On Differences in Effective and Spectral Radiance MSG Level 1.5 Image Products

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1 INTRODUCTION

1.1 Purpose and Scope

The effective radiance image product is expected to become operational in May 2008. In order to have a reference for the changes applied and to understand the differences observed between spectral and effective radiance, the 24th STG SWG meeting requested EUMETSAT to clearly document the changes applied in one document, including the reasons for differences between simulated and effective radiances (Action 24.21). Such a document is considered very useful for the entire process of the introduction of effective radiances.

1.2 Reference Documents

[RD 1] A Planned Change to the MSG Level 1.5 Image Product Radiance Definition, v1A, 5 January 2007, EUM/OPS-MSG/TEN/06/0519

[RD 2] Radiometric Calibration of MSG SEVIRI Level 1.5 Image Data in Equivalent Spectral Blackbody Radiance, EUM/OPS-MSG/TEN/03/0064

[RD 3] Effective Radiance and Brightness Temperature Relation for Meteosat 8 and 9, v1, 28 January 2008, EUM/OPS-MSG/TEN/08/0024

[RD 4] A Simple Conversion from Effective Radiance back to Spectral Radiance for MSG Images, EUM/OPS-MSG/TEN/07/1053

2 DIFFERENCES BETWEEN THE SPECTRAL RADIANCE PRODUCT AND THE EFFECTIVE RADIANCE PRODUCT

During the parallel dissemination trial, it was possible to receive the Meteosat 9 Level 1.5 images in effective radiance in parallel with the operational spectral radiance product via EUMETCast from 21 January through to 17 March 2008. EUMETSAT intends to change the operational MSG Image Service to effective radiance in May 2008. The announcement together with the reason for this change can be found in [RD 1]. [RD 1] also suggests a method for conversion of spectral radiance to effective radiance to support the preparations for the change. It is important to understand that the change to effective radiance is not simply an implementation of the approximate formula presented in section 4 of [RD 1]. The purpose is to change all relevant calibration parameters (derived on ground and in orbit) to create a consistent effective radiance product. [RD 1] does not provide any assumptions for the applied change; rather it points out the way forward and the expectations for the effect of the change. The keyword is "expectations" here, because today’s results were not known at that time. [RD 1] therefore says: "Please note that this is only an approximation which is provided for the sole purpose of preparation for the intended change to effective radiances. No guarantee for the accuracy of this simulation can be given."

The following changes were applied to fully implement the new effective radiance:

1. Change of radiance definition: i.e. in all processing steps, radiance is expressed in effective radiance. No approximations are used;
2. New analysis of on-ground instrument test data: Ground characterisation is now done in effective radiance;
3. Improved instrument model as a result of ground testing analysis: The simple second order fit is replaced by a physical model. The same model is used for ground characterisation and in-orbit data processing within the IMage Processing Facility (IMPF);
4. Gain and non-linearity are now modelled rather than kept constant.

Now, the inconsistency between user expectations and actual processing – as expressed in [RD 1] – has been replaced by a fully consistent data processing. The modelling of the instrument in terms of effective radiance is the same in both the IMPF and in the ground testing data analysis. Hence, errors created by “fit of a fit” problems (see Section 3) do not exist anymore. Also, the new model also removes problems with the treatment of non-linearity that were identified in [RD 1]. IMPF internal changes were also applied to achieve a fully consistent processing and to remove digital filter artefacts from blackbody data (see below).

The conversion suggested in [RD 1] converts spectral radiance into brightness temperatures and uses an approximate formula to calculate effective radiance. The basic assumption is that the effective radiance derived from both products is always the same. With the full implementation of the effective radiance in the IMPF, we now find that this assumption is not exactly true: When inverting both effective radiance images and spectral radiance images to brightness temperatures, they are not exactly identical.

The reasons for the differences are:

1) The non-linearity of the detectors with respect to the optical signal (see Section 3):
   i. The non-linearity has been newly determined from the instrument ground testing data in terms effective radiance. The problems with the existing treatment of non-linearity in the spectral radiance product that were identified earlier ([RD 1]) are now obsolete.
   ii. A correction of the non-linear with instrument background has been introduced via the new instrument model in the IMPF. The "Non-linearity errors" mentioned in Section 5 of [RD 1] are not just corrected but the parameters fully replaced by parameters relating count to effective radiance.
2) A problem with the blackbody data downlinked from the spacecraft has been discovered and corrected (see Section 4). The first few pixels of a blackbody line are corrupted by the on-board digital filter (this is not a problem for the image data). Inclusion of this corrupted data in the blackbody processing caused an error in the calculated radiance of all infrared channels of less 0.1%, which is non-linear when expressed in temperature. The corrupted data is now discarded.

These differences are displayed in Figure 1 and discussed in some detailed in the following sections.

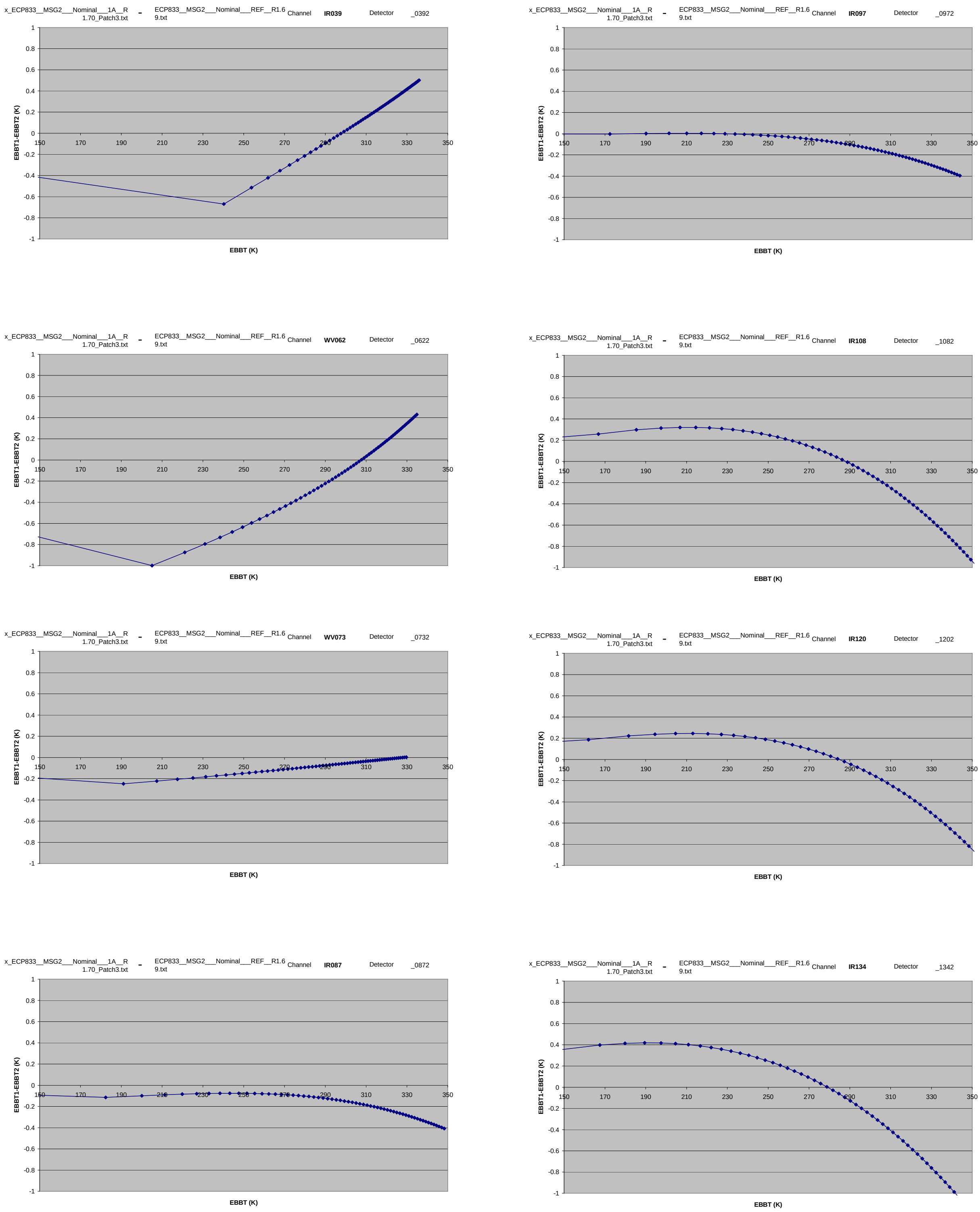

Figure 1 Comparison of the look-up tables used for Level 1.5 image generation with and without the change to effective radiance (middle detector only). The radiance values in the lookup tables are converted to temperatures using the appropriate method for each product ([RD 2] and [RD 3]). Shown is the difference EBBT(Effective)-EBBT(Spectral)

3 CHANGES TO THE IMAGE PROCESSING FACILITY SOFTWARE AND THE TREATMENT OF NON-LINEARITY

The inconsistency between user expectations and actual processing should be replaced by a fully consistent data processing right from the outset, i.e. starting from the on-ground instrument characterisation. This needs to include a modelling of the instrument in terms of effective radiance that is used in both the IMPF and in the ground characterisation data analysis. This new model also removes problems with the treatment of non-linearity that were identified earlier.

The instrument manufacturer suggested a modified modelling of SEVIRI in the form of a closed formula of count (ΔC, numerical offset removed) of effective radiance L^{eff}:

$$\Delta C = \frac{G}{1 + B \cdot L^{eff}} \cdot L^{eff} \tag{1}$$

For practical use, this is inverted to a function of effective radiance from count:

$$L^{eff} = \frac{\Delta C}{G} \cdot \frac{1}{1 - B \cdot \Delta C / G} \tag{2}$$

The re analysis of the ground testing data now provides the means to calculate the formal parameters G and B on-board[1]. The gain G can be described by the programmable electrical amplification and the throughput of the optics (with a weak dependency from the temperature of the instrument), whereas the non-linearity B is determined also by the throughput, and by the temperature. This new instrument model is as close as possible to the physics of the instrument. The ground testing allows determining the necessary parameter by a fit of counts vs. effective radiance of a blackbody source under various conditions.

Prior to the change to effective radiance, the instrument was characterized by a second order fit of count vs. spectral radiance at a “symmetry wavelength”. From there, a single non-linearity parameter was determined that included corrections for the non-linear response of the detector towards absorbed energy and spectral corrections for the difference between absorbed energy (effective radiance) and spectral radiance. This non-linearity parameter was assumed to be constant for each detector. Inside the IMPF, using this parameter, a second quadratic relationship was generated: namely, spectral radiance at “reference wavelength” as a function of count. This was done inaccurately and the error due to this inconsistency was estimated in [RD 1].

The new scheme allows a fully consistent description between effective radiance, non-linearity and the physics of the instrument. Therefore, the problems arising from the use of different wavelengths do not exist anymore. The IMPF software and databases can now take

[1] The formal parameters G and B can be interpreted as generalized gain and non-linearity:
$\left.\frac{\partial \Delta C}{\partial L^{eff}}\right|_{L^{eff}=0} = G$, and $\left.\frac{\partial^2 \Delta C}{\partial L^{eff\,2}}\right|_{L^{eff}=0} = -2BG$

full advantage of the new model. Moreover, the internal radiometric processing of the IMPF is fully performed in terms of effective radiance and in units of $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$. This includes blackbody processing, equalization of detectors within one channel, straylight correction and star detection. Although this is true also for the solar channels, there is no noticeable effect on these, because they are linear (so B=0) and the calibration is performed via the MPEF vicarious calibration that has always been in effective radiance.

For the processing of the blackbody, the relationship between temperature and effective radiance is established by a set of tables that are used for both ground characterisation data processing and mission data processing within the IMPF.

4 DATA CORRUPTION BY THE ON-BOARD DIGITAL FILTER

Within SEVIRI, image data is processed in 12 bit representation. Prior to the downlink, the data is filtered using a digital filter and then reduced to a 10 bit representation. The purpose of the filter is to reduce processing artefacts. This filter is implemented as a Finite Impulse Response filter (FIR) with 9 samples length. The filter is applied individually on each detector line. The filter is initialised at the begin of each line (at the Eastern edge in the image). The initialisation is performed with zeros so that at the Eastern edge a few pixels have a significantly lower count than the rest (Figure 2). There is no problem for the image data because the Earth horizon stays far away from this area.

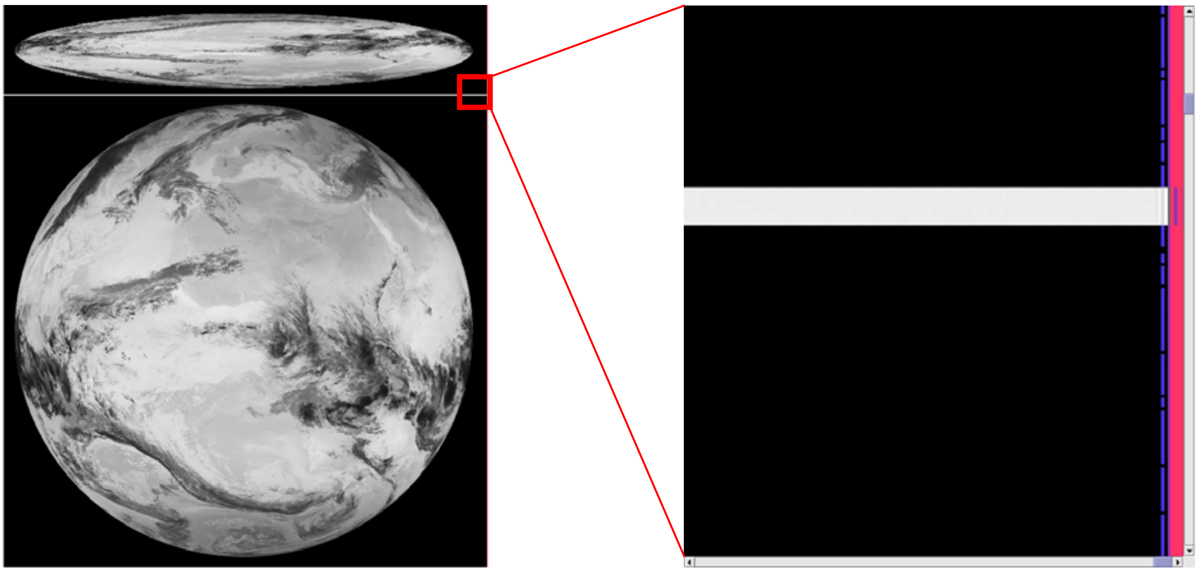

Figure 2 Effect of FIR filter. Left, raw image (MSG2, IR120, 29. Jan. 08, 00:45). The grey line is a blackbody measurement. Right, zoom of eastern part, including blackbody line. The effect of the FIR is enhanced with colours: red =0 blue 50 raw counts.

The blackbody calibration measurement (seen as a grey line in Figure 2) is no different to any other line in terms of SEVIRI data processing. Hence, the corruption is also visible in the blackbody data.

It has been discovered that, up to now, the few pixels corrupted by the FIR filter initialisation effect have not been discarded but erroneously included into the averaging of the blackbody measurements. As they are significantly smaller than the true blackbody measurements, the instrument response to the blackbody was underestimated and hence over-corrected by 0.1%. As a result, the calibration curves were adjusted so that the resulting Level 1.5 Radiance was 0.1% too high.

This problem has been removed during the implementation of the effected radiance. The net effect is that images are 0.1% darker than without the correction of this problem. As the correction represents a linear change by 0.1% in radiance, the differences in equivalent blackbody temperatures are non-linearly dependant on the channel and signal. It is worth underlining that this FIR filter problem is fully independent of the effective radiance change; it has just been corrected at the same time.

5 OTHER DIFFERENCES

It is important to understand that the relationship between the effective and spectral radiance image product streams (such as during the Parallel Dissemination phase) is not a constant one. As both products are created in real-time, there is a different model history within each production chain that leads to differences in the geometric performances (both of which are well within the specifications). Hence, a direct pixel to pixel relationship does not exist. Moreover, for the radiometric performance, two different models exist which develop differently in time (again, both streams are well within the specification). The implication of this is that, the relationship between effective radiance and spectral radiance – as produced by the real-time production chains– varies slightly with time.