Instrument Calibration Issues: Geostationary Platforms

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Abstract

The main products derived from geostationary satellite data and used in Numerical Weather Prediction (NWP) assimilation are the Atmospheric Motion Vector and Clear Sky Radiance products. These products provide an important addition to the global observing system and are in general of good quality. There are however known deficiencies in the products related to either the calibrated image data used for the product extraction, or in the product derivation methodologies applied. All products are affected by the calibration accuracy. The calibration of the instruments on-board geostationary satellites provides a challenge to the operational data providers. Instrument pre-launch characterisation, in-orbit change, behaviour and anomalies are only some of the issues that have to be dealt with if an accurate calibration is to be provided. This paper will give a brief overview of the current status of the calibration of the first and second generation Meteosat satellites. Both series of satellites have an on-board black-body calibration that provides the basic calibration of the data. For the first generation satellites only the black-body calibration unit on Meteosat-7 is used. The currently operational older satellites Meteosat-6 and Meteosat-5 are cross-calibrated to Meteosat-7. The calibration is monitored with vicarious calibration using in-situ measurements, numerical weather prediction fields or cross-calibration to other satellites. The paper will give particular emphasis is given to the calibration approach and to known corrected and uncorrected anomalies and behaviour of the instrument and the data provided. Additionally an overview of currently known problems in the derived products will be given.

1. Introduction

The calibration of the geostationary first and second generation Meteosat satellites is based on an on-board black-body calibration unit. Due to limitations the black-body calibration unit on the Meteosat First Generation (MFG) satellites is operational only for Meteosat-7. The other two, currently operational MFG satellites Meteosat-5 and Meteosat-6 are cross-calibrated with Meteosat-7. Hence, the Meteosat-7 black-body calibration provides the reference calibration for all first generation satellites. The blackbody calibration on the first Meteosat Second Generation (MSG) satellite Meteosat-8 is fully operational. The largest source of uncertainty in the calibration is the modelling of the front-optics that is not a part of the black-body calibration. For Meteosat-8 three different black-body calibration models that take into account the effects of the front optics are applied and agree within 0.1 - 0.5 K with each other, depending on channel. The calibration, as monitored by vicarious and cross-calibration , suggest that the calibration provided is accurate to about 1.0 K or better. For the Meteosat-7 independent monitoring suggest that there is a residual bias of the order of 2.5 – 3 K. This bias is mainly due to less accurately modelled impact of the front-optics than for Meteosat-8 and may require further improvement.

Additionally to the obvious calibration issues the Meteosat Visible and Infrared Imager (MVIRI) of the first generation satellites also have some significant corrected and uncorrected anomalies and behaviour. The effects impact both the geometric and radiometric accuracy of the instrument. Additionally to these effects the MFG-satellites are also highly impacted by so-called eclipse effects. These effects caused by solar reflection through the optical path have occasionally a significant impact on the image data. On Meteosat-8 the eclipse effects have to a large extent been avoided through a better design of the radiometer and residual effects can be modelled and corrected.

The calibration is only the first pre-requisite for the derivation of the main products used in Numerical Weather Prediction (NWP) assimilation. Currently the Atmospheric Motion Vectors (AMV) and Clear Sky Radiance (CSR) products are used operationally by several various NWP centers. These products are generally of high quality and form an important addition to the global observing system. The derivation of these products depend highly on not only the calibration, but also on cloud classification accuracy, cloud height assignment and the dependency between the extracted parameter and how well it represents the parameter that the NWP assimilation scheme expects.

This paper will give a brief overview of known problems in the image data used to derive the products and the products themselves.

2. Black-Body Calibration

The black body calibration approach is based on the use of a cold and a hot reference observation. For the MFG satellites these reference observations are provided by the cold black body that has the ambient spacecraft temperature and the hot black body that is heated to about 50 K above the temperature of the cold black body. For the MSG satellites the cold temperature is based on space-view and there are two different heated black –bodies, the cold black-body and the hot black-body. For both satellite types the black body calibration sequence starts by interrupting the nominal optical path before the front optics, either with the insertion of a mirror (MFG) or by the black-body itself (MSG) (see Figure 1. for MSG). For MFG this will first give the cold reference temperature and the mirror will then be moved to view the heated black-body. For MSG the insertion of the black-body in the optical path will always give warm reference temperature, either the cold reference, currently every two hours, or the hot reference, currently twice per day. These measurements then provide the reference signal that can be used to calibrate the real observations. For further details see e.g. Pili (2000) for the MSG satellites.

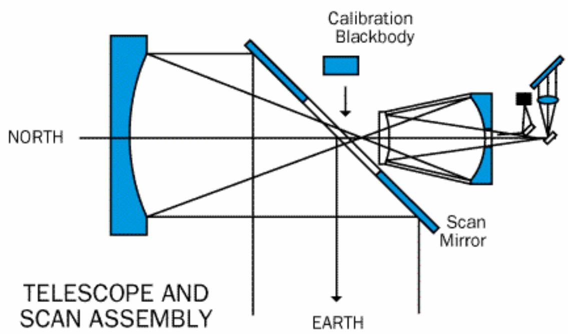

Figure 1. A schematic description of the SEVIRI telescope and scan assembly with the black-body.

The relationship between digital counts and the observed radiance is assumed generally assumed to be linear: i.e. C (L)=g R (λ ,T)+C 0 ,(S1) where C (L)is the digital count output from the instrument, R (λ ,T) the measured radiance ,λ is the wavelength (in practice a spectral interval),T is the effective black-body temperature of an observed scene, g is the gain (the inverse is the calibration coefficient),and C 0 I the offset. The assumption of linearity between counts and radiance causes a small error for the MFG. For MSG these effects are corrected by using coefficients measured before launch. It should be noted that for MSG the actual measurements are done with three detectors simultaneously. The insertion of the mirror (MFG) or the black-body itself (MSG) in the optical path necessitates the application of a correction that takes into account the effects of the front optics, particularly the primary mirror (see Figure 1). For MFG the model is highly sensitive to various parameters that have in the past been tuned by comparisons with alternative calibration methods. For MSG three different front optic models have been developed. Also these models can be tuned and currently all models agree to within 0.1-0.5 K. It should be noted however, that the selection of which model to use is done by vicarious calibration. The current vicarious calibration for MSG is using the narrow-band Synsatrad Radiative Transfer Model developed at EUMETSAT (Tjemkes and Schmetz, 1997) together ECMWF forecast data to simulate the top of atmosphere radiances. Figure 2 shows the results from the current EUMETSAT vicarious calibration for the 7.3 and 12.0 micron channels indicating a change in the validation environment caused by the introduction of retuned parameters for continuum and HITRAN 2004. The new configuration will be come operational in early 2006. The current black-body calibration value is indicated with a dashed line. Corresponding monitoring figures for the operational clear sky radiances as given by the Numerical Weather Prediction (NWP) Satellite Application Facility (SAF) home page is shown in figure 3.

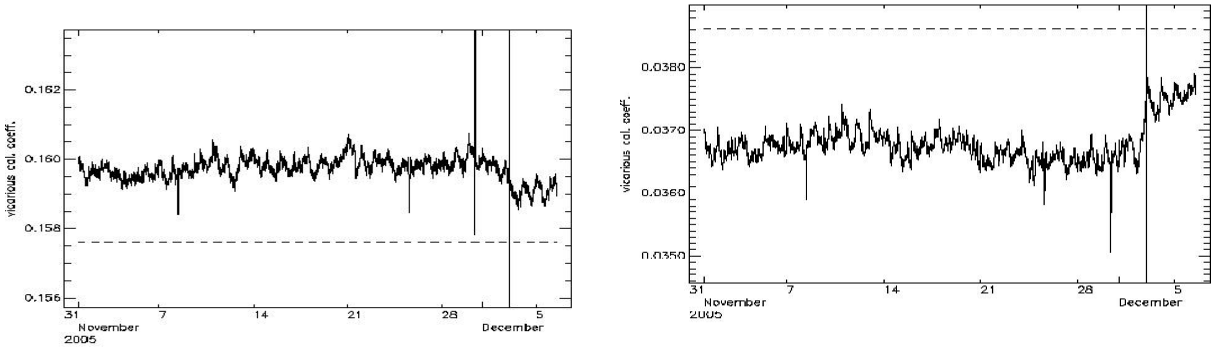

Figure 2. Examples of vicarious calibration moniroting at EUMETSAT (12.0 micron left, 7.3 micron right).

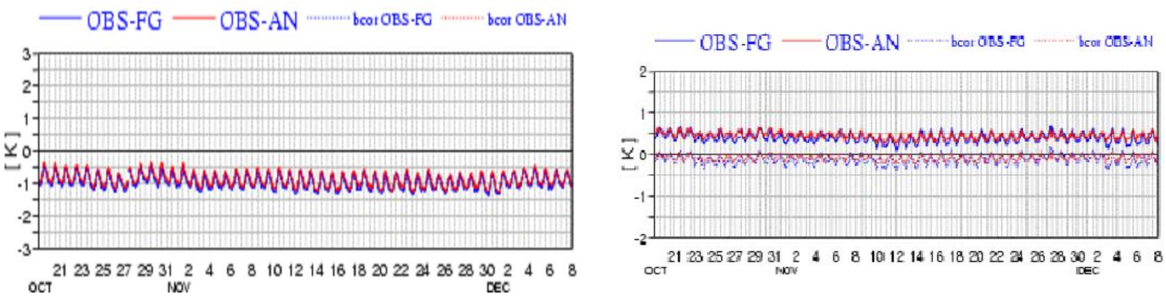

Figure 3. Examples of Clear Sky Radiance monitoring provided by the NPW SAF (12.0 micron left, 7.3 micron right).

3. Image anomalies and eclipse effects

The image data from the Meteosat satellites are generally of high quality. It should however be noted that the first generation satellites are affected by eclipse effects, when solar radiation is reflected via the front optics onto the detectors. These effects manifest themselves as bright stripes, bows or spots. Figure 4 gives an example of these effects as apparent on the water vapour images. Currently these effects are not flagged by the image processing. To alleviate the impact of these effects the Meteorological Products Extraction Facility (MPEF) flags product lines affected. However, the checks are simple and the user will have to take that into consideration during the eclipse periods that occur twice a year for a couple of weeks. Additionally to the eclipse effects there are some known anomalies on the first generation satellites.

Additionally to the eclipse effects some of the first generation satellites also have problems effecting the image quality. Meteosat-4 that is no longer operational had problems with the on-board electronics. These problems saturated consecutive pixels over a few lines during certain periods. The effect was named “fish” was not correctable when occurring, but the problem was limited by reconfiguring the spacecraft twice a year, with a minimum impact on product quality. Meteosat-5 is affected by a loose lens in the cold optics causing a significant geometric anomaly. This anomaly is well characterised and corrected during image rectification and has therefore no significant impact on the products. However, there is a residual effect in the observed gain that may wary with 1-2% from image to image and this effect is currently not accounted for. Figure xx shows the impact of the residual radiometric anomaly on global averages during commissioning as seen by the redundant detectors. A different set of detectors are used operationally for which the effect is smaller.

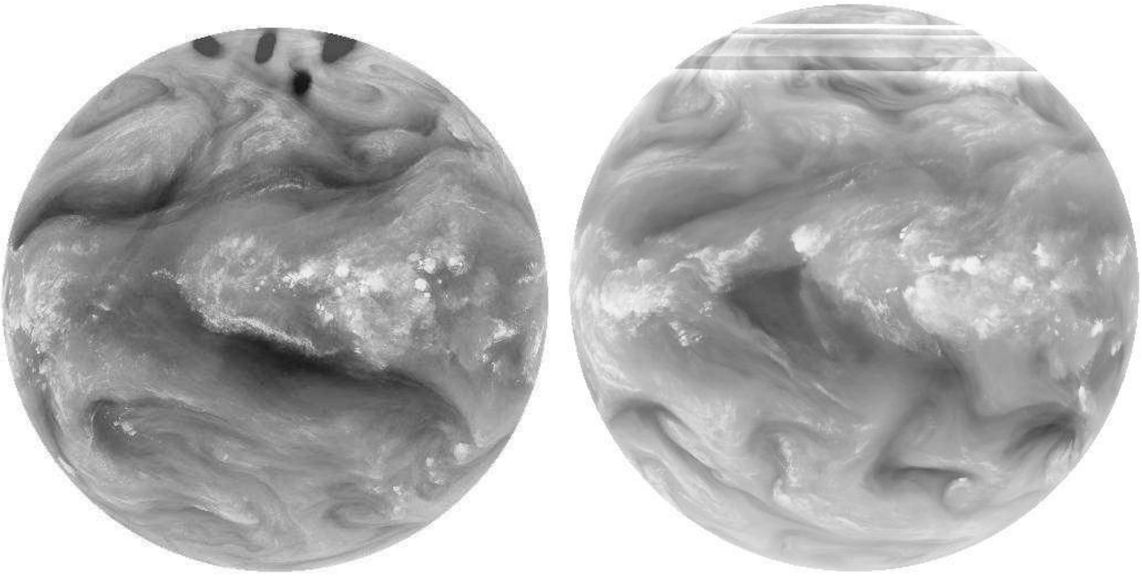

Figure 4. Eclipse effects as can be seen on the water vapour images of the first generation Meteosat satellites.

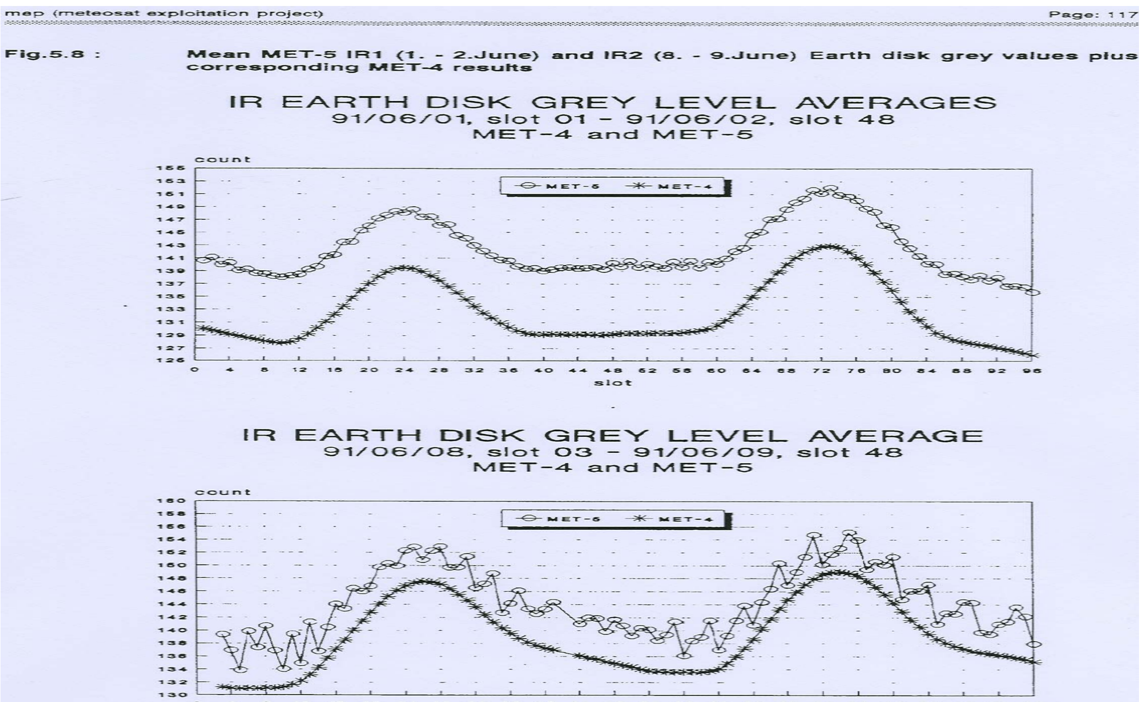

Figure 5. The impact of the rotating lense on the mean IR Earth disj grey levels for the operational (top) and the redundant detector (below).

Meteosat-6 has a more problematic anomaly, i.e. the whole cold optics is loose. This anomaly is difficult to correct for as the behaviour is erratic (Figure 6).Initially the devised correction scheme used consecutive images (and scanned image lines) together with simulated radiances over sea. Figure xx shows the impact of the anomaly on area averages before and after correction. This approach that rendered the satellite usable was still occasionally not detecting the anomalies, hence having a detrimental impact on the product quality. Currently, Meteosat-6 is cross-referenced to Meteosat-7 and the correction scheme is eliminating most of the anomalous effects.

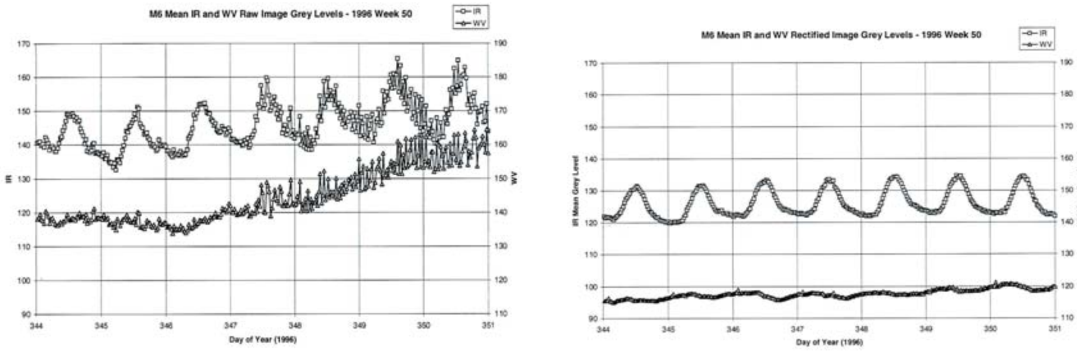

Figure 6. The impact of the Meteosat-6 anomaly on the observed mean radiances for the IR and water vapour channels (left). To the right the corrected radiances.

The situation with respect to eclipse effects and anomalies is for the first Meteosat Second Generation satellite, operational as Meteosat-8 significantly better. No known anomalies are present and the design of the instrument minimises the impact of eclipse effects. Additionally, in case of residual eclipse effects these can be correct with the on-ground correction software. Hence, there are no limitations to the use of Meteosat-8 data through the eclipse periods.

4. The Clear Sky Radiance product

The clear sky radiance product is one of the main products derived operationally at EUMETSAT. The product has two major parts that can cause biases or errors, i.e. the calibration and cloud detection. Currently all calibration errors or biases are translated directly to the product. These biases can in an assimilation scheme be corrected for through bias correction schemes. More problematic is the effect of undetected or wrongly classified clouds that can cause a cold bias in the observations. The cloud contamination effect can be seen in figure 3, where a strong diurnal effect is visible. This effect is due to poorly detected clouds in the night, however, also diurnal effects in the model may impact the comparisons. Additionally to these effects special care should be taken to use the correct sub-satellite point in assimilation. Though the satellites are geostationary and hence located over the equator, there is a natural variation to this location, the inclination. During the nominal life-time of the satellites the inclination is kept to +/- 1 degree latitude causing a very small impact on the use of the data. However, all the first generation satellites are now past the nominal lifetime and there is no fuel left for the so-called inclination manoeuvres. Hence the satellites are operated in a high inclination mode, which implies that there is a very strong diurnal cycle in the sub-satellite point. Currently Meteosat-7 is already at a 7 degree inclination and the impact of using a wrong SSP is significant. This is demonstrated in figure 7 showing a diurnal pattern in the observed bias during assimilation at ECMWF. This effect is completely removed when using the correct SSP. Also Meteosat-6 and –7 are currently operated in a high inclination mode with an inclination of 5 and 2 degrees respectively. For all satellites the inclination is increasing with roughly one degree per year.

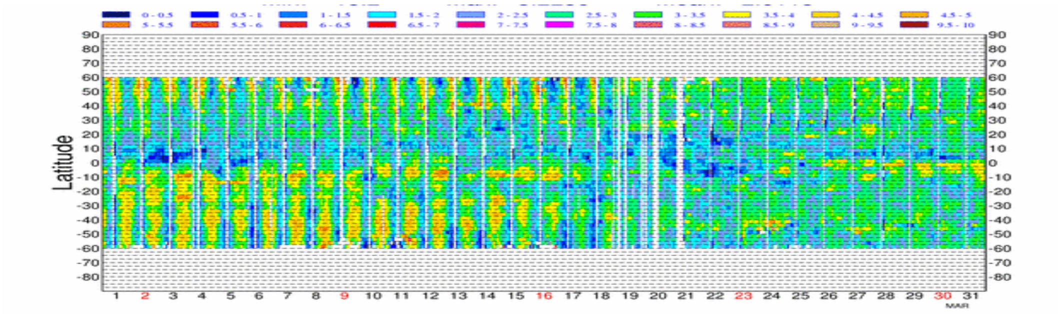

Figure 7. The impact of not using the correct sub-satellite point in NWP assimilation of clear sky radiances.

5. The Atmospheric Motion Vectors

The Atmospheric Motion Vectors derived by tracking atmospheric features in consecutive images form currently an essential part of the global observation system. Currently this data is used as single point measurements during data assimilation, which introduces some biases attributed to the data. The size of the tracking template is generally of the order of 80 km * 80 km, though both higher and lower resolution products are available. The single point approximation is not only related to the horizontal scale of the winds, but also to the fact that the radiance up-welling from clouds and clear sky targets is emitted from atmospheric layers defined by the optical depth of the target. An additional effect is that the clouds do not necessarily travel with the wind speed at the top of the clouds, but rather at a lower level. For low level clouds this is at EUMETSAT corrected by applying a cloud base or inversion height to the AMVs., but for high level clouds there are currently no means to provide an appropriate correction. The size of the templates is also important for the validation of the derived winds. Generally, the AMVs are compared to collocated radiosondes with a collocation area that is comparable to the target size. However, decreasing the distance to the radiosondes decreases also the discrepancies between the observations as shown in Figure 8, where the normalised RMS error (NRMS) is decreasing collocation distance.

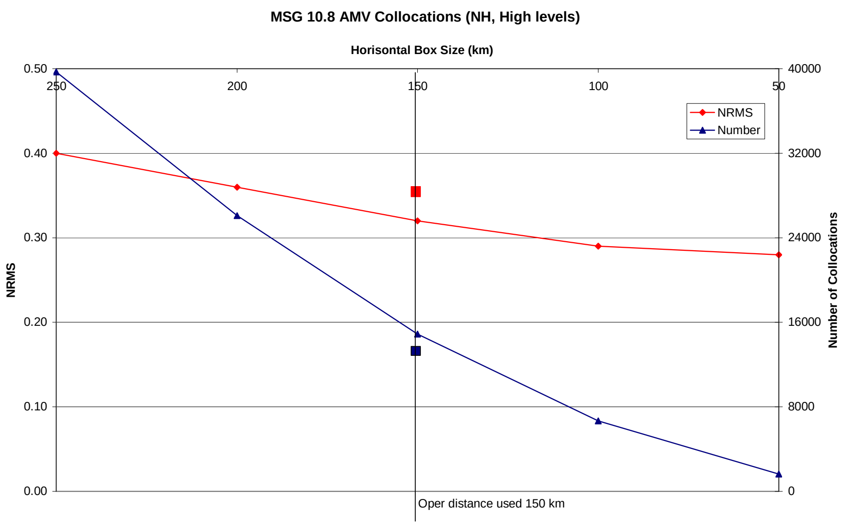

Figure 8. The impact of decreasing the collocation distance for AMV vs. radiosondes for the Normalised RMS error (RMS divided by mean wind speed) (red), but also for the number of collocations (black).

It seems however that the most dominating error in the AMVs does not originate from the way the data is used in assimilation, but is rather related to uncertainties in the height assignment of the winds. The height assignment is affected both by calibration problems, but also to the methodologies used to correct for semitransparency. For the first generation satellites this correction performed by using observations in both the water vapour and infrared channels (e.g. Schmetz et al., 1993). With the MSG satellites also the CO2 channel can be used to define the current height of the clouds. Both of these corrections are already derived operationally for the MSG data at EUMETSAT, however only the CO2-slicing is used for the final AMV height. The correction schemes also have a strong dependence on the scenes and cloud classification scheme, which defines the initial cloud types in a target area. The accuracy of the various methods has been investigated thoroughly (Nieman et al, 1993) and it has been shown that they agree to within 50 – 80 hPa of each other, which is significant in areas with strong wind shears. Figure 9 present examples of current monitoring proved by the NWP SAF monitoring page.

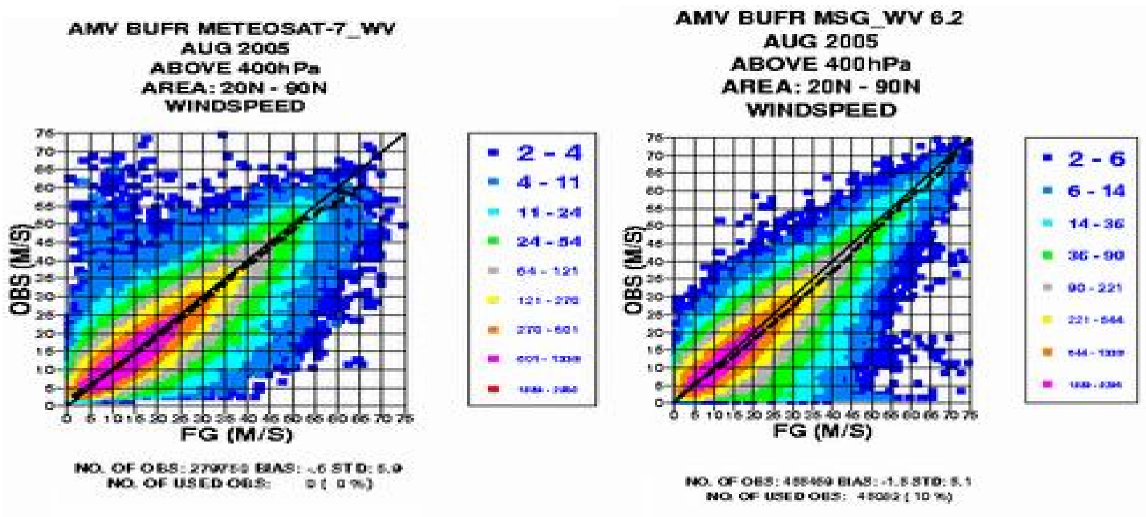

Figure 9. AMV monitoring results provided by the NWP SAF monitoring page for Meteosat-7 (left) and Meteosat-8 (right) water vapour cloud tracked winds.

6. Reprocessing

The Meteosat image archive currently spans back more than 25 years. This data set provides one of the longest continuous satellite data sets derived with the same instruments. It should be noted that there has over the years been some improvements to the image both in terms of signal-to-noise ratio as well as in going from 6 to 8-bit observations. For all satellites except Meteosat-7 the calibration was based on vicarious calibration. It therefore one of the main tasks of the EUMETSAT reprocessing environment to provide improved calibration that together with state of the art algorithms will be able to provide significantly improved products. Figure 10 shows an example of the improvements observed in the AMV errors over time. The black curve denoted MIEC shows the Normalised RMS error (RMS error divided by the mean winds speed) for the operational winds derived in the mid eighties. The blue curve denoted ARNO shows the improvement achieved with the reprocessing environment in support to the ECMWF ERA project. Additionally to these two curves two curves related to CGMS statistics are shown as a reference.

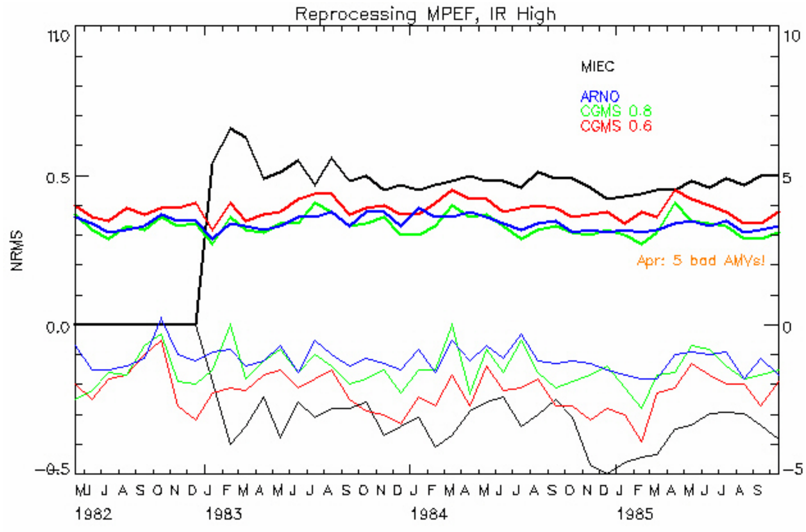

Figure 10. The impact of improved calibration and methodologies on the AMVs as demonstrated during the EUMETSAT reprocessing activities in support of ECMWR re-analysis activities.

7. Conclusions

The use of satellite data in Numerical Weather Prediction still presents both the data users and the provides with great challenges. Image calibration errors and anomalies are still degrading the quality of the derived products, but additionally issues related to data representatives are a challenge for data assimilation. With the advent of Meteosat Second Generation improvements in all these areas have already been seen, and in the years to come further improvements are expected. An additional challenge to the operational data derivation and dissemination is the provision of well calibrated consistent products suitable also for climate research. To address these specific issue EUMETSAT is currently reprocessing the first generation Meteosat satellite data, and will in the future continue this activity as methodologies and science keep improving.

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