MESOPSHEO Products specification: OH, Temperature Rayleigh and PMC from GOMOS observations

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Summary

1. Temperature Rayleigh product

1.1. Principle

The spectrum of the limb sunlight scattering is observed during each star occultation at the same time than the star spectrum. In absence of scattering by aerosol and clouds particles, the observed signal is only due to Rayleigh scattering by air molecules and is directly proportional to atmospheric density. This is the case in the stratosphere above about 30-35 km and in the mesosphere in absence of PMCs. It is then possible to derive the vertical profile of temperature using the hydrostatic equation and the perfect gas law that relate atmospheric temperature, density and pressure. This method is commonly used in Rayleigh temperature lidars. Preliminary tests using GOMOS bright limb observations around 400 nm have shown the possibility to retrieve the temperature profile in the altitude range 35 to 85 km.

1.2. Algorithm

1) For all daylight observations, the limb scattering is estimated in 3 wavelength bands of 20-nm width each from 420 to 480 nm using the upper and lower background spectra.

2) In order to estimate the contribution of the straylight, a second order polynomial fit is made on the data with tangent altitude above the higher altitude where some signal from the limb scattering is expected, about 100 km. The fit is extrapolated to the full altitude range 35-100 km and removed from the observed signal in order to extract the Rayleigh scattering contribution.

3) A spectral inversion is made on the vertical profiles of Rayleigh scattering using a simple onion peeling method.

3) The inverted Rayleigh scattering signal is proportional to the atmospheric density. The temperature profile is computed from the density profile using the methodology developed for Rayleigh lidars (Hauchecorne and Chanin, 1980; Keckhut et al., 1993). Two relations relate atmospheric temperature, pressure and density profiles:

- the perfect gas law : $PV= nRT$
  where P is the pressure, V the volume, n the number of moles, R the gas constant and T the temperature
- the hydrostatic equilibrium : $dP=-rg\ dz$
  where g is the gravity acceleration and dz the altitude increment.

Using these two equations, the temperature profile is computed assuming a seed pressure at the top of the profile (about 90 km) taken from the MSIS00 climatological model (Hedin, 1991), and integrating downwards the hydrostatic equation.

4) The method is applied to the 3 spectral bands and to the upper and lower background spectra. 6 temperature profiles are retrieved. The temperature profile is taken as the median of the 6 profiles and its uncertainty as the rms dispersion.

5) This method has been applied to the whole database of bright limb GOMOS observations from 2002 to 2012 in order to provide climatology of upper stratospheric-mesospheric temperature. A more detailed description of the algorithm will be given in Hauchecorne et al. [2018].

1.3. Quality consideration

Data screening: a profile is removed if

- Solar zenith angle > 84°
- Top altitude top < 125 km
- Bottom altitude > 35 km

The vertical inversion is made assuming a single scattering of sunlight.

1.4. References

Hauchecorne A., M.L. Chanin, Density and temperature profiles obtained by lidar between 35 and 70 km, *Geophys. Res. Lett.*, 7, 565-568, 1980.

Keckhut P., A. Hauchecorne, M.L. Chanin, A critical review of the data base acquired for the long term surveillance of the middle atmosphere by Rayleigh lidar, *J. Atm. Ocean. Tech.*, 10, 850-867, 1993.

Hauchecorne A., L. Blanot et al., A new MesosphEO dataset of temperature profiles from 35 to 85 km using Rayleigh scattering at limb from GOMOS/ENVISAT daytime observations, to be submitted to Atmospheric Measurements and Techniques, 2018.

1.5. Temperature Rayleigh Product description

Filename: MESOSPHEO_T_RAYLEIGH_GOMOS_RXXXXX_SYYYY.nc

RXXXXX: ENVISAT Orbit number

SYYYY: GOMOS star identification number.

Type of product: Level 2.

Description: Temperature profiles retrieved from limb scattered GOMOS measurements.

Dimensions:

- Nb_alt = number of altitudes

Table 1: information about variables of the TEMERATURE_RAYLEIGH product

VARIABLE NAME	DESCRIPTION	Dimension	Type	UNITS
altitude	Altitude of the tangent point of the LOS	vector (nb_alt)	float	km
Temperature_rayleigh	Median temperature profile of the 6 temperature profiles (2 spatial bands, 3 wavelengths)	vector (nb_alt)	float	K
Error_temperature_rayleigh	Random error	vector (nb_alt)	float	K

	on Temperature			
Dispersion_temperature_rayleigh	Standard deviation of the 6 temperature profiles (2 spatial bands, 3 wavelengths)	vector (nb_alt)	float	K
Temperature_model	Temperature of the GOMOS external model	vector (nb_alt)	float	K
Pressure_model	Pressure of the GOMOS external model	vector (nb_alt)	float	Pa

Table 2: information about global attributes of the TEMPERATURE_RAYLEIGH product

GLOBAL Attribute NAME	DESCRIPTION	Dimension	Type	UNITS
Stars identification number	Altitude of the tangent point of the LOS	1	string	/
Envisat orbit number	Envisat orbit number	1	string	/
Sensing_start	Start time of the first measurement of the GOMOS observation.	1	string	Calendar day
Latitude (degree)	Mean latitude of the GOMOS observation.	1	string	degree
Longitude (degree)	Mean longitude of the GOMOS observation.	1	string	degree
Solar zenith Angle (degree)	Mean Solar Zenith Angle of the GOMOS observation.	1	string	degree
Occultation Obliquity (degree)	Obliquity (=verticality) of the GOMOS observation for the line of sight at 50 km of tangent height.	1	string	degree

2. OH nightglow product

2.1. Hydroxyl GOMOS

GOMOS observes O_2 and H_2O in two dedicated spectrometers SPB1 and SPB2 centred around 765 and 940 nm. These spectral bands contain airglow emission from OH Meinel bands that are visible in dark limb GOMOS spectra. Airglow observations can be useful to better understand atmospheric phenomena that remain in question, such as: the solar forcing on the middle atmosphere through the NO_x chemistry. The signal is relatively low and it requires very careful dark charge and stray-light corrections and a filtering of spectra affected by aurorae at high latitude. A preliminary analysis has been made [1]. It demonstrated the method and provided a first climatology.

A full climatology of OH limb emission was built covering the period 2002–2012, corresponding almost to a full solar cycle. The signal is too low to obtain OH profiles at single occultation level. Only monthly mean profiles averaged in specified latitude bands were created (Level 3 data).

2.2. Algorithm

For this task the following steps are done:

1/ Extraction of all spectra in the upper and lower background bands of SPB2 for tangent altitudes between 80 and 100 km using GOMOS IPF 6.01 Level1b data. All occultations except bright occultations are extracted. Check if presence of stray-light variable with altitude flag + aurorae flag. A reference spectrum without OH emission is created by averaging spectra at high altitude (>110km).

2/ Independently for each background band (lower and upper) a summation of spectra is made in predefined latitude, longitude, time and altitude ranges:

- Latitude bands: 10° wide from 90°S to 90°N
- Time: monthly mean average
- Altitude layers: 2 km wide from 80 to 100 km

Before the spectra are summed, each spectrum is corrected by substraction of the high altitude spectrum.

Filtering: stray-light flagged and aurorae flagged data are discarded.

3) Determination of the baseline in summed spectra using pixels outside of OH emission bands.

4/ For each summed spectrum the integration of the OH signal is made over all pixels containing OH emission (after removal of the base).

2.3. References

Bellisario, C., P. Keckhut, L. Blanot, A. Hauchecorne, P. Simoneau, O2 and OH night airglow emission derived from GOMOS-ENVISAT instrument, J. Atmos. Ocean. Tech., 31 (6), 1301-1311, 2014.

2.4. OH nightglow Product specification

Filename: climato_OH_gomos.nc

Type of product: Level 3.

Description: climatology of OH nightglow emission observed by GOMOS.

Disclaimer:

- GOMOS suffered from a strong increase of dark current through the mission. The dark current is corrected in the operational GOMOS processing chain. An additional correction is done in the current MesosphEO OH processing chain when removing the high altitude spectrum. However, despite these corrections, the shot noise due to dark current is increasing throught the mission. Consequently, the quality of the current OH emission data may be slightly reduced when going toward the end of the mission.
- For the product delivered at the end of the MESOSPHEO project, we used all products with illumination condition indicator “pcd_illum”= 0, 1, 2, 3 and 4. Note that GOMOS products have an other indicator of illumination condition: “limb”. This indicator can be equal to 0 (night observation) or 1 (day observation). All data with “limb”=1 have been discarded. The GOMOS product with pcd_illum=1 AND limb=0 have been kept for computing this OH climatology but there number is very small.
- For the product delivered at the end of the MESOSPHEO project we have discarded all products which were contaminated by an aurora. (We used our own aurora detection algorithm).
- For the product delivered at the end of the MESOSPHEO project we have discarded observation for which the stray-light was not possible to be corrected (either too intense stray-light or altitude changing stray-light).
- For the product delivered at the end of the MESOSPHEO project we have selected all available star_ID because we considered that the stellar leakage that happen especially for bright stars could be perfectly corrected by the removal of the high altitude spectrum.

Dimensions:

- nb_alt: number of altitude bins
- nb lon: number of longitude bins
- nb_lat: number of latitude bins
- nb_time: number of time bins

Table 3: information about variables of OH_NIGHTGLOW product

VARIABLE NAME	DESCRIPTION	Dimension	Type	UNITS
OH_emission	Integrated flux of OH emission lines through the GOMOS line of sight	Array (nb_alt, nb_lon, nb_lat, nb_time)	float	electrons

err_OH_emission	Error on integrated flux of OH emission lines	Array (nb_alt, nb_lon, nb_lat, nb_time)	float	electrons
nb_spectres	Number of GOMOS measurement spectrum used	Array (nb_alt, nb_lon, nb_lat, nb_time)	int	/
nb_prod	Number of GOMOS products used	Array (nb_lon, nb_lat, nb_time)	int	/
alt_max_emission	Altitude above sea level of the maximum of the OH emmission	Array (nb_lon, nb_lat, nb_time)	float	Km
start_time	Mean time of the first bin	1	double	Julian day, Day since 1, 473 B.C.E at 12:00:00
Start_lat	Mean latitude of the first bin	1	Float	Degree
Start_lon	Mean longitude of the first bin	1	Float	Degree
Start_alt	Mean altitude of the first bin	1	Float	Km
Step_time	Step of the time grid	1	Double	Day
Step_lat	Step of the latitude grid	1	Float	Degree
Step_lon	Step of the longitude grid	1	Float	Degree
Step_alt	Step of the altitude grid	1	float	km

Table 4: information about global attributes of OH_NIGHTGLOW product

GLOBAL Attribute NAME	DESCRIPTION	Dimension	Type	UNITS
Gomos_processor_version	Name and version of the GOMOS processor used to build the GOMOS products.	1	String	/
Illumination conditions	Selected observation illumination conditions (0=full dark, 1=bright limb, 2=stray-light,	1	string	/

	3=stray-light, 4=twilight+straylight) of GOMOS observations			
Stars identification number	Star identification number of the selected stars.	1	string	/
Aurora contaminated products	Keep or discard the GOMOS products contaminated by aurora	1	String	/
Stray-light contaminated products	Keep or discard the GOMOS products with strong and altitude varying stray-light signal.	1	String	/
Background band(s)	Name of the Spatial GOMOS Background Bands that were used.	1	String	/

3. PMC product

3.1. GOMOS PMC observations

GOMOS limb-scatter observations allow the determination of altitude and brightness of Polar Mesospheric Clouds (PMCs). The two fast 1 kHz photometers centred at 470 and 650 nm are used for the PMC retrieval [2]. The photometer signal includes the star signal that is estimated at high tangent altitude and removed. A careful estimation of the stray-light, coming from a the direct sun and from the earth surface and clouds, has to be made before the analysis. In addition UV-visible spectra of the bright limb can be used for the determination of the mean particle radius.

The GOMOS PMC measurements were used to study the asymmetry between the two hemispheres in terms of altitude, brightness and frequency occurrence of NLCs. In MesosphEO project a new analysis of PMC parameters will be made covering the full life of ENVISAT (2002-2012) starting from the IPF 6.01 version of Level 1b GOMOS data. Level 2 product at single occultation level and Level 3 products averaged over latitude bands and time periods will be created.

3.2. Algorithm

Level 2 Single occultation products

1. Extraction signal of fast photometers for daylight occultations in GOMOS IPF6 Level1b data. Seasonal and latitudinal limits
2. Subtraction of the stray light using an algorithm derived from the GOMOS bright limb project.
3. Detection of the presence of a NLC. A 3rd degree polynomial fit is applied to the flux curve of the two photometers between 55 and 100 km. In absence of NLC the fit follows well the exponential decrease of the Rayleigh scattering profile and the chi2 of the fit is near 1. If the chi2 of the fit exceeds a threshold of 1.8 for the two photometers we consider that a NLC is present. A visual inspection is made to eliminates false detections (less than 4%).
4. Retrieval of useful information

   Detection flag (presence of NLC or not)

   Altitude of maximum radiance

   Intensity of maximum radiance

Level 3 averaged products

5-day mean averaged products in 5°-wide latitude bands

Extracted from Level 2 NLC products:

- Frequency of NLC occurrence (number and percentage of PMC detections)
- Mean altitude of maximum radiance
- Mean intensity of maximum radiance

3.3. Réference

K. Pérot, A. Hauchecorne, F. Montmessin, J.-L. Bertaux, L. Blanot, F. Dalaudier, D. Fussen, and E. Kyrölä. First climatology of polar mesospheric clouds from GOMOS/ENVISAT stellar occultation instrument. Atmospheric Chemistry & Physics , 10:2723–2735, March 2010

3.4. PMC Level2 product specification

Filename: MESOSPHEO_PMC_GOMOS_level2_MM_YYYY.nc

MM = Month, from '01' to '12'.

YYYY = Year

Type of product: Level 2.

Description: lists the individual PMC events detected by GOMOS, with the associated geolocation, SZA and altitude of the maximum of emission of the PMC.

Dimensions:

- n_prod: number of GOMOS product

Table 5: information about variables of the Level-2 PMC product

VARIABLE NAME	DESCRIPTION	Dimension	Type	UNITS
time	Julian Date of the start time of the GOMOS observation where a PMC was detected.	Array(n_prod)	double	Day since 0h Jan 1, 2000
longitude	Longitude of the tangent point for the LOS with tangent point altitude = 80 km.	Array(n_prod)	float	degrees_east
latitude	Latitude of the tangent point for the LOS with tangent point altitude = 80 km.	Array(n_prod)	float	degrees_north
sza	Solar Zenith Angle of the tangent point for the LOS with tangent point altitude = 80 km.	Array(n_prod)	float	degrees
PMC_altitude	Altitude of the maximum of emission of the detected PMC	Array(n_prod)	float	Km (NaN value when the altitude of the maximum of emission could not be determined)

3.5. PMC Level-3 product specification

Filename: MESOSPHEO_PMC_GOMOS_level3.nc

Type of product: Level 3.

Description: Climatology of PMC detected by GOMOS.

Dimensions:

- nb_time: number of time bin
- nb_lat: number of latitude bin
- nb_lon: number of longitude bin

Table 6: information about variables of the Level-3 PMC product

VARIABLE NAME	DESCRIPTION	Dimension	Type	UNITS
time_start	Start time of the bin	Array(nb_time)	double	day since 0h Jan 1, 2000
time_end	Stop time of the bin	Array(nb_time)	double	day since 0h Jan 1, 2000
longitude_start	Start longitude of the bin	Array(nb_lon)	float	degrees_east
longitude_stop	Stop longitude of the bin	Array(nb_lon)	float	degrees_east
latitude_start	Start latitude of the bin	Array(nb_lat)	float	degrees_north
latitude_stop	Stop latitude of the bin	Array(nb_lat)	float	degrees_north
pmc_count	Number of occultation with a PMC detected	Array(nb_lon,nb_lat, nb_time)	int	No unit (Fill value if no GOMOS observation done in this bin.)
pmc_frequency	Frequency of occultation with a PMC detected	Array(nb_lon,nb_lat, nb_time)	float	% (Fill value if no GOMOS observation done in this bin.)
pmc_altitude	Mean altitude of the maximum of emission of the detected PMCs	Array(nb_lon,nb_lat, nb_time)	float	Km. (- fill value if no PMC detected in this bin - NaN if PMC(s) detected in this bin but altitude of the maximum of emission could not be retrieved for all detected PMCs)