GOME/ERS-2: NEW HOMOGENEOUS LEVEL 1B DATA FROM AN OLD INSTRUMENT

S. Slijkhuis(1), B. Aberle(1) , M. Coldewey-Egbers(1), D. Loyola(1), A. Dehn(2), T. Fehr(2)

(1) Deutsches Zentrum für Luft und Raumfahrt (DLR), 82234 Weßling-Oberpfaffenhofen, Germany,
(2) ESA ESRIN, C.P. 6400044 Frascati, Italy
Email: sander.slijkhuis@dlr.de

ABSTRACT

In the framework of ESA's "GOME Evolution Project", a reprocessing will be made of the entire 16 year GOME Level 1 dataset. The GOME Evolution Project further includes the generation of a new GOME water vapour product, and a public outreach programme.

In this paper we will describe the reprocessing of the Level 1 data, carried out with the latest version of the GOME Data Processor at DLR. The change most visible to the user will be the new product format in NetCDF, plus supporting documentation (ATBD and PUM). Full-mission reprocessed L1b data are expected to be released in the 4th quarter of 2015.

1. INTRODUCTION

The Global Ozone Monitoring Experiment (GOME) was launched on-board the ERS-2 satellite, in 1995, and operated until the switch-off of ERS-2 in 2011. GOME is a nadir-viewing, scanning spectrometer that measures the solar radiation scattered by the atmosphere in the ultraviolet and visible spectral region. The instrument can measure a range of atmospheric trace constituents, with the emphasis on global ozone distributions [1].

The status of scientific results of the GOME data sets was presented at ESA's ATMOS 2012 Conference. As a result of the discussion rounds, the scientific user community formulated a set of recommendations [2] also addressing the exploitation of the 16 years of GOME measurements. In addition, the quality assessment and validation of the Level 2 GDP 5 project [3] and the Ozone Climate Change Initiative project led to the recommendation of improving and consolidating the existing GOME level 1 product. The current GOME L1b products are not consistent because they were generated using different processor versions; a reprocessing covering the complete mission didn't take place up to now.

These recommendations have led to ESA's "GOME Evolution Project". The objective of the activity is to provide the EO user community with improved GOME Level 1 data products, in an easily accessible data format, based on updated GOME calibration algorithms and improved in-flight calibration characterisation for the complete mission. In addition, an evolution of the Level 2 water vapour algorithm (currently used for GOME-2/MetOp) shall be developed for GOME and the corresponding global H_2O data set of the full mission shall be reprocessed. The data sets will be generated at DLR and distributed to the EO user community. A validation of the L1b radiances, and of the H_2O data, will be carried out. Furthermore a long-term goal of the project is to build up a central and international point of outreach addressing secondary schools and universities in order to stabilize and strengthen the educational program related to atmospheric composition missions in general and ERS-2/GOME in particular. As basis existing schemes of outreach plans and processes shall be used that are already in place, for example the DLR "School Lab". The creation of a web gallery is also part of the project, featuring the GOME/ERS-2 mission and related scientific achievements.

2. NEW VERSUS OLD LEVEL-1b PRODUCT

The current ("old") GOME Level 1b data product contains geolocation, uncalibrated measurements, plus all necessary calibration data (and thus is in modern terms more like a level 1a product). A software "Extractor" tool is needed to convert these data to calibrated radiances, or to calibrated solar irradiance. This was designed with the scientific user in mind, and has the advantage that users may selectively apply or omit certain calibrations. The main rationale for doing so was that, at the time of launch in 1995, GOME was the first instrument in space where the DOAS method (Differential Optical Absorption Spectroscopy) for the retrieval of trace gases was to be used [4]. At the time, DOAS from space was unexplored territory, and there was an urge for maximum flexibility. In addition, such a data product structure allows for minimum data storage requirements.

In the mean time, DOAS from space has been well established, and is the retrieval method of choice for all existing and planned European UV-VIS spectrometers (GOME, SCIAMACHY, OMI, GOME-2, UVN/ Sentinel-4, UVNS/Sentinel-5[P]). Next to pure scientific users, there are also more operationally-oriented users. Since no or few users will use anything else than fully calibrated radiances, and since GOME L1b product size is no longer an issue, the time-

---

Proc. 'ATMOS 2015, Advances in Atmospheric Science and Applications',
Heraklion, Greece, 8–12 June 2015 (ESA SP-735, November 2015)

consuming and somewhat cumbersome method of using a special Extractor tool to read the GOME L1b product will be dropped.

The new GOME Level 1b product will contain fully calibrated (ir)radiances in NetCDF-4 format. The product format and structure are designed to be similar to the upcoming Sentinel-5 Precursor mission, as well as to a future reprocessed SCIAMACHY data product. Following the request from the users, an addition compared to the old product is geolocation information for the PMD (Polarisation Measurement Device) measurements.

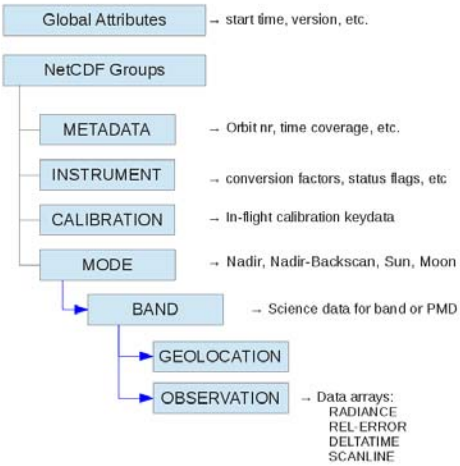

Figure 1. NetCDF structure of the new GOME L1b product

The new Level 1b product will be accompanied by an ATBD (algorithm theoretical baseline document) and a PUM (product user manual). The full-mission L1b product data + documentation are expected to be released in the 4th quarter of 2015.

3. L1b REPROCESSING IMPROVEMENTS

3.1. Overview

The level 1b data improvement part of the GOME Evolution Project contains the following tasks:

- Optimum and uniform use of calibration data: analyse the in-flight calibration data and find out the optimal calibration settings for the complete mission
- Updated algorithms for polarisation correction and degradation correction
- Optimal usage of dark current measurements discriminating between SAA / non-SAA (South Atlantic Anomaly) conditions.

3.2. Analysis of in-flight calibration data

In the framework of the project, the complete set of the GOME in-flight calibration parameters has been analysed. The long-term monitoring of their behavior is of great interest in order to draw conclusions on the long-term stability of the instrument.

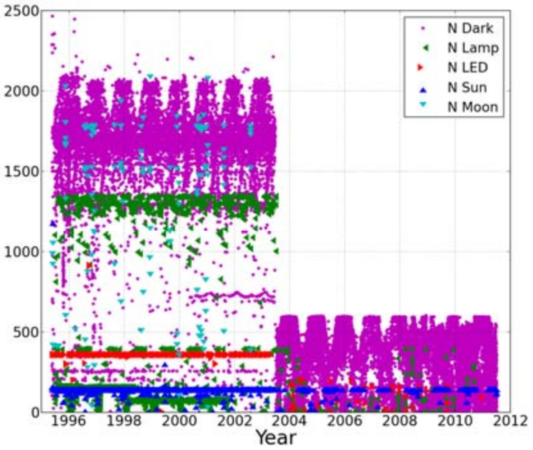

Figure 2. Number of calibration measurements versus time

Fig. 2. shows the number of available GOME in-flight calibration measurements for the whole period. The calibration data base contains dark current measurements for all integration time patterns, spectral lamp measurements for the wavelength calibration, LED measurements for the pixel-to-pixel gain correction, as well as the sun mean reference spectra and the moon and PMD measurements. After the tape recorder failure in June 2003 the number of calibration measurements is significantly reduced, since only data within reach of an ERS-2 receiving station were transmitted to ground.

A complete description of the calibration data analysis for measurements up to 2007 has been given in [5]. Here we will elaborate just on the spectral lamp measurements, and on the dark signal inside / outside the South Atlantic Anomaly (SAA).

3.3. Line selection for Spectral Calibration

To assign a certain wavelength to each individual detector pixel, the instrument houses a platinum-chromium-neon hollow cathode emission lamp, which provides a sufficient number (~67) of atomic emission lines of the three elements. Because of well-known spectral positions, the spectrometer can be calibrated during flight and the corresponding parameters – obtained by fitting a polynomial through the pixel-wavelength pairs – are stored in the calibration data base.

The spectral calibration varies in first line with pre-disperser temperature; in the calibration database spectral calibration coefficients are stored (and used) as function of temperature. The stability of the spectral calibration thus depends on the stability of the temperature, but also on the stability of the intrinsic line position. The latter may vary e.g. if the line is a blend where the intensity ratio of the line components varies. Fig.3 shows the time series of the temperature at the pre-disperser prism from 1995 to 2011, for which an increase of 4K is observed. Outliers are due to instrument and/or cooler switch-offs.

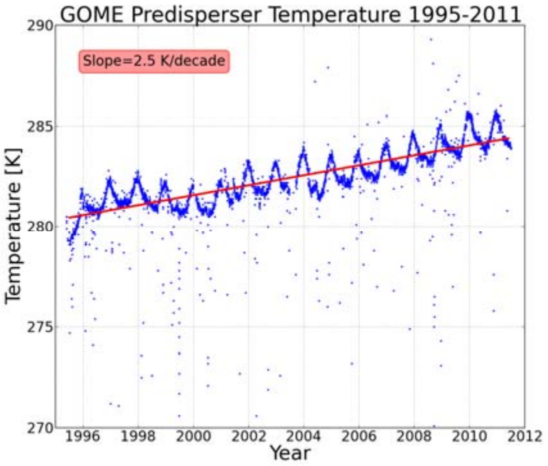

Figure 3. GOME pre-disperser temperature during the mission

This temperature increases during the lifetime and has a seasonal variation; the spectral calibration for one temperature thus may cover a long time range. Thus it is important that the intrinsic line positions remain stable.

Fig.4 shows the time series of the line parameters (from top to bottom: line position, intensity, Full Width Half Maximum, and skewness), exemplarily for one emission line. This particular line does show a small jitter in both position and skewness (asymmetry) but still qualifies for use in the spectral calibration (the position is accurate to better than 0.01 pixel).

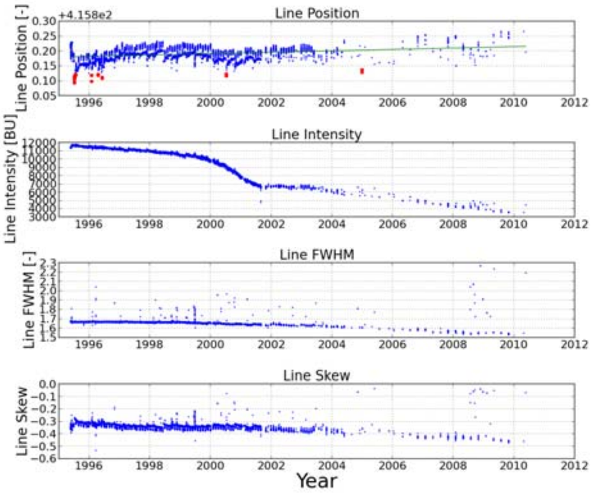

Figure 4. Example of an analysis plot for spectral line stability (see text), red points are rejected measurements

Fig. 5 shows the improvement in spectral stability for the new line selection versus the old one. The figure depicts, for one pre-disperser temperature, the standard variation of the spectral calibration for all measurements at that temperature. Spectral calibration being the wavelength for each pixel after a polynomial fit through the line positions of each measurement.

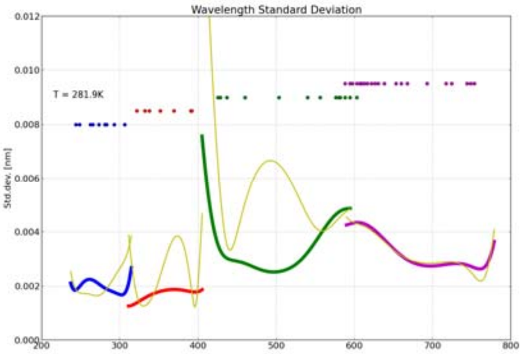

Figure 5 Standard deviation of spectral calibration at each wavelength over time (for one temperature) .
Thin lines: old L1b data; Thick lines: new L1b data
Dots: spectral positions of the individual emission lines

3.4. Dark signal inside / outside the SAA

The dark signal is measured at the night side of each orbit, for each integration time pattern, and updated accordingly in the calibration database. These dark spectra are then used at the next orbit for dark signal correction. Dark measurements over the SAA suffer from enhanced particle impacts. This produces increased noise (see Fig. 6), but also lifts the median dark signal.

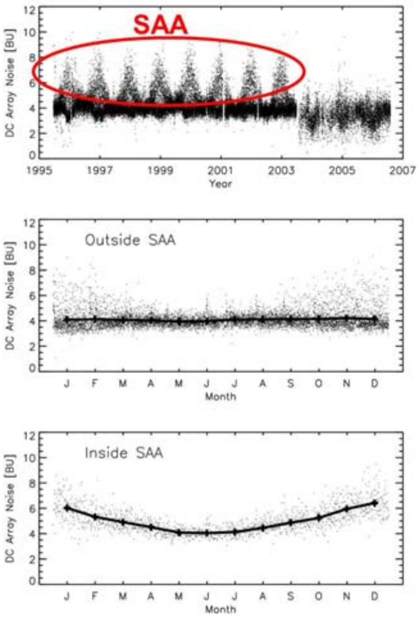

Figure 6 Dark signal noise levels. Upper panel: noise over time. Lower two panels: seasonal variation of the noise inside and outside the SAA region

In the old algorithm, there was a mitigation for channel 1 only (this is the channel with lowest radiances, thus most susceptible to dark signal correction errors), using the signal after dark correction in dedicated "blind pixels" [6][7]. The new algorithm defines an "inside SAA" and an "outside SAA" region for dark signal values in the calibration database. These regions are identified on the basis of PMD noise level. Measurements inside or outside the SAA region get their own dark signal correction.

3.5. Degradation

By means of the daily solar irradiance measurements the degradation of the GOME sensor was monitored. Fig. 7 shows the irradiance on the 3rd of July each year, relative to the chosen zero point from July, 3rd 1995. By comparing spectra from the same day, any seasonal effects caused by the diffuser BSDF (Bi-directional Scattering Distribution Function) cancel out. In channels 1 and 2, the intensity decreased by 85-95% and 45-85%, respectively. The degradation is lower in channels 3 and 4, but became significant in channel 3 in 2001. The main degradation may be explained in terms of deposits on the scan mirror. This causes not only absorption, but also a low-frequency interference pattern that explains why the transmission may temporarily increase at UV wavelengths [8]. The high frequency residuals are mainly due to changes in the etalon structures.

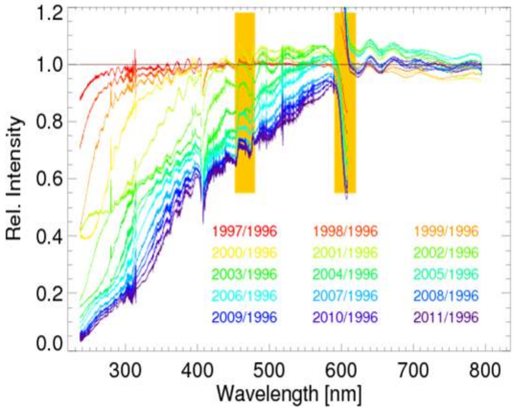

Figure 7. GOME degradation after each year, relative to 03.07.1995. Yellow bars show dichroic's features

The approach to correct for the degradation is to compare all solar spectra with the corresponding irradiance from July, 3rd 1995. The irradiances are corrected for seasonal BSDF effects using the "smoothed BSDF" function described in [6][7]. The degradation is fitted in wavelength by a polynomial in each channel, while in time these polynomial coefficients are smoothed using a Savitzky-Golay filter.

3.6. Polarisation correction algorithm

The radiance calibration of the GOME instrument is sensitive to polarisation. GOME measures the atmospheric polarisation in three broad-band detectors for wavelengths above ~360 nm. For the UV wavelengths, a polarisation curve from theory is used. Polarisation is taken as constant, to the single scattering value, for wavelengths up to λ_0 (near 300 nm, see Fig. 8).

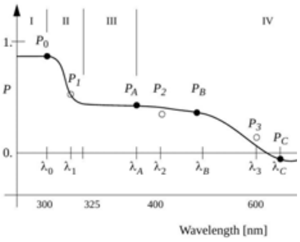

Figure 8 Polarisation curve used in GOME; points P_A, P_B, P_C come from the PMD measurements

Between λ_0 and the connection to the first PMD, an exponential-like function is fitted, the "GDF" [6][7]. This function is parameterised using the description from [9]. The function needs values for airmass, albedo, and Ozone column. Airmass is calculated from spherical geometry, albedo is calculated from measured reflectance at 380 nm (using a look-up table depending on geometry).

In the old algorithm, the Ozone column was taken from climatology. The new algorithm uses Ozone values from the current GOME Level-2 total column O3 product.

4. REFERENCES

[1] Burrows, J.P., M. Weber, M. Buchwitz, V. Rozanov, V. Ladstätter-Weißenmayer, et al., The Global Ozone Monitoring Experiment (GOME): Mission concept and first Scientific Results, J. Atmos. Sci., Vol. 56, pp. 151-175, 1999

[2] ATMOS 2012: Sessions and Recommendations, EOEP-DTEX-EOPS-RD-12-0002, 2012

[3] GOME/ERS-2 GDP 5.0, Total Ozone Column, Validation Report, TN-IASB-GOME-GDP5-VR, 2012, http://atmos.eoc.dlr.de/gome/docs/DLR_GOME_GDP5_RFM.pdf

[4] GOME Users Manual, ESA SP-1182, 1995

[5] Coldewey-Egbers, M., S. Slijkhuis, B. Aberle, D. Loyola, Long-term analysis of GOME in-flight calibrat-ion parameters and instrument degradation, Applied Optics, Vol. 47, No. 26, p.4749, 2008

[6] Slijkhuis, S., B. Aberle, and D. Loyola, Improvements of GDP Level 0–1 Processing System in the Framework of CHEOPS-GOME, ESA SP-628, 2006, http://earth.esa.int/workshops/atmos2006/participants/516/paper__paper_ASW_cheops_final.pdf

[7] CHEOPS-GOME ATBD, CH-TN-DLR-GO0003, 2006, https://wdc.dlr.de/sensors/gome/degradation_files/literature/atbd_cheops.pdf

[8] Snel, R., In-orbit optical degradation: GOME experience and SCIAMACHY prediction, ESA SP-461 CD-ROM, 2000
[9] Schutgens, N.A.J. and P. Stammes, Parametrisation of Earth's polarisation spectrum from 290 to 330 nm, JQSRT 75, p.239, 2002