MIPAS INSTRUMENT AND LEVEL 1 VERIFICATIONS USING LEVEL 2 RETRIEVAL CODE

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ABSTRACT

MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) is a Fourier transform spectrometer operating on board the ENVISAT satellite and is acquiring high spectral resolution middle infrared emission limb sounding spectra of the Earth atmosphere from space. The instrument measures an interferogram that is transformed and calibrated in the Level 1 analysis. The calibrated spectrum is used in Level 2 for the retrieval of minor atmospheric constituents. The fitting technique used in Level 2 has also been exploited for the retrieval of some instrument parameters and for the verification of the results of Level 1 calibration. The results of this verification procedure are discussed.

1. INTRODUCTION

MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) is a high resolution Fourier transform spectrometer operating on board the ENVISAT satellite. The instrument measures an interferogram of the atmospheric limb emission in the middle infrared. Four contiguous spectral bands are simultaneously observed in the spectral interval from 685 to 2410 cm^{-1} (corresponding to wavelengths from 14.6 to 4.15 μm). The Level 1 analysis [1] performs the Fourier transformation of the interferograms and determines the spectral distributions with an unapodised spectral resolution of 0.025 cm^{-1}. In Level 1 the intensity calibration, the frequency calibration and the determination of the Instrument Line Shape (ILS) are also performed.
The calibrated spectra are used in the Level 2 analysis for the retrieval of the vertical profile of several atmospheric constituents, as well as the temperature and tangent pressures. The retrieval is performed using the Optimised Retrieval Model (ORM) that was developed [2] under an ESA contract for near real time (NRT) analysis of the measurements. The results of the verification of the baseline assumptions that have been adopted in the ORM code are discussed in [3]. The operational version of the ORM is implemented in the ENVISAT Payload Data Segment (PDS) and is being used for the retrieval of atmospheric vertical profiles of temperature, pressure and volume mixing ratios of O_3, H_2O, CH_4, HNO_3, N_2O and NO_2, in the altitude range from 12 to 68 km.
The scientific version of the ORM includes some additional options for the retrieval of instrumental parameters as well as geophysical data. Considering the complexity of the overall process, in which the spectrum is obtained from the transformation of the measured interferogram and the spectrum is used in turn in an inversion process for the retrieval of the geophysical data, the possibility of determining instrumental parameters as part of the final data analysis step provides an important consistency check and in some case very accurate measurements.
The retrieval in Level 2 of the instrumental parameters that concern frequency calibration, intensity calibration, instrument line shape and instrument offset are discussed in the following sections.

2. FREQUENCY CALIBRATION

Fourier transform spectroscopy provides very accurate determination of the spectral frequency. One option of the scientific ORM code is the possibility of fitting for each retrieval a band-dependent parameter for the scaling of the spectral frequency. This operation provided a rich statistics of this quantity for a few orbits, as a function of the limb scanning sequences (75 sequences per orbit), as a function of the retrieval (seven retrievals for each sequence) and as a function of the measurement band (one or two bands in each retrieval). No discrimination was made as a function of the tangent altitude.
The fit of the scaling factor led in most cases to a significant reduction of the residuals pointing out the possibility for an improvement of the frequency calibration.
A systematic difference was observed in the frequency error of the different bands suggesting the need for a frequency dependent correction. Introducing in the Level 2 pre-processor a frequency-dependent correction according to the following law:

$$f(s) = As + Bs^2 \qquad (1)$$

with $A = 2.60511 \cdot 10^{-6} \mathrm{cm}^{-1}$ and $B = -2.140841 \cdot 10^{-9} \mathrm{cm}^{-2}$ constants, the band dependent error is removed. The need for a quadratic term indicates that the instrument has a small non-linear distortion in the frequency scale. Since this effect is not modelled in Level 1 it leads to a bias in the determination of the linear scaling factor. The above frequency correction law provides the correction for the non-linear effect as well as for the related bias introduced in Level 1.

An example of the result obtained when the frequency correction is applied is shown in Fig. 1 in the case of orbit 2081. The deviation from unity of retrieved frequency scaling factor is plotted as a function of the sequence number for a few different retrievals and bands. Different colours are used depending on the number of spectral points used in the fit: green is used for fits that use less than 100 points, red for fits that use less than 1300 points, and blue is used for fits that use more than 1300 points. As expected the internal agreement of the curves depends on the accuracy of the retrieval as determined by the number of fitted points. Consistent frequency corrections are obtained for different species and bands, but different corrections are obtained for different sequences.

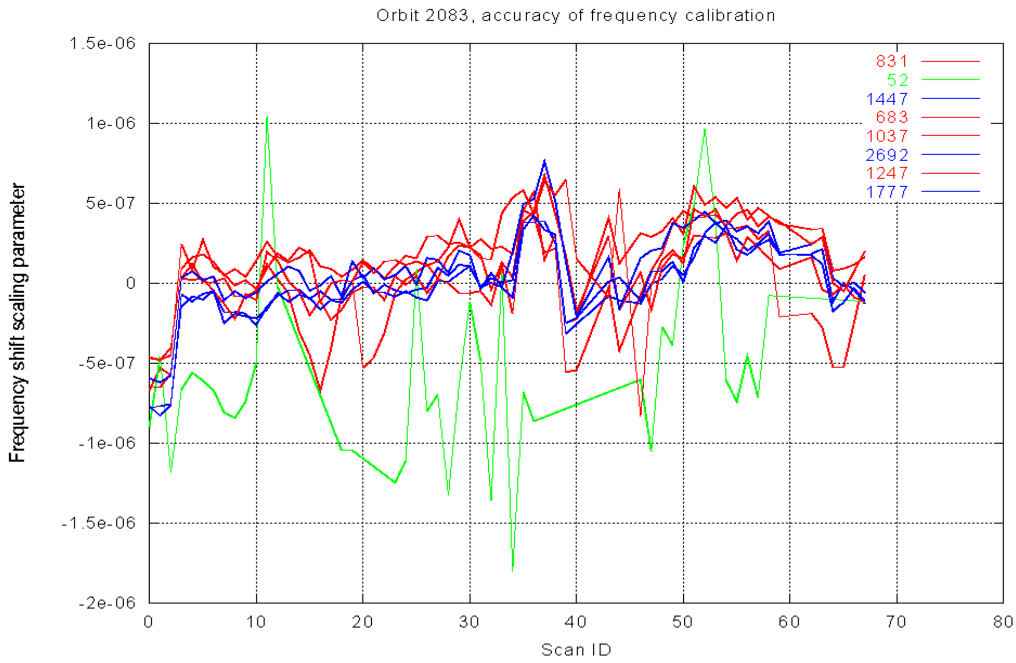

Fig. 1 – Deviation from unity of retrieved frequency scaling factor for different bands and different retrievals as a function of the sequence number

The frequency error that is measured by this procedure is always smaller than the accuracy requirement of one part in 10^6, but sufficient stability is observed in the frequency scale for a much more accurate frequency calibration. From the scatter that is observed between the values we deduce that the frequency scale can be determined with an r.m.s. accuracy of about 1 part in 10^7.

When the correction of Fig. 1 is applied to the frequency scale a major reduction of the χ^2 – test of the retrieval and no significant change in the products are observed. We conclude that the accuracy of Level 2 retrievals is little affected by errors in the frequency scale (this is the reason for the relaxed requirement), even if a very accurate determination of this quantity is possible from the spectra analysed in Level 2. This further improvement of the frequency calibration is not needed for the quality of geophysical data retrieval, but is important for diagnostic studies of the residuals in which all concurrent errors must be minimised .

3. INTENSITY CALIBRATION

One option of the scientific ORM code is the possibility of fitting, for each retrieval, a band-dependent parameter used to scale the spectral intensity. The fit of this parameter does not lead to a significant reduction of the residuals. Fig.2 shows the comparison of the χ^2 – test of the retrieval when this factor is fitted and when it is not fitted. In most cases the same χ^2 – test value is obtained.
In some cases the retrieved parameters differ from unity by amounts larger than the retrieval errors, however the statistics of the values does not provide a consistent indication of a required change in the intensity calibration. Furthermore we observe that a large correlation is present between the scaling factor and the retrieved geophysical data.

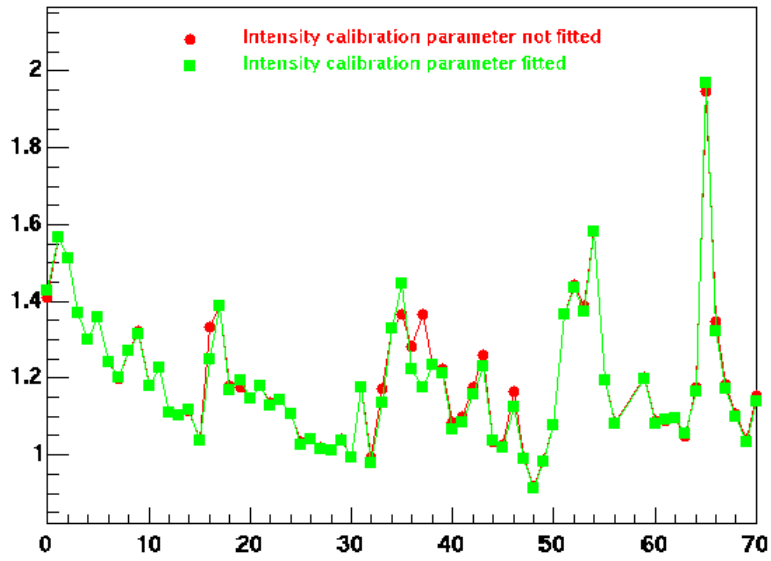

Fig. 2 Comparison of the χ^2 – test obtained when the intensity calibration is fitted with the χ^2 – test obtained without intensity fit.

Level 2 retrievals are clearly affected by intensity errors, but these errors map directly into the retrieved quantities and no significant evidence can be detected in Level 2 about intensity errors.

4. INSTRUMENT LINE SHAPE

The ILS is determined in Level 1 with an empirical expression that is used in Level 2 for the simulation of the observations.
Another option of the ORM scientific code is the possibility of fitting for each retrieval a band-dependent parameter used to modify the ILS provided by Level 1. After the convolution with the ILS provided by Level 1, the simulated spectrum is convoluted with an additional function that is equal to the combination of a *sinc* function (with resolution equal to the unapodized resolution of MIPAS spectra) with a $sinc^2$ function of double resolution. The two functions correspond respectively to the ILS of a box-car apodization and of a triangular apodization. The combination of the two corresponds to trapezoid apodization of value one at zero path difference and of value one minus *c* at maximum path difference, where *c* is the fitted parameter. This parameter is the ILS broadening parameter that measures the requirement for either a broader ILS (positive values) or a narrower ILS (negative values).
The fit of this parameter leads to some but not important reduction of the residuals. Furthermore, it has negligible effect in VMR retrievals, but a high correlation with pressure retrievals. This correlation with pressure is the reason for the requirement of an accurate ILS, and is also the cause of the difficulties in the retrieval of the ILS from the atmospheric measurements.

In order to avoid this problem it is necessary to limit the interference of the atmospheric broadening that is greater at low altitudes. Therefore, special sensitivity tests were made with retrieval limited at altitude above 40 km. Fig. 3 shows the value of the parameter *c* as a function of the sequence number obtained in these tests for the case of ozone retrieval from orbit 2081. The results obtained in the two bands where ozone is fitted are compared as a function of the sequence number.

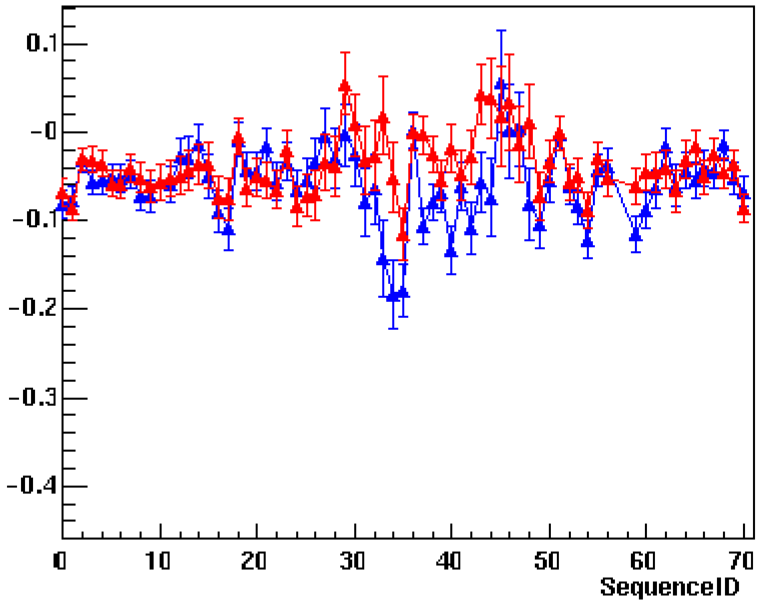

Fig. 3 ILS broadening parameter of band A (red points) and band B (blue points) obtained in the case of ozone retrieval from orbit 2081.

Significant variations are observed as a function of the sequence number, and on average the broadening parameter is negative, suggesting that the real ILS may be sharper than the one provided by Level 1. Similar results are obtained in the other retrievals.

Therefore, we obtain on average an indication for a sharper ILS, but the large variability of the results leaves the suspicion that other modelling effects may be interfering with this test.

5. INSTRUMENT OFFSET

A zero level is present in the measured spectrum because of instrumental effects such as scattering, diffraction and calibration errors. The Level 1 processor applies a correction for this offset, however a residual uncorrected offset component could be present also in the calibrated spectra that are processed in Level 2. For this reason the operational ORM fits an offset parameter for each spectral interval (microwindow, MW) used in the retrieval, but in order to limit the number of unknowns the offset is assumed to be tangent altitude independent.

The question exists of how large is the instrument offset and whether an altitude independent model is adequate.

Fig. 4 shows the comparison of the frequency dependent Noise Equivalent Spectral Radiance (NESR) of MIPAS measurements with the average offset retrieved with ORM in the different MWs. The offsets are plotted at the central frequency of the MWs. Fig. 4 shows the results obtained in the case of orbit 2081. The instrument offset is much smaller than the NESR of the measurements and can in practice be considered equal to zero.

In order to verify if the altitude-independent model is adequate, a further option of the scientific ORM code is the possibility of fitting an altitude-dependent instrument offset. Fig. 5 shows the comparison of MIPAS NESR with the average offset obtained at a few selected altitudes. A larger scatter of values than in Fig. 4 is obtained, but no altitude trend and no frequency dependent bias are observed.

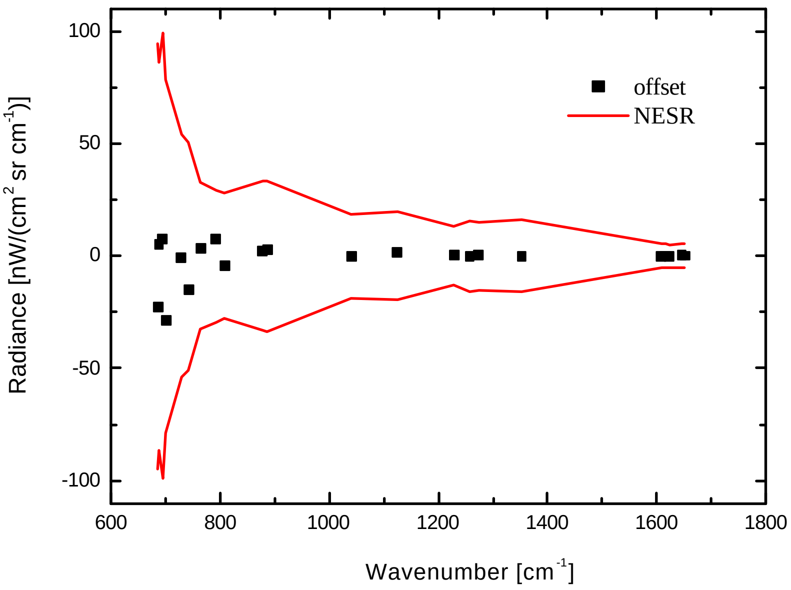

Fig. 4. Comparison of the average offset retrieved with ORM in the different MWs with the NESR of MIPAS as a function of frequency. The offsets are plotted at the central frequency of the MWs. The results of orbit 2081 are shown.

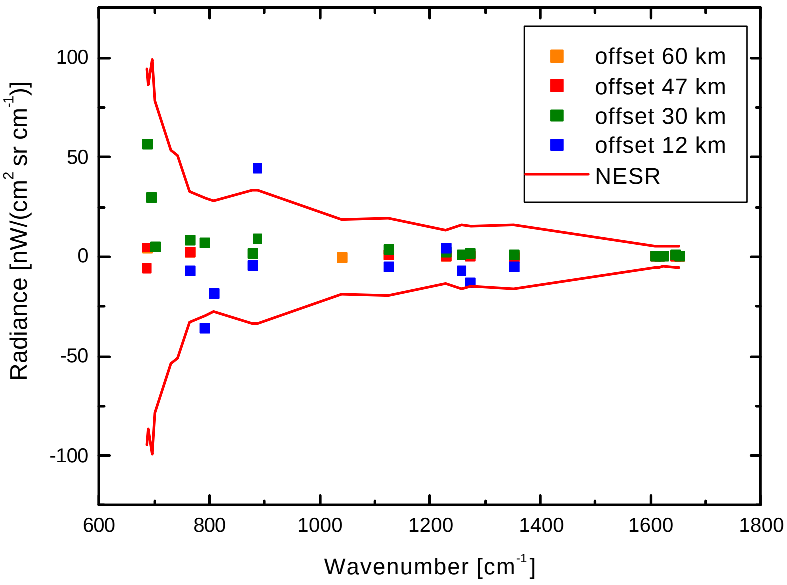

Fig. 5. Comparison of the average offset obtained in the retrieval of an altitude-dependent offset with the NESR of MIPAS as a function of frequency. The offsets are given for a few selected altitudes and are plotted at the central frequency of the MWs. The results of orbit 2081 are shown.

These results validate the choice of fitting an altitude-independent offset and provide assessment of the experimental value of this offset that is found to be very close to zero.

6. CONCLUSIONS

Compared to the operational Level 2 processor of MIPAS, the scientific version of the ORM includes some additional options for the retrieval of some instrumental parameters as well as geophysical data. Using these options Level 2 analysis has been used to validate the quality of the measurements that are obtained from the MIPAS instrument after the Level 1 analysis.

A small non-linear frequency dependence of the spectral frequency calibration was detected. After the correction of this systematic effect we find that the frequency calibration meets the requirements of one part in 10^6, but sufficient stability is observed in the frequency scale that would allow for a frequency calibration with an r.m.s. accuracy of about 1 part in 10^7.

Tests performed for the assessment of the intensity calibration did not provide conclusive evidence of an error on this parameter, but in this case Level 2 analysis cannot provide a stringent verification.

On average we obtain an indication that the real ILS could be slightly sharper than that modelled in Level 1 analysis, but the large variability of the results leaves the suspicion that other modelling effects may be interfering with this test.

A very small instrument offset is observed and the assumption of an altitude-independent instrument offset is legitimate.

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7. REFERENCES

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