Ground Segment for ERS-2 GOME Sensor at the German D-PAF

D. Loyola, W. Balzer, B. Aberle, M. Bittner, K. Kretschel, E. Mikusch, H. Mühle, T. Ruppert, C. Schmid, S. Slijkhuis, R. Spurr, W. Thomas, T. Wieland, M. Wolfmüller

German Aerospace Research Establishment (DLR)
German Remote Sensing Data Centre (DFD)
D-82234 Weßling, Germany
Diego.Loyola dlr.de
http://www.dfd.dlr.de/info/AUC/GOME

Abstract

The Global Ozone Monitoring Experiment (GOME), launched on April 21st 1995 on board the second European Remote Sensing Satellite (ERS-2), is designed to measure a range of atmospheric trace constituents, with particular emphasis on global ozone distributions. The German Remote Sensing Data Centre (DFD) plays a major role in the design, implementation and operation of the GOME Data Processor (GDP), the ground segment for the GOME sensor. Major components of the GDP are the complete GOME data archive, the earthshine spectra calibration step, the total ozone column retrieval process, and the integration into the D-PAF Data Management System. Raw GOME data are converted into öcalibrated radiancesö during the Level 0-to-1 processing by the application of a series of calibration algorithms. Calibration parameters are calculated from in-flight observations of darkness, calibration lamp, internal LED and sun measurements. Total columns of ozone and other trace gases are derived during the Level 1-to-2 processing using three main algorithms. The Initial Cloud Fitting (ICFA) determines the fractional cloud cover of the pixel scene using measurements close to and within the O_2 A-band around 760 nm. The Differential Optical Absorption Spectroscopy (DOAS) algorithm retrieves effective slant column amounts of atmospheric trace gases from spectral data in the UV and visible regions. The third algorithm calculates appropriate Air Mass Factors (AMFs), by which the slant columns are divided to yield geometry-independent vertical column amounts. In July 1996 the GDP became fully operational, with derived earthshine spectra and total ozone columns generated on a routine basis.

Keywords: GOME, Total Ozone Measurements, D-PAF

Introduction

The Global Ozone Monitoring Experiment (GOME) was launched on April 21st 1995 on board the second European Remote Sensing Satellite (ERS-2). GOME is a nadir-viewing spectrometer covering the wavelength range from 240 nm to 793 nm with a resolution of 0.2 nm to 0.33 nm. The sensor scans across-track in three steps with pixel size of 360 km x 40 km. The instrument can measure a range of atmospheric trace constituents, with the emphasis on global ozone distributions.

Besides the on-line components under ESA responsibility, the GOME Data Processor (GDP) system is the off-line ground segment of the GOME sensor. The processing of GOME data is done at the German D-PAF which is part of the Deutsches Fernerkundungsdatenzentrum (DFD). The GDP incorporates the complete GOME data archive, the radiance calibration step (level 0-to-1), the total column trace gas retrieval process (level 1-to-2), and an image processing chain for the generation of higher-level products. Figure 1 shows an overview over the steps in GOME data processing.

The first operational algorithm concentrates on the retrieval of total column amounts of O_3 and NO_2 using the Differential Optical Absorption Spectroscopy (DOAS) technique. GDP is the first DOAS application to remote sensing from space.

The main part of the paper are Sections 2 and 3, which contain a detailed description of the GOME Data Processor. The status of level 2-to-3 processing is mentioned briefly in Section 4. Section 5 presents a summary of the D-PAF and ESA ground segment interfaces. Finally, Section 6 describes the availability of GOME products.

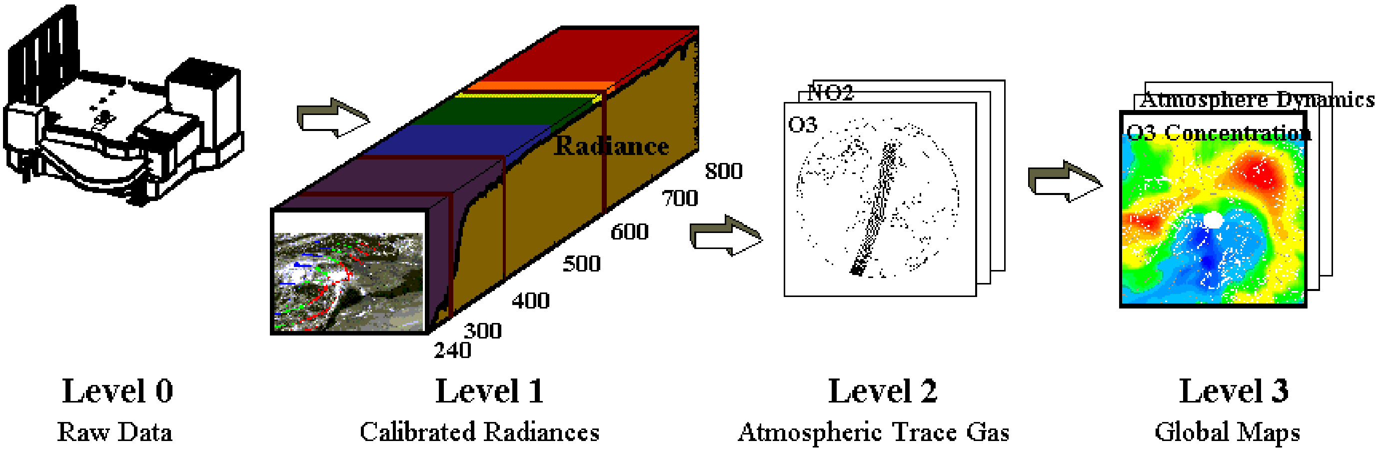

Figure 1. The steps of GOME data processing

Level 0-to-1 Processing

Raw GOME data (level 0) is converted into 'calibrated radiance' (level 1), see Figure 2, by applying a series of calibration algorithms [13] based on the evaluation of certain calibration parameters. The latter are determined (in-flight) on a regular basis during the mission, from GOME observations on the dark side of the orbit or from PtCrNe-line-lamp observations, internal LED observations and solar calibration measurements. Additional parameters used in the level 0-to-1 processing were evaluated during the pre-flight calibration phase. All extracted calibration parameters are added to a complete 'calibration database', which will cover the lifetime of GOME. The main steps of the GOME level 0-to-1 processing are described in the following subsections.

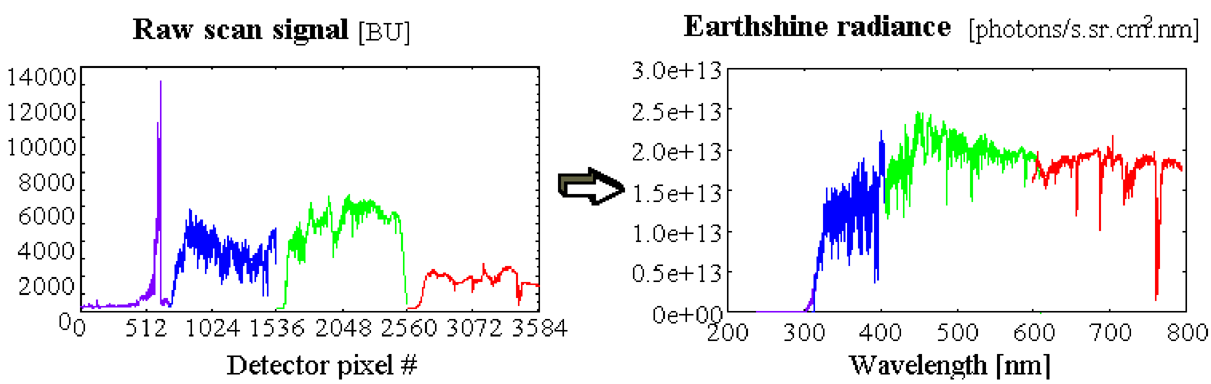

Figure 2. The level 0-to-1 processing

Signal Corrections

Measured signals are corrected for *dark signal* using measurements from the dark side of the orbit; *cross-talk* on the readout bias signal is filtered out. *Pixel-to-pixel* variations in detector Quantum Efficiency are corrected using measurements of the uniform spectral output of internal LED light sources. Correction for *straylight* is carried out using on-ground characterization of the straylight in terms of an uniform and a ghost component.

Spectral Calibration

The wavelengths corresponding to the various detector pixels are determined by fitting a 4^{th} order polynomial through the pixel positions of spectral lines from the internal PtCrNe-line lamp. The spectral calibration varies slightly with instrument temperature; it is determined in 0.1 K intervals.

Radiometric Calibration

The 16-bit binary unit (BU) data of the array detector are transformed into calibrated radiances (photons s^{-1} sr^{-1} cm^{-2} nm^{-1}) by application of the instrument response function. This includes a correction for scan mirror position; instrument polarisation sensitivity is neglected in this step. Once a day the Sun is observed over an on-board diffuser. A daily solar reference spectrum is generated which is used to calculate the *earthshine albedo* from the measured radiances.

Polarisation Correction

The signals of 3 PMD detectors, which measure one polarisation component of the incoming light (covering a broad spectral range), are combined with the science data to retrieve atmospheric polarisation fraction. This is used to obtain polarisation correction factors for the calibrated radiances.

Geolocation

At every detector readout (1.5 sec) the projected field-of-view on the Earth surface is calculated (4 corners and centre). Also provided are the corresponding viewing angles, and the solar zenith- and azimuth angles at 3 locations in the ground pixel (both the edges and the centre).

Quality Assessment

A number of checks such as identification of *dead pixels*, *hot pixels*, *saturation* and *sun-glint* are performed for the sun irradiance and earthshine measurements to assess their quality [8].
The irradiance spectra in the UV are continually compared with data from SOLSTICE and SBUV instruments [9] and the agreement is found to be better than 5% in the wavelength region between 300nm and 400nm, but up to 10% in the UV below 300nm. SOLSPEC data is used to validate GOME solar irradiance beyond 400nm and again the agreement is better than 5%. The UV discrepancy is partially due to a lack of characterisation of diffuser degradation [6] up to now.

Level 1-to-2 Processing

The Level 1-to-2 processing chain contains two main algorithms and one 'pre-processing' algorithm [14]. The DOAS fitting technique retrieves effective slant column amounts (ESCs) of trace gases, and the AMF algorithm (a radiative transfer computation) generates Air Mass Factors (AMF) for the conversion of slant columns to geometrically independent vertical trace gas columns. The cloud pre-processing algorithm (ICFA) is a fitting routine designed to compute the fractional cloud cover using GOME measurements. The results from these three algorithms are combined in the process which calculates the vertical columns. An important auxiliary data sources are the climatological and spectroscopic databases [12]. Though the first operational algorithm mainly concentrates on the retrieval of atmospheric columns of O_3, the total NO_2 column is also calculated.

Cloud Fitting Algorithm

In order to determine ozone amounts more accurately, a correction is required for cloudy and partially cloudy scenes. The Initial Cloud Fitting Algorithm (ICFA) extracts information about clouds from GOME measurements close to and within the O_2 A-band around 760 nm [5]. The average transmittance through this band defines a relationship between cloud-top height given by the ISCCP climatology and the computed fractional cloud cover.

DOAS Fitting

The Differential Optical Absorption Spectroscopy technique is used for the retrieval of effective slant column amounts of atmospheric trace gases from moderately high-resolution spectral data in the UV and visible regions of the spectrum [10]. DOAS involves the least squares fitting of ratioed measurement spectra to a set of reference spectra which are either absorption cross-sections taken from the literature [1,2] or instrument-specific reference measurements [4]. Figure 3 shows a schematic description of DOAS.

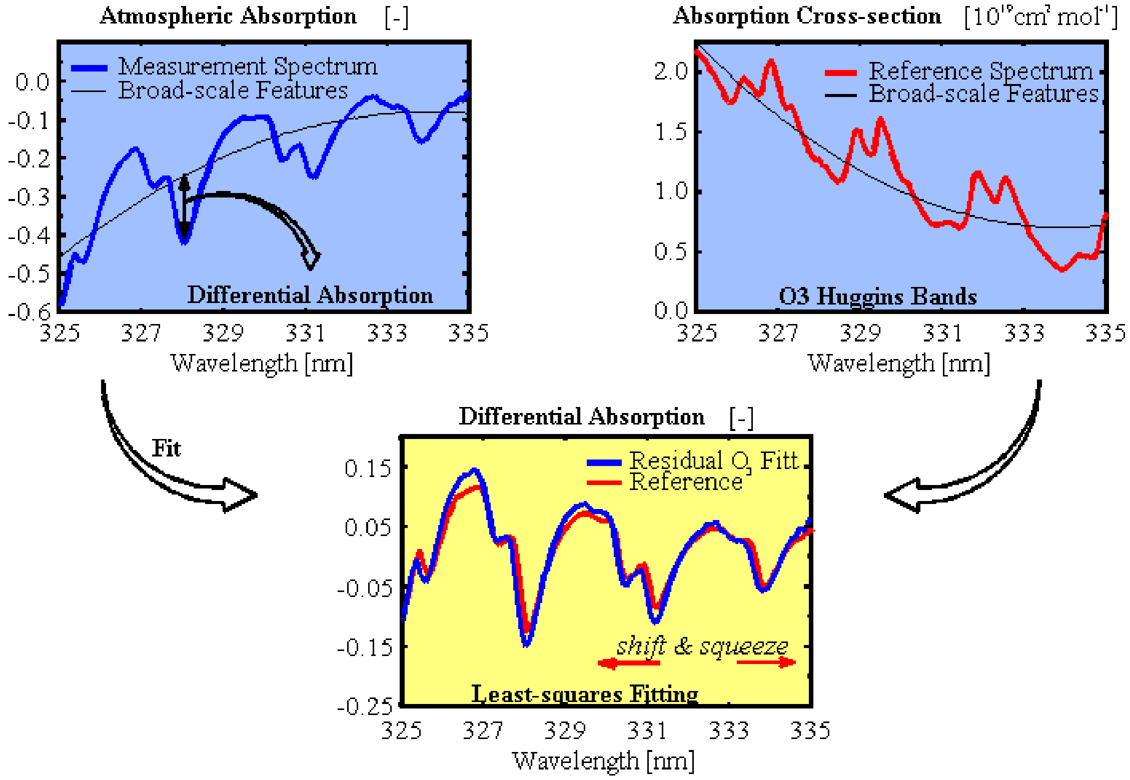

Figure 3. Schematic description of the DOAS technique

At present, two fitting windows in the UV (325-335nm) and the visible part of the spectrum (425-450nm) are used to retrieve the slant column densities of O_3 and NO_2. The UV window is optimised for O_3 retrieval (Huggins bands), the visible one for NO_2.

Air Mass Factor Calculation

Division of the DOAS-fitted slant column densities by a suitable Air Mass Factor (AMF) yields the vertical column densities, independent of viewing geometry [11]. AMFs are calculated twice (down to ground and to cloud-top) for pixels with total cloud cover, and once for clear pixels. AMF computation is purely a radiative transfer simulation, as the calculation of absorption paths in the atmosphere requires only the viewing geometry information from the level 1 product. Database requirements include global climatological datasets of temperature, pressure and trace gas concentration profiles, plus absorption cross-sections of O_3 and NO_2 [1,2,4], and auxiliary data for aerosol optical properties and surface and cloud reflectances.

At present, the AMFs are calculated for just two wavelengths - 325nm in the UV, and 437nm in the visible; these are representative values for the fitting windows used in GDP. Across-pixel variation of AMFs is allowed for by computing AMFs at three positions across the pixel (left, centre and right) and computing an intensity-weighted mean value.

Calculation of vertical column densities

For a given trace gas, the representative total AMF is determined as the linear combination of AMFs to cloud-top and to ground, weighted with the cloud fractional cover f_c provided by ICFA.

The Vertical Column Density (VCD) in units of [$mol\ cm^{-2}$] is

$$VCD_{total} = \frac{ESC + f_c \cdot GVC \cdot AMF_{cloud}}{AMF_{total}}$$

where *ESC* is the DOAS slant column, and *GVC* denotes the 'Ghost Vertical Column', i.e. the column below cloud-top which must be derived from climatological profile information, see Figure 4. For O_3, *GVC* is only a small fraction of the total atmospheric column.

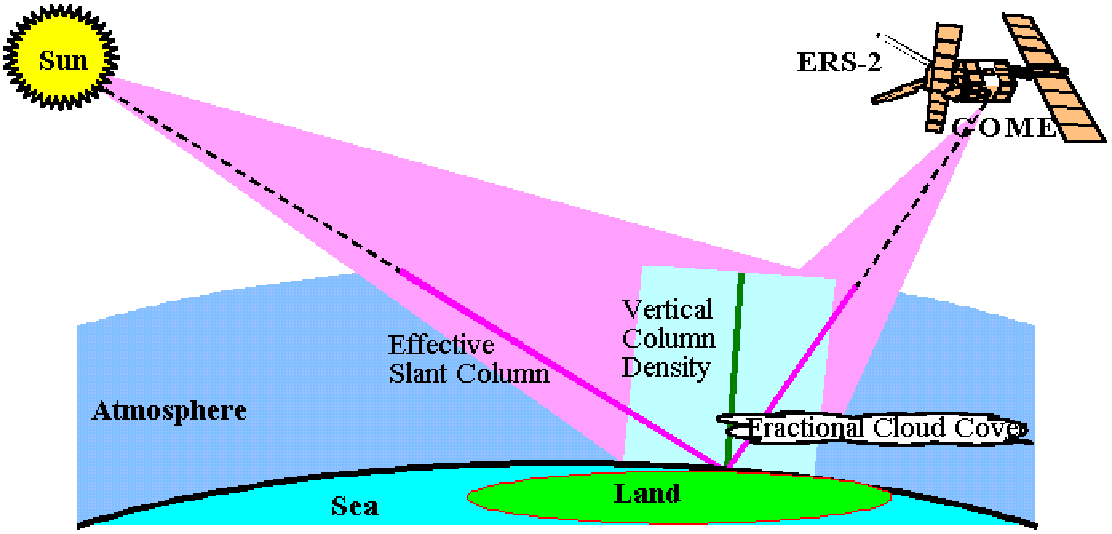

Figure 4. Derivation of the vertical column density

Quality Assessment

The level 2 product contains the VCDs of O_3 and NO_2 as well as results from the constituent level 1-to-2 algorithms. There are also a number of flags in the level 2 product that indicate both the quality and the appropriateness of the ICFA, DOAS and AMF retrieval [8].

The GOME Validation Campaign ran from September 1995 to March 1996 at the end of the Commissioning Phase [6], further validation has been carried out since by interested groups. Table 1 summarises the results of the comparison between GOME and ground-based (Dobson, Brewer and spectrometers in the NDSC and SAOZ networks) total ozone data from July to December 1996 [7].

Solar Zenith Angle	Mean Difference (1 sigma)	Standard Deviation (2 sigma)
< 70°	< 3%	< 10%
> 70°	< 8%	< 15%

Table 1. Confidence level for GOME total column ozone compared with ground based measurements

The day-to-day fluctuation of NO_2 for all latitudes was shown to be reasonable, and so are the slant columns. But the AMF values are too high due to the NO_2 climatology currently used. New climatologies will be considered for next releases of the GDP.

Level 2-to-3 Processing

GOME Level 3 data products are generated operationally to provide the scientific community with data and tools to allow for a more immediate conversion of GOME data into scientific progress and to satisfy public interests. Daily global maps of total column ozone are computed in different projections using the Harmonic Analysis technique for daily composites, see Figure 5, and the Kalman-Filter for generating global maps for a specific time (snap shot). Daily total column ozone zonal mean values are derived and compared to today's climatologies (e.g. CIRA '96). Suitable atmospheric parameters such as wave one and two amplitudes and phases are calculated on a daily basis to monitor the evolution of the dynamical behaviour of the atmosphere [3]. To assure the quality of the level 3 data processing, routine comparisons are made to TOMS total column ozone and to selected ground-based Dobson stations.

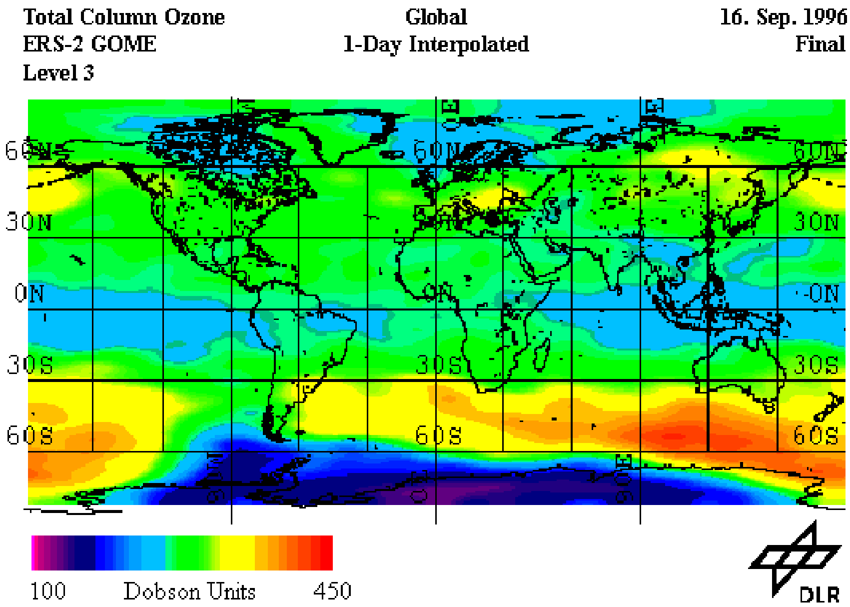

Figure 5. An example of a level 3 data product for Sep. 16, 1996

Data Management System for ERS-1/2 at D-PAF

The Data Management System (DMS) is the central functional interface between all D-PAF processing systems on one side and ESA's off-line ground segment for ERS-1/2 on the other side. The DMS consists of functions for cataloguing and archiving ERS-1/2 data sets, controlling the processing, handling orders received by ESA, controlling central operations, and reporting to EECF.

Catalogue for GOME data: The DMS catalogue stores the data sets for all GOME raw data and data products: level 0 downlinks, level 1 and level 2 Products, bundling products level 1 covering 3 days and level 2 covering 1 month.

Processing Control for GDP: The DMS processing control system determines all input data, initiates and monitors the order generation for GDP screening of GOME Exabytes, GDP level 0-to-1 and level 1-to-2 processing, and bundling of level 1 and level 2 composite products.

Archival Reporting to ESA: For all new bundled level 1 and level 2 products DMS generates a Global Archiving Report containing the catalogue data for these products and transmits the reports to EECF Central User Service (CUS) via telecommunication link. Based on these reports CUS generates customer orders for GOME level 1 and level 2 products and transmits the orders to D-PAF.

Order Handling and Order Status Reporting: The CUS customer orders are received by DMS and transferred to the D-PAF Product Generation System (PGS) which generates CD-R copies of the ordered products. Finished orders are transferred by DMS to the D-PAF Accounting and Distribution Service for CD delivery to the customers.

Availability of GOME Products

GOME data are available free of charge, provided contact has been made with ESA/ESRIN helpdesk (eohelp esrin.esa.it).

The medium for distribution of level 1 data is CD-R; each disc contains products for 3 days (around 35 orbits). Level 2 data are distributed via an ftp-server at DFD which is under ESA responsibility and via CD-R containing products for one month. Level 3 data routinely generated at DFD are available on Internet (http://www.dfd.dlr.de/info/AUC/GOME).

During operational processing, Exabyte cassettes prepared at the receiving stations are transported overland to DFD (see Figure 6). Thus, GOME data are usually available about 2-4 weeks after a satellite overpass.

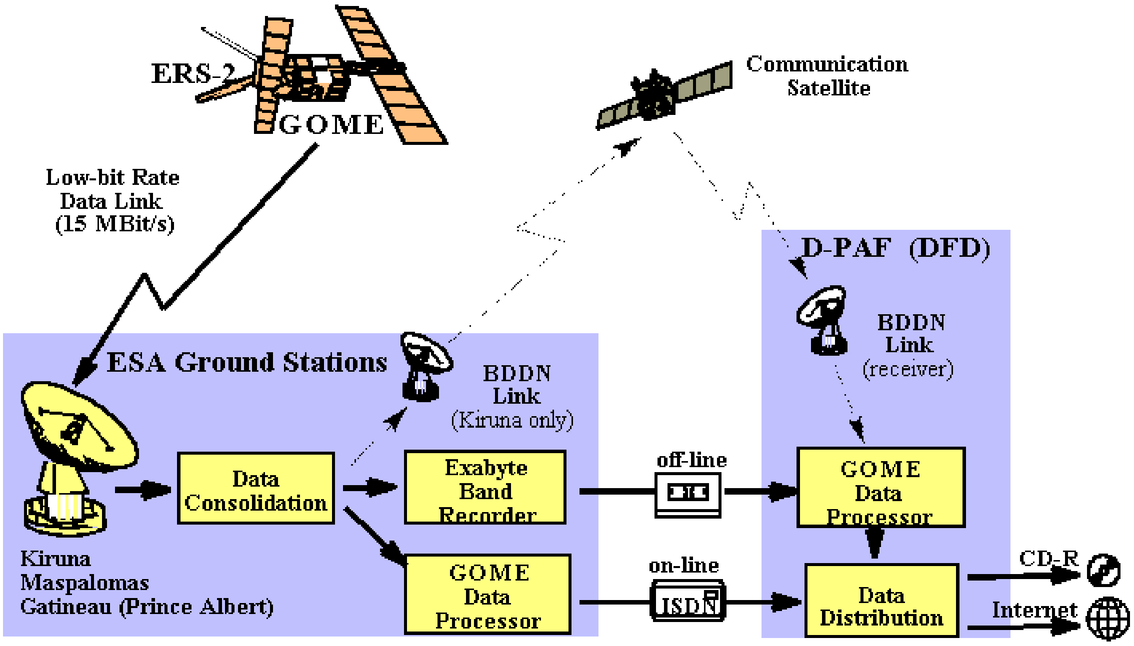

Figure 6. The way of the GOME data

GOME Near-Real-Time Products

GOME near-real-time products are available since the end of January 1997. The GDP system was installed at the Kiruna station (Sweden) in collaboration with the University of Bremen and ESA as part of an Arctic winter campaign. The technical solution has been conceived to work automatically and it is fairly inexpensive.

The Kiruna station receives 10 out of the 14 daily GOME orbits. The corresponding *level 1 and level 2* near-real-time products have the *same precision* as the off-line products and are available *one hour* after acquisition.

Conclusion

We described the complete data processing for GOME, from level 0 to level 3. Various calibration algorithms such as dark signal correction, pixel-to-pixel gain correction, wavelength calibration and polarisation correction are required to convert raw level 0 data to the calibrated, radiometrically corrected and geolocated radiance data.

The level 1-to-2 processing step generates pixel-by-pixel level 2 products via two main algorithms: The DOAS fitting for retrieving effective slant column trace gas absorber amounts, and the associated AMF conversion to geometrically-independent vertical columns. A cloud pre-processing algorithm is used to generate cloud cover information. GOME represents the first application of the DOAS retrieval technique to space-borne remote sensing instruments.

Precision errors from the DOAS algorithm are small for the retrieved trace gas columns - typically 1% is found for the O_3 content and 10% for NO_2. Comparison with ground based measurements show good agreement for ozone total column within a range of 3% for low sun zenith angles, and 8% for solar zenith angles greater than 70°.

GDP is also capable to produce GOME level 1 and level 2 near-real-time products operationally as it is being done since January 1997.

Acknowledgements

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