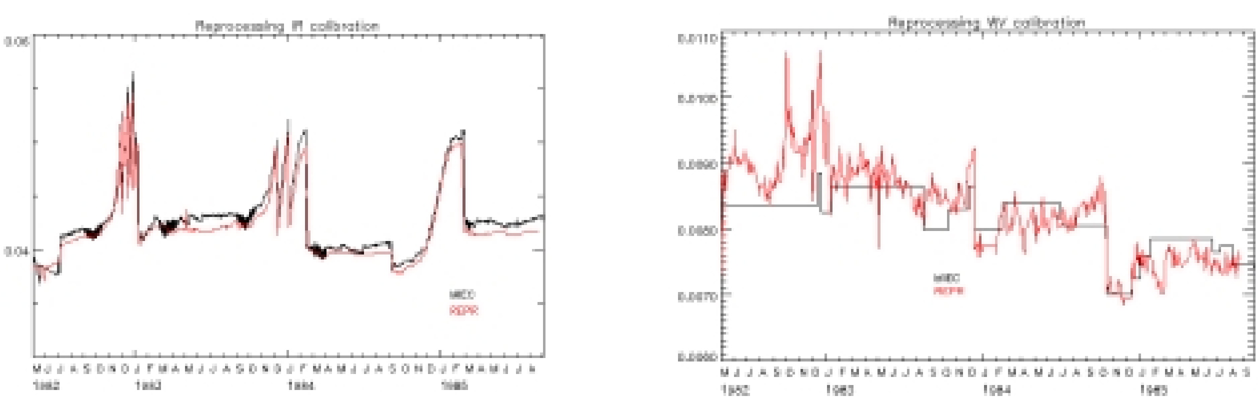


Figure 6 and 7: Reprocessed calibration vs. MIEC calibration

5.2 AMV Products

The collocation of AMVs with radiosonde wind observations provides an independent tool to estimate the quality of the AMV product, but has limitations such as an uneven geographical distribution, varying quality and availability. Different collocation methods have been discussed, ending in a recommendation from the fourth international winds workshop 1998, in the following called the CGMS method. That method has never been applied for Meteosat official statistics. The differences between the two methods are in short:

"CGMS"	150 km horizontal distance	"Meteosat"	200 km horizontal distance
	25 hPa vertical distance		50 hPa vertical distance
	Nearest match only		Nearest match ?

Concerning the nearest match it is not known if this was applied at MIEC, but it is applied for all Meteosat statistics since September 2001, i.e. start of reprocessing.

No official recommendation for filtering of "bad radiosondes" has been issued, but has nevertheless always been applied for Meteosat statistics: A comparison is not used if the AMV and the observation differ more than 30 m/s in speed or 60° in direction. This filtering also rejects bad AMV:s, but has proved to return good and reliable results over the years. Parallel test within the reprocessing project has shown that the applied radiosonde filtering is unnecessary "hard", and that rejection of collocations with observations speed > 100 m/s and direction difference more than 90° is in most cases sufficient.

Another statistical difficulty has arrived with the present approach to disseminate all AMVs passing a very low quality threshold (0.3). Statistics on all disseminated winds is therefore not really reflecting the quality in a fair way, and therefore two different "quality cut-offs" are used in this paper; QI = 0.8 which returns the number of AMVs per product comparable with MIEC products, and QI = 0.6 which is the lowest presently used cut off at ECMWF.

When comparing the reprocessed IR AMVs and the historical MIEC IR AMVs with radiosonde wind observations, the results are similar for all three heights. Hence, only the results for the collocations of the high-level AMVs (above 400 hPa) are presented (All areas).

In Figure 8 the upper part shows the normalised RMS vector against R/S observations. The used normalisation factor is the averaged radiosonde wind speed. The black line represents the historical MIEC data, available from January 1983, and the blue line shows the official Meteosat statistics and is comparable to the MIEC statistics. The difference to the CGMS QI > 0.8 statistics is small, and for both curves the improvement against the MIEC statistics is 30%, corresponding to about 3 m/s. For QI > 0.6 the improvement is ca 20%.

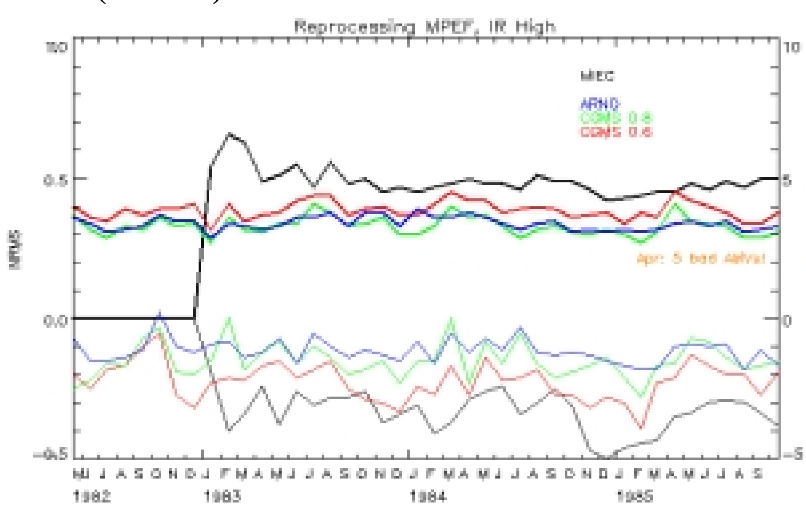


Figure 8: AMV collocations. Top: Norm. RMS VD. Bottom: Speed Bias (scale to right)

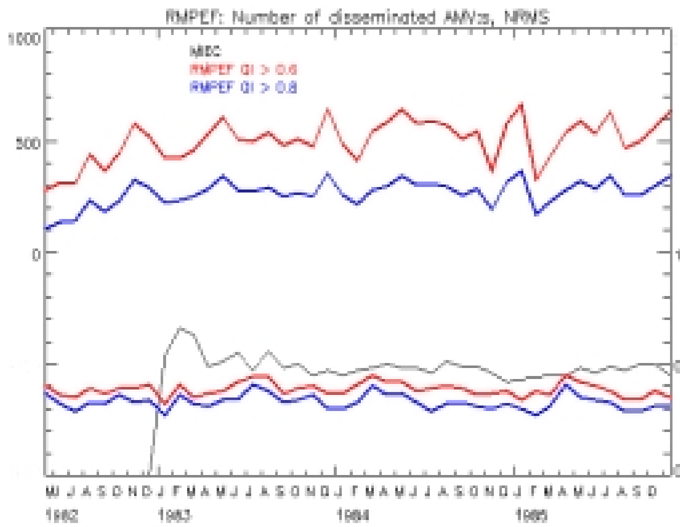


Figure 9: Number of high IR winds and NRMS VD.

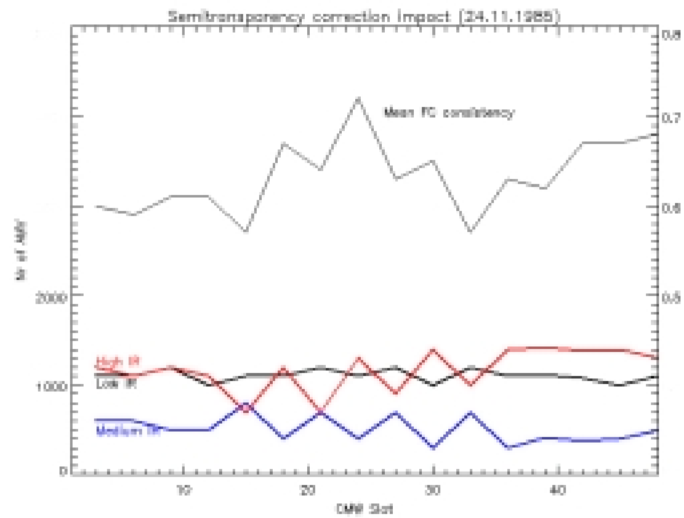


Figure 10: Semitransparancy correction impact

Concerning the number of disseminated winds, the QI level 0.8 returns a similar number of winds as was disseminated in a typical MIEC product, about 700 per product. No exact figures for the amount of distributed AMVs was saved for the first years of Meteosat, but a rough calculation indicates about 40000 AMVs a month, compared to the about 250000 from RMPEF (QI > 0.8). Since the product size is about the same, this increase in numbers is a function of the increased frequency only. Using the QI level 0.6 increases the number of AMVs per product with almost 100%, and the quality is still 15-20% better than MIEC (Figure 9).

As mentioned in sector 2, semi-transparency correction is not applied for every second AMV product (uneven central slot) during daytime, which has a direct impact on both quality and number of extracted IR winds. This is demonstrated in figure 10, where slots 15, 21, 27 and 33 have a considerably smaller number of high level IR winds, and correspondingly larger number of medium and low level winds. This has also an impact on the total quality, here demonstrated as the mean consistency with the used forecast for AMVs with QI > 0.6. A simple mean value of all uneven slots 15-33 compared to all even slots 18-36 for the whole year 1985 confirms a 5 % better FC-consistency with semi-transparency correction, based on AMVs with QI > 0.6.

Due to the low quality of the WV images from the pre-operational Meteosats, only very few WV AMVs with acceptable quality are extracted, about 5% of the numbers received from Meteosat 7. Figure 11 (right) compares the high level IR AMVs with the high level WV AMVs and even if the average quality is comparable, the variation is big and based on very few values.

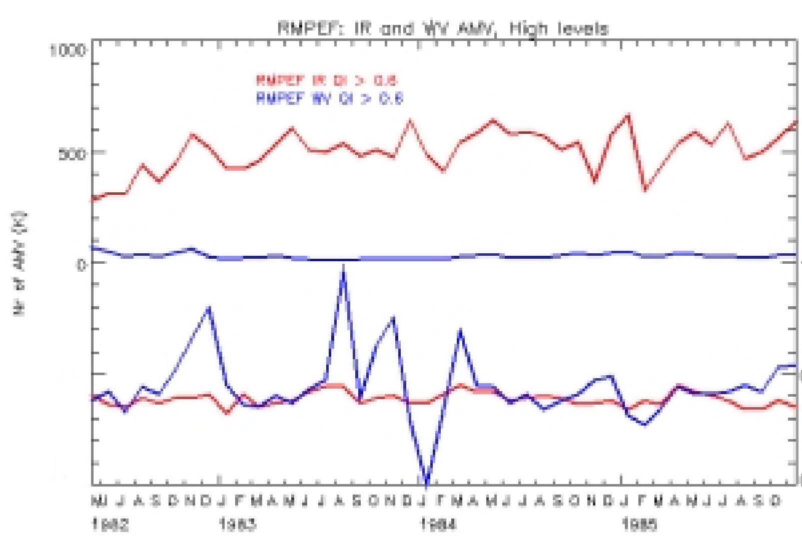


Figure 11: Reprocessed IR vs. WV winds

Two types of VIS AMVs are being produced both within the operational and the reprocessing system. First the low-resolution VIS AMVs are produced, as part of the ELW product every 1,5 hour, from images having the same amount of pixels (2500 x 2500) as the IR images. Since collocations with radiosondes on low levels are in general difficult to handle, and no VIS AMVs were produced by MIEC, the quality is only compared to the operational VIS AMVs (for the same period 2001) in terms of departure from the ECMWF First Guess, as seen in the impact experiment (Table 1).

In addition also AMVs from the high-resolution VIS images are derived. 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 lines for every second image generates an error of 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 (Table 2).

VIS	SH	Tropics	NH
NRMS VD	0.28 (0.28)	0.38 (0.36)	0.26 (0.23)
Speed Bias (m/s)	0.13 (0.03)	0.75 (0.68)	0.13 (-0.02)

Table 1: Departure statistics for RMPEF VIS AMVs against the ECMWF First Guess from an ERA-40 experiment using the ELW data. The period covered is 1 July - 10 August 1988, and statistics for winds with QI>60 % are shown. Numbers in brackets show First Guess statistics from operational monitoring of Meteosat-7 VIS AMVs for the same period in 2001.

HRV	SH	Tropics	NH
NRMS VD	0.36 (0.37)	0.48 (0.49)	0.35 (0.33)
Speed Bias (m/s)	0.21 (0.12)	0.88 (0.89)	0.17 (0.14)

Table 2: As Table 2, but for the RMPEF HRV product with current HRV statistics in brackets.

The lower quality of the HRV product compared to the VIS product (also for the operational Meteosat 7 HRV), is mainly an effect of different AQC schemes. The HRV returns a higher average QI.

6 ECMWF Impact Experiments

A validation dataset of RMPEF AMVs for the period 1 July - 10 August 1988 has been used by ECMWF for assimilation and forecast impact experiments using the ERA-40 configuration. ERA-40 uses ECMWF's 6-hourly 3-dimensional variational (3DVAR) data assimilation system with a spatial model and analysis resolution of T159 (approx. 125 km) and 60 levels in the vertical. 10 day forecasts were performed from each 12 UTC analysis. Two experiments are discussed: The experiment "CTL" used the old MIEC IR AMVs only, whereas experiment "ELW" used the complete RMPEF Meteosat-2 ELW product instead, taking a similar approach as for the current operational assimilation of Meteosat-7 AMVs (e.g., Rohn et al. 2001).

There is a considerable impact on the tropical mean wind analysis as a result of the assimilation of the reprocessed AMVs (Fig. 12, right). A similar impact from AMVs has been reported for the ERA-15 project (Kållberg and Uppala 1998), and these results highlight the role of AMVs in determining the tropical wind field in the model.

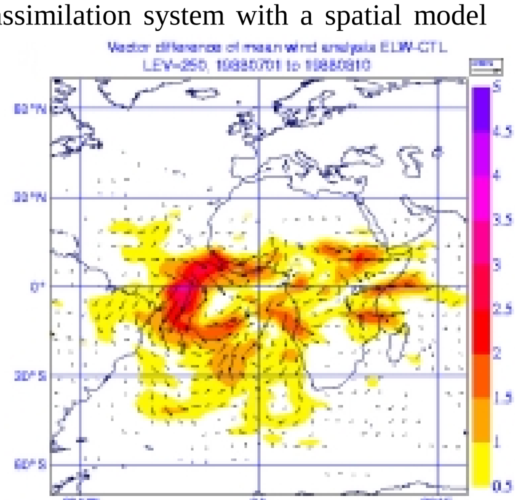


Figure 12: Impact on ECMWF analysis

The reprocessed AMVs have a positive and statistically significant impact on extra-tropical geopotential forecasts, particularly over the Southern Hemisphere. Figure 13 shows the anomaly correlation of the 200 hPa geopotential forecasts validated against an experimental ERA-40 analysis without reprocessed Meteosat-2 winds. Particularly encouraging is the positive impact of the reprocessed winds compared to the MIEC AMVs over the Australia/New Zealand region, downstream of the Meteosat-2 area of influence. RMS errors of the wind vector forecast show similar pattern, with a small negative impact over the tropical region (not shown). The latter finding may suggest a revision of the QI-based quality control applied to the reprocessed winds in the tropics.

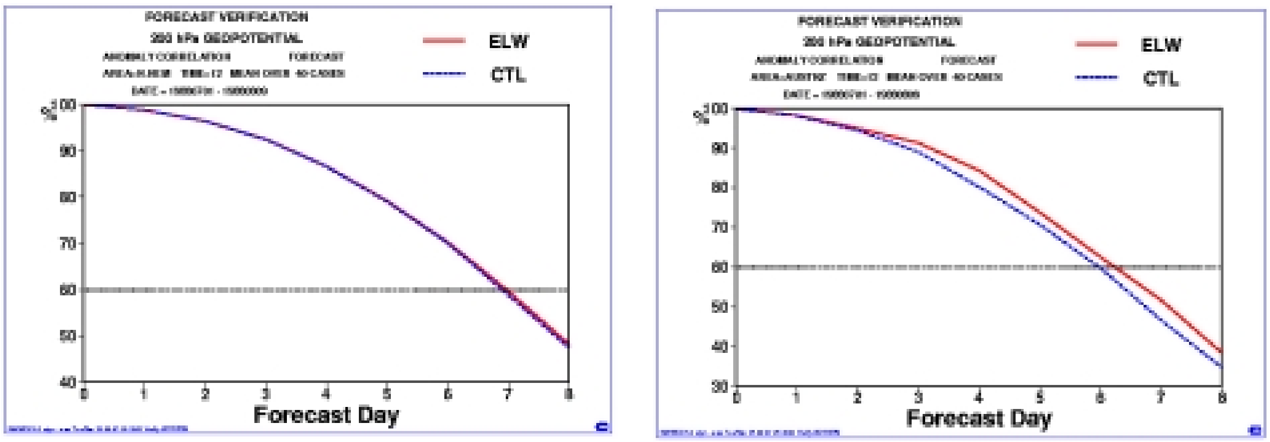


Figure 13: Anomaly correlation for the 200 hPa geopotential height forecast vs forecast range for the ERA-40 impact studies (40 cases 1 July - 9 August 1988). The red line shows the result for the experiment “ELW” with reprocessed winds, whereas the dashed blue line indicates the result for the experiment “CTL” with the old MIEC data. Both experiments have been validated against an experimental ERA-40 analysis. The two panels show values for the Northern and the Australia/New Zealand region, respectively.

7 Conclusions

The number of AMVs per reprocessed product increased drastically with respect to the original MIEC products. One reason for this increase is the use of all spectral channels for AMV derivation (MIEC only used the IR), another reason is the changed dissemination strategy: while MIEC only disseminated the very best winds, the operational MPEF and the reprocessing MPEF disseminate almost all winds with a quality index. The quality of the reprocessed AMV products is similar to the quality of the operational products for IR and VIS AMVs. With respect to the MIEC products there is a marked increase in quality, when comparing all reprocessed AMVs with a QI larger than 0.8 with the historical AMVs. A quality increase can still be seen in the normalised vector RMS if AMVs with a QI larger than 0.6 are used in the comparison with the MIEC products.

Due to the large noise of the WV imagery both the quality and the number of reprocessed WV AMVs are reduced drastically compared to the current operational product. The quality of the IR AMVs is also indirectly impacted via a degraded performance of the semi-transparency correction.

The derived HRV products, which is using a low resolution image for every second slot, have a quality very similar to the present operational HRV products.

Initial forecast impact experiments at ECMWF with the ERA-40 configuration show encouraging results from the assimilation of the reprocessed AMVs. Forecasts of the geopotential are significantly improved when the reprocessed winds are used instead of the old MIEC winds, particularly over the Southern Hemisphere. Currently, there is a small negative impact on the tropical wind forecast, and this needs further investigation.

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