The Second Global Ozone Monitoring Experiment (GOME-2) on MetOp: An Overview of Data Processing, Commissioning Activities, and Long-Term Monitoring

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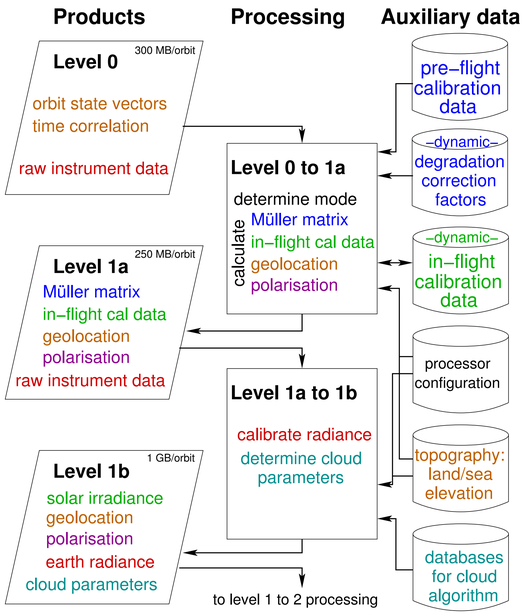
Level 0 to 1 data processing: (ir)radiances, polarisation, clouds



The level 0 to 1 processor converts raw instrument data into geolocated, spectrally and radiometrically calibrated earth radiances and solar irradiances augmented by polarisation and cloud parameters and data quality flags.

Data are processed in two steps according to the instrument mode. The level 0 to 1a processor calculates in-flight calibration data from the measurements in the five calibration modes (Dark, LED, SLS, WLS, Sun). Pre-flight calibration data on radiance and polarisation response are converted into Müller matrix elements (MMEs). The level 1a to 1b processor calibrates earth radiances using these in-flight calibration data and MMEs.

Products will be in the EUMETSAT Polar System (EPS) binary format.

Polarisation · Signals measured by GOME-2 depend on the polarisation state of the incoming light which in turn depends on the observed scene, in particular observation geometry and cloudiness. In the Müller matrix formalism, the polarisation state is characterised by Stokes fractions. Stokes fractions are determined for each ground pixel from the observation geometry (single scattering value for the short wavelength end) and ratios of measurements from the two polarisation channels. From these Stokes fractions, polarisation correction factors for the main channel signals are derived.

Earth radiances · Calibrated earth radiances are calculated from main channel signals by applying a sequence of calibration steps covering dark signal subtraction, corrections for pixel-to-pixel gain variations, Etalon effect and straylight, polarisation correction, and spectral and radiometric calibration.

Cloud parameters · An effective cloud fraction and cloud top pressure are retrieved for each GOME-2 ground pixel using the Fast Retrieval Scheme for Clouds from the Oxygen A band (FRESCO) developed by KNMI. The FRESCO retrieval method is based on a comparison of measured and simulated reflectivities in three approximately 1 nm wide spectral windows in and around the oxygen A band (758, 761, 765 nm).

Level 1 to 2 data processing: geophysical data products

Ozone Profile (KNMI) · The ozone profile products are produced using the VERA (VErsatile Retrieval Algorithm) retrieval algorithm which uses an optimal estimation formalism. The forward radiative transfer model used is a scalar version of the LIDORT model. In order to minimise residual errors in the retrieved ozone profile resulting from the use of a scalar forward model, look-up tables will be used to correct the modelled radiances for errors due to the neglect of polarisation. Additionally, the amplitude of the ring absorption is included as an auxiliary parameter in the state vector.

Total Column Ozone & Trace Gases (DLR) · The algorithms used to generate the total column and trace gas products are based on the Differential Optical Absorption Technique (DOAS). The operational GOME/ERS-2 Data Processor V4.0 (GDP V4.0) provides the basis for the operational processor for GOME-2 on MetOp. Under the responsibility of ESA, the updated processor GDP4.0 is being used to reprocess the entire GOME/ERS-2 data set. Continuity between GOME on ERS-2 and GOME-2 on MetOp is therefore assured.

Aerosol (KNMI) · The Aerosol Optical Depth (AOD) will be retrieved using measurements from the GOME-2 PMDs. The retrieval algorithm will incorporate a linearized vector radiative transfer model and the inversion will be performed using the Levenberg-Marquardt method. The algorithm is currently under development and is the subject of an O3MSAF Visiting Scientist activity. In addition to the AOD, an Absorbing Aerosol Index (AAI) will also be produced on an operational basis.

Clear-Sky UV (DMI) · The Near Real Time UV product provides daily clear-sky UV-fields expressed as a UV index and consists of twenty three contour maps for pre-specified regions, two text files containing general information and estimated accuracies, and an html file for easy access to the maps and information contained within the product. The processor employs the widely used UVSPEC radiative transfer model and is based on look-up tables. The only dynamic input used is an assimilated GOME-2 total column ozone field provided as an internal O3MSAF product by KNMI.

UV with Clouds & Surface Albedo (FMI) · The Off-line UV product contains the daily UV dose in J/m2 weighted with four different action spectra: erythema induction (CIE87), generalised plant damage, DNA damage, and skin cancer induction. The two most critical inputs are the estimated diurnal cloud cover and surface albedo.

Product NRT Offline Both	Characteristics	Estimated Uncertainties		
Ozone profile	Eleven layers of ozone mixing ratio [ppm]	<10% in the stratosphere and <30% in the troposphere for six to eight independent pieces of information.		
		SZA	**Accuracy (1σ)**	**Precision (1σ)**
Total column ozone	Total vertical column amount in Dobson Units	$< 70°$	–2%...+4%	$< 2\%$
		$< 90°$	5%...8%	$< 3\%$
Trace gases	Total vertical column amount in molecules/cm^2	**SZA**	**Accuracy (1σ)**	**Precision (1σ)**
NO_2	operational	$< 70°$	5%...20%	5%...20%
NO_2	operational	$< 90°$	5%...20%	5%...10%
BrO tropics	operational	N/A	20%...50%	50%...100%
BrO trop. enhancement	operational	N/A	>100%	10%...50%
BrO other	operational	N/A	20%...50%	10%...50%
SO_2	experimental	$< 65°$	50%...100%	50%...100%
SO_2	experimental	$> 65°$	>100%	>100%
SO_2 volcanic	experimental	$< 65°$	50%...100%	5%...30%
SO_2 volcanic	experimental	$> 65°$	>100%	>30%
HCHO	experimental	N/A	>100%	>100%
HCHO biomass burning	experimental	N/A	50%...100%	20%...50%
OClO ozone hole	experimental	$> 75°$	50%...100%	20%...50%
OClO	experimental	other	>100%	>100%
Aerosol	Absorbing Aerosol Index (AAI), Aerosol Optical Depth (AOD) and Aerosol Type (desert dust, smoke and volcanic ash)	AAI: No accuracy estimates. AOD Accuracy < 20%. The AOD will only be computed if AAI > 1		
Clear sky UV fields	Surface level spectral UV irradiance. Product available as a clear sky UV index	Accuracy 1 UV index		
UV fields with clouds and albedo	Spectral UV doses weighted with appropriate action spectra for clear sky and cloudy conditions	Accuracy < 20% for a 100x100 km^2 grid		

The GOME-2 instrument on MetOp...

Satellites, launch dates	MetOp-A (2006), -B (2010), -C (2015)
Orbit	polar, sun-synchronous, near-circular descending node crossing at 09:30h MLST
Instrument	nadir-scanning UV/VIS grating spectrometer
Wavelength range	240–790 nm in 4 main channels 300–800 nm in 2 polarisation channels (PMD)
Spectral resolution FWHM	0.26–0.51 nm (main channels)
Swath width	Default 1920 km
Spatial resolution	Default 80 x 40 km^2
Data rate	400 kbit/s or 300 MB/orbit

Commissioning 1: In-orbit verification

Main purpose	☞ Verify instrument complies to its requirements ☞ Compare in-flight to pre-flight performance ☞ Optimise timeline settings as needed
Timing	Launch + 1 week to Launch + 8 weeks
Areas covered	Thermal, power, functional, performance
GOME-2 data	Housekeeping telemetry and level 0 data
Reference data	Requirements and pre-flight measurements
Analysis tools	GPP, DAPB,...
Participants	ESA (lead), EUMETSAT, Galileo Avionica/TPD (support), GMV (support)

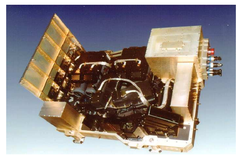
Mode	Performance parameters checked
Dark	Offset, fixed pattern, dark signal and noise, cross talk, light tightness
LED	Pixel-to-pixel gain variation, saturation, linearity, memory effect
SLS	Dispersion, spectral alignment/resolution/stability
SLS via diffuser	Sun diffuser reflectivity
WLS	Etalon, channel overlap positions
Sun	Optical throughput, signal-to-noise, Sun FoV
Earth	Signal levels (saturation check, IT optimisation), pointing/scanning, spectral straylight UV channel, performance of polarisation channels
Moon	Moon observations, pointing

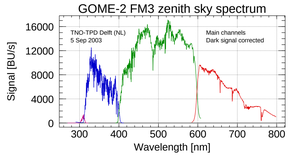
Commissioning 2: Validation

Main purpose	☞ Ensure that products satisfy the EPS End User Requirements and continuously improve to satisfy the evolving state of the art user requirements
Timing	Launch + 8 weeks to Launch + 6 months, continuing with long-term validation activities
Areas covered	Level 1 verification & validation, level 2 validation including feedback
Analysis tools	GPP, Cal/Val Facility, O3MSAF on-line services, BEAT,...
Participants	EUMETSAT (lead), ESA, O3MSAF, additional scientific support as necessary

Level 1 Verification, Confidence Checking and Validation · GOME-2 level 1 products cannot be fully validated without feedback from the validation of level 2 products. A preliminary validation of the earthshine radiance spectra and albedo can be achieved by confidence-checking of the UV albedo and comparison of radiance spectra to those calculated using an RTM or from other satellite sensors. Additionally the following parameters can be verified and/or validated: geolocation parameters, wavelength calibration parameters, Stokes fractions, cloud parameters, sun mean reference spectrum.

Level 2 Product Validation · Validation of these products will be primarily based on comparison with other independently validated spatially and temporally collocated measurements. Sources of independent validation data sets include ground-based data, satellite-based data, and aircraft- and balloon-based data. Validation of atmospheric constituent retrievals will be carried out at EUMETSAT in support of level 1 validation activities. Additionally, the O3MSAF will provide on-line validation services providing automated comparisons of level 2 data products with measurements from selected ground-based stations. Feedback from the scientific community is also expected to provide valuable information.





...and its calibration

Internal calibration · GOME-2 is equipped with three internal calibration sources which are regularly used both pre-flight and in-flight:

LED Light emitting diodes
SLS Spectral light source: NeArPtCr hollow cathode lamp
WLS White light source: Quartz Tungsten Halogen lamp

Furthermore, **Dark** signals are recorded regularly.

Pre-flight calibration · Using external calibration stimuli and environmental conditions approximating the expected in-orbit conditions as closely as possible, a number of instrument parameters have been characterised: absolute radiometric response, bi-directional scattering distribution function of the sun diffuser, polarisation sensitivity, straylight characteristics, and instrument slit function. GOME-2 has been used to record reference absorption cross sections of ozone and NO_2 at a number of temperatures.

In-flight calibration · In addition to performing the various internal calibration measurements, GOME-2 will observe the **Sun** once per day via a quartz quasi-volume diffuser.

Long-term monitoring

Main purpose	☞ Monitor instrument performance ☞ Condense and statistically analyse monitoring data ☞ Provide correction factors for level 0–1 processing
Timing	Instrument lifetime
Areas covered	Engineering: thermal, electrical, scanner Stability of in-flight calibration parameters Optical throughput and sun diffuser reflectivity Polarisation parameters
Input data	Level 1a/1b products, in-flight calibration data
Reference data	Pre-flight and "day 1" in-flight measurements

Data processing: Implementation

Level 0 to 1 Ground Processor Prototype (GPP) · A stand-alone level 0–1 processor has been developed at GMV. Initially primarily intended to be a testbed for algorithm development and creation of a reference test data set for the operational processor, the GPP has now grown into a multi-platform suite of tools: the main level 0–1 processor, offline tools for data visualisation, long-term monitoring and product quality statistics, and auxiliary test tools. The main processor has been coded in C++ (using MySQL to store in-flight calibration data) and is able to process an orbit of data from level 0 to level 1b within a few minutes on a single-processor PC.

Operational Level 1 Products · The operational Level 1 products from GOME-2 on MetOp will be produced centrally at EUMETSAT in the Core Ground Segment (CGS) by the GOME-2 Product Processing Facility (GOME-2 PPF). PPF and GPP share the same algorithm and format specifications (PGS & PFS, see References below).

Operational Level 2 Products · The responsibility for the operational extraction of meteorological or geophysical (level 2) products from GOME-2, and the provision of related operational services including on-line validation services, lies with the Satellite Application Facility on Ozone Monitoring (O3MSAF). The O3MSAF consortium is coordinated by the Finnish Meteorological Institute (FMI) in Helsinki. Scientific experts external to the SAF Consortium are involved through the SAF Visiting Scientist Programme.

Near Real Time level 2 products will be available within 3 hours from sensing.

References

The second Global Ozone Monitoring Experiment (GOME-2): An overview, EUMETSAT Programme Development Department Technical Memorandum No. 11
The GOME-2 level 0 to 1 Ground Processor Prototype: An introduction, MO-TN-ESA-GO-0560
GOME-2 Level 1 Product Generation Specification (PGS), EPS.SYS.SPE.990011
GOME-2 Level 1 Product Format Specification (PFS), EPS.MIS.SPE.97232