Technical Note on MIPAS non-linearity correction

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1. Introduction

Out of the MIPAS detector channels A1/A2, B1/B2, C1/C2, and D1/D2, the long wavelength channels A1/A2 and B1/B2 show a non-linear response to the incident photon flux. The varying response as a function of incident photon flux has to be corrected prior to radiometric calibration. For this purpose, NL-correction parameters have been determined on ground and have been applied to all measurements throughout the mission. During the mission it has turned out that the non-linear channels exhibit a certain aging which also has an impact on the non-linearity. Therefore the NL-correction parameters have to be adapted to the aging.

The NL-correction parameters determined on ground are used up to MIPAS level 1 V5 (up to level 2 V6), while new NL-correction parameters, deduced from in-flight characterisation measurements and taking the detector aging into account, have been applied in V7.

2. Non-linearity correction

In order to deduce the NL-correction parameters, the non-linearity curve has to be determined. In principle, this is the detector output (voltage) as a function of the incident photon flux. Unfortunately the complete detector output (AC+DC signal) is not measured. The only signal available is the digitized AC part of the interferogram (ADC), while the DC contribution is suppressed and not known. Since the degree of non-linearity depends on the total photon flux, a method had to be developed that allows to estimate the total detector output from the measured AC signal.

The interferogram peak, i.e. the difference between maximum and minimum, $ADC_{max-min}$, is proportional to the DC signal and can be used to estimate the latter.

As a more rigorous alternative, the so-called DCzero method has been developed. The DC zero point is defined as the detector DC value obtained when the radiation of the source outside the interferometer is zero. In the ideal case (modulation efficiency = 1, no phase/digitization errors) the ZPD signal corresponds to the DC zero point for the complementary detector outputs labelled with 2 (for regular detector output the ZPD value is 2AC(ZPD) larger than the DCzero point). Knowing the modulation efficiency and correcting for phase errors, this information can be used to position interferograms with different light levels on a common detector curve, although only AC values were measured. The detector curve (represented by a polynomial) is then fitted to minimize the non-linearity-caused out-of-band artefacts for a number of IF16 interferograms covering a large range of incident photon fluxes. The method requires raw data mode IF16 interferograms since in nominal mode interferograms the digital filtering (decimation) removes the out-of-band artefacts. There are 30 IF16 measurement sequences available covering the entire mission in an irregular manner.

The DCzero method has been successfully tested using laboratory measurements obtained with the Bruker IFS125HR spectrometer at DLR. In contrast to MIPAS-ENVISAT this spectrometer can be configured to yield DC interferograms. Thus, the correct positioning of the interferograms by the DCzero method was validated using a real instrument with a similar type of non-linear detector.

The required modulation efficiency is obtained from a combined fit of out-of-band artefacts and gain ratios from nominal mode IF4 measurements (blackbody measurements at different blackbody temperatures).

3. Detector aging

The detector aging has been taken into account by investigating the change of non-linearity over time. Since the aging is faster at the beginning of the mission than at the end, a regression in orbit, and orbit$^{1.25}$ was performed for evenly spaced points of the detector curve. Further regression parameters were instrument temperature and ice absorption, as these quantities also influence the NL characteristics. From the regression coefficients detector curves were reconstructed and used in further processing, leading to non-linearity correction coefficients as used in V7.

4. Interchannel ratios

In IF16 mode, the spectral channels show a certain spectral overlap (see Fig. 1) which allows checking the self-consistency of the data. In absence of radiometric errors, the calibrated radiance in the overlapping regions must be the same for the different bands. The mean ratios between the different bands in overlapping regions have been calculated for 30 IF16 measurements (one value for all scans) throughout the mission, and a linear fit in orbit (or time) has been applied to the data. Table 1 shows the radiance ratios between different bands at the beginning and the end of the mission as deduced from the linear fit using V7 data. The linear channels D1/D2 and C1/C2 show an excellent agreement of better than 0.1 %, whereas the non-linear channels show discrepancies of up to 2.7 %, pointing towards a non-perfect non-linearity correction.

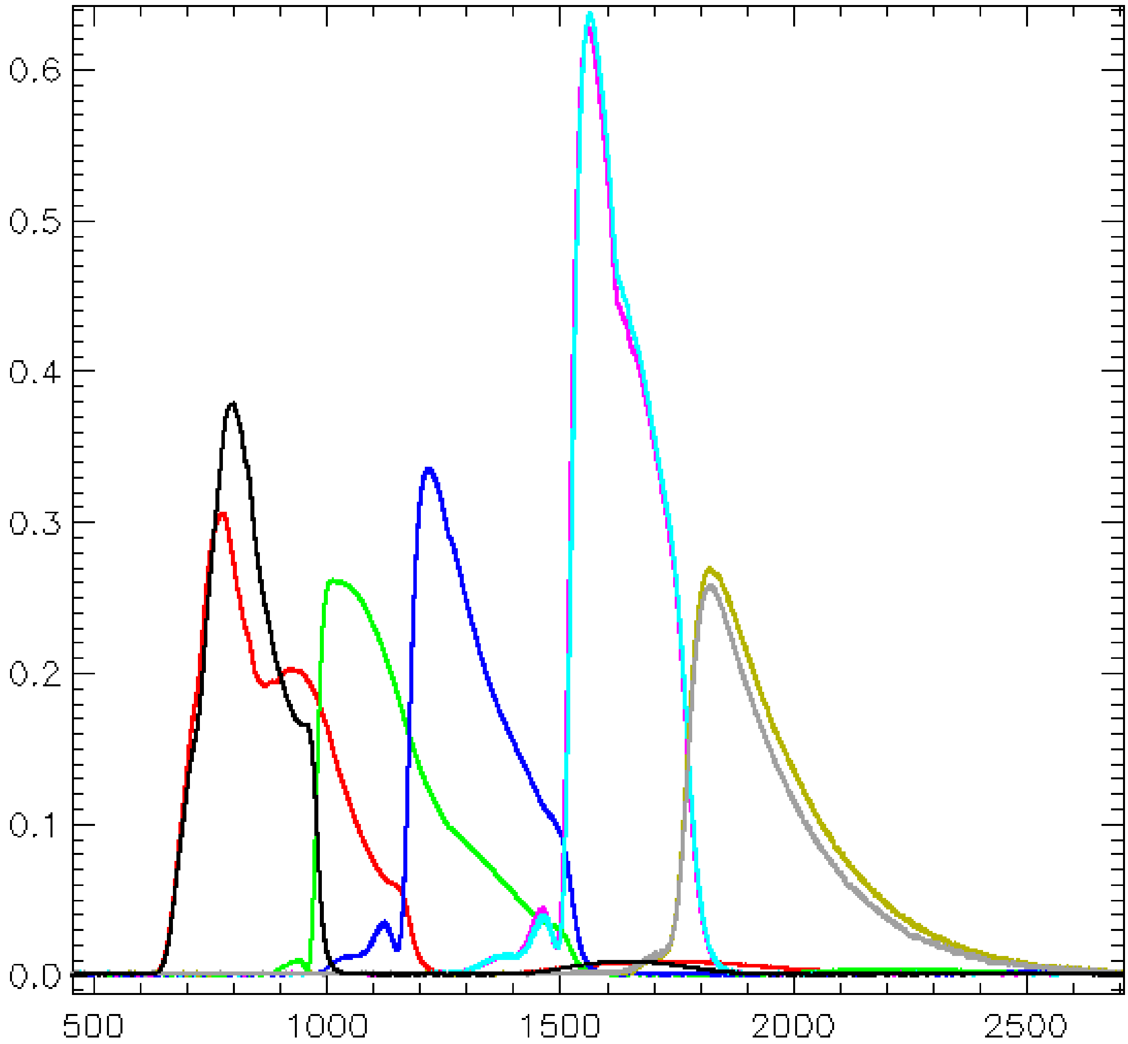

Figure 1: Raw data mode spectra showing overlapping regions

Channels	Ratio @ orbit 0	Ratio @ orbit 50000
A2/A1	1.0048	1.0025
B1/A1	1.0276	1.0271
B1/A2	1.0108	1.0124
B2/A2	1.0123	1.0207
B2/B1	1.0047	1.0011
C1/B1	1.0249	1.0123
C2/B1	1.0229	1.0114
C1/B2	1.0181	1.0061
C2/B2	1.0154	1.0051
C2/C1	0.9996	1.0000
D1/C1	0.9936	0.9986
D2/C1	0.9951	0.9947
D1/C2	0.9985	0.9973
D2/C2	0.9952	0.9937
D2/D1	1.0002	1.0000

Table 1: Radiance ratios between channels in overlapping bands for V7. The error is estimated to be below 0.4 %.

When taking the linear D channels as reference, the scaling error in the non-linear channels A1, A2, B1, and B2 at the beginning and at the end of the mission sums up as follows:

Channels	Ratio @ orbit 0	Ratio @ orbit 50000
Dx/A1	1.033	1.018
Dx/A2	1.028	1.015
Dx/B1	1.017	1.003
Dx/B2	1.012	1.002

Table 2: Radiance ratios between the linear D channels and the non-linear channels, calculated from the various band overlaps, V7.

When doing the same exercise for V5 data, the numbers are as follows:

Channels	Ratio @ orbit 0	Ratio @ orbit 50000
Dx/A1	1.014	1.017
Dx/A2	1.023	1.030
Dx/B1	1.010	1.014
Dx/B2	1.003	1.024

Table 3: Radiance ratios between the linear D channels and the non-linear channels, calculated from the various band overlaps, V5.

In both cases, discrepancies of up to 3 % occur, pointing towards systematic errors in both data versions. The drift (difference between ratio @ orbit 5000 and ratio @ orbit 0) is generally smaller for V5, except for channel B2.

5. Modulation Efficiency

As already explained in Section 2 the modulation efficiency has to be known in order to deduce the detector DC signal from the measured AC signal. For the V7 data, modulation efficiencies of 0.87, 0.86, 0.79, and 0.74 for the channels A1, A2, B1 and B2, respectively, have been assumed. These values have been deduced from measurements, combining IF16 and IF4 data.

The uncertainty of these values is, however, high (see Fig. 2), indicating that the determination of the modulation efficiency from measured data is questionable. The assumed modulation efficiency has a comparably large impact on the NL correction parameters and the resulting scaling factors of the spectra, therefore a good estimate of the modulation efficiency is crucial for the determination of the NL-parameters.

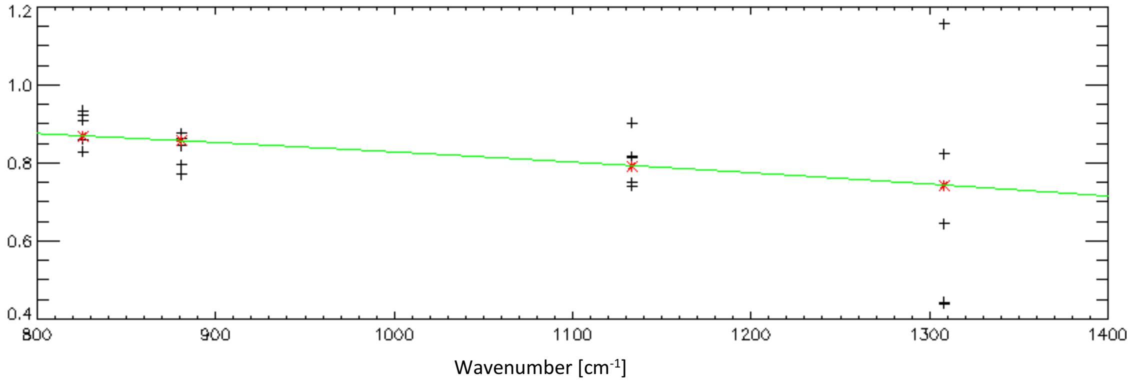

Figure 2: Modulation efficiency as deduced from combined IF16 and IF4 measurements. Black: individual values, green: second order polynomial fit, red: values for the four non-linear channels taken from the fit.

6. Review of the NL-correction

In view of the discrepancies in the interchannel ratios as shown in Table 2, the NL determination method has once again been reviewed. Since the DCzero method in general could be successfully validated with the Bruker IFS125HR spectrometer at DLR, the remaining source of uncertainty is the estimation of the modulation efficiency. The attempt to deduce the modulation efficiency from measured data turned out to be not reliable, therefore the modulation efficiency is estimated from theoretical considerations.

Theoretical considerations have led to the assumption that the modulation efficiency:
a) should be better than 0.9
b) should be rather constant with wavenumber
c) does not change over the mission

(a) is deduced from the quality of the optical components and from the requirement for the modulation efficiency to be better than 0.88.

(b) is based on the assumption that the instrument is well aligned. Only in case of misalignment the modulation efficiency decreases with wavenumber following a cosine curve.

(c) is deduced from the observation that the gain function in band D, which is neither affected by ice nor by non-linearity, is rather constant throughout the mission. In case of modulation changes due to misalignment, the gain function would change as well.

Following these considerations, a modulation efficiency of 0.91 has been assumed for all bands. With this value, new NL-correction parameters have been determined, the correction has been applied to the IF16 data, and new interchannel ratios have been determined. These results are shown in Table 4:

Channels	Ratio @ orbit 0	Ratio @ orbit 50000
Dx/A1	1.021	1.006
Dx/A2	1.011	0.998
Dx/B1	1.001	0.997
Dx/B2	1.001	0.991

Table 4: Radiance ratios between the linear D channels and the non-linear channels, calculated from the various band overlaps, V7 modified.

With the new modulation efficiency, the channel ratios are more consistent than for V7. This is another hint that the estimated modulation efficiency was underestimated during the determination of the NL parameters for V7.

The new estimate for the modulation efficiency is still arguable, but there is physical evidence, that this new estimate is more realistic than the old one and it makes the data more consistent as seen by the interchannel ratios.

Since the modulation efficiency obviously does not change over time (as can be seen from the constant gain function in the linear channels), the drift in the interchannel ratios over the mission is still present in the modified dataset. The change of modulation efficiency yields a channel dependent but orbit/time independent scaling of the radiance. Note that for channel B1 the drift has changed from -1.4 % in V7 to -0.4 % in the modified V7. This is not linked to the modulation efficiency, but for channel also the fit of the NL-artefacts has changed between the two versions. For V7 a quadratic and a cubic artefact have been fitted, while for the modified V7 only the quadratic artefact has been fitted, because the cubic artefact is too weak, leading to unphysical results. The improvement in the interchannel ratios for B1 indicates that fitting only the quadratic artefact is more reliable for this band.

The drift of up to 1.5% over 10 years is still not explained and has to be considered in the error budget.

7. Second step NL-correction

Because of the discrepancies in the interchannel ratios, a so-called second step NL-correction has been proposed. For this second step, a correction factor has been applied to the calibrated spectra. This correction factor is calculated from the interchannel ratios and is dependent on $ADC_{max-min}$ and orbit. The correction factors are determined such that after the correction interchannel ratios are 1 between overlapping channels throughout the mission. It should be noted, however, that individual measurements still show a scatter over more than 1 %.

14 test orbits have been calculated with corrected radiances, and validation of the corresponding level 2 results is under way. This shall help to judge if “forcing” the data to consistent interchannel ratios improves the validation results.

8. Conclusion

The parameters for the new non-linearity correction as applied in V7 are deduced from in-flight measurements and take into account variable conditions like temperature changes, ice contamination and especially detector aging. The quality of the non-linearity characterization is limited, because IF16 and IF4 data, which is needed for the characterization, is sparse (only 30 IF16 orbits are available throughout the whole mission, and only five IF4 measurements). Even more important, the detector DC, which is needed to place the IF16 measurements correctly on the detector curve, is not measured and must therefore be estimated from the measured AC-coupled interferogram.

Nevertheless, this non-linearity characterization is the best we can get out of the data, and the validation against the interchannel ratios shows a reasonable consistency of better than 2 %, mostly better than 1 %. A fine-tuning of the estimate of the modulation efficiency could slightly improve this agreement, but the drift over the mission will not change, therefore a certain inconsistency in the order of 1 - 2 % will remain.

The validation against level 2 products does not give a clear picture which non-linearity correction is better, since other sources of uncertainty are superimposed to the non-linearity error. The new parameters, however, based on in-flight characterization, do not show generally worse results than the old parameters. When using a better estimate for the modulation efficiency, the underestimation of temperature at the beginning of the mission in V7 will be mitigated.

The recommendation for V8 is to use non-linearity parameters which are deduced from in-flight characterization as for V7, but with an improved estimate of the modulation efficiency.

In case level 2 temperature validation gives an unambiguous indication that drifts are better represented in the V7 plus second step correction data, the recommendation should be altered.