GOME Data Processing at I-PAF: the Aerosol Optical Thickness Retrieval from GOME Spectra

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Abstract

The GOME instrument, on board the ERS-2 satellite, has been designed in order to collect radiation over the entire wavelength region from 240 to 790 nm, in which several atmospheric species and also aerosols and clouds can be observed. A prototypal processor for the aerosol optical thickness retrieval and aerosol classification starting from GOME data has been developed. This processor has been devised as a tool to be used for the development of an operational GOME data processing chain at the I-PAF. The implemented retrieval algorithm is based on a spectral reflectance fitting procedure of the measured radiances by GOME instrument. The maximum likelihood principle has been used in order to define the objective function. The ranking is made choosing the minimum among the least squares residuals computed for different aerosol classes. For each pixel the output of processor gives the aerosol optical thickness, the aerosol classification, a relative retrieval residual and a flag that indicates if the pixel is cloudy. The results of some different GOME real data sets are shown.

Keywords: GOME, aerosol, optical thickness retrieval, PAF

Introduction

The determination of atmospheric aerosol load and classification on a global scale is a crucial item to refine the analysis of the Earth radiative balance.

Natural and anthropogenic aerosols may play a decisive role in determining Earth surface temperature changes; knowledge of global aerosol distribution is mandatory since temperature changes may be not uniform in space.

Aerosols can be retrieved from data collected by GOME instrument, on board of the ERS-2 satellite, that collects radiation over the wavelength region from 240 to 790 nm.

The fast atmospheric spectral radiative transfer model (RTM) GOMESIM for calculation of reflection of solar radiation based on the analytical Sobolev approach is used to fit the reflectance computed from GOME measurements with simulated data where aerosol content is assumed. The retrieving of both aerosol class and optical thickness is tested assuming that an aerosol layer is present in the Earth atmosphere. The retrieval algorithm has been implemented in a prototypal processor for the aerosol optical thickness and aerosol classification generation from GOME data (PGADP). This processor has been devised as a tool to be used for the development of an operational GOME data processing chain at the I-PAF.

The Radiative Transfer Model GOMESIM

The adopted cloudless plane parallel atmospheric RTM GOMESIM is briefly described here; a more comprehensive description can be found in (Guzzi et al, 1996).

The solution of the monochromatic Radiative Transfer Equation (RTE) is based on the formulation proposed by Sobolev (Sobolev, 1963), in case of pure a pure scattering vertically homogeneous atmosphere bounded with a Lambertian reflecting surface. The reflectance or brightness coefficient is expressed as

$$\rho = P(\gamma)\rho_1 + \Delta\rho \quad (1)$$

being $P(\gamma)\rho_1$ the single scattering coefficient $P(\gamma)$ the atmospheric scattering phase function and $\Delta\rho$ the higher order of scattering coefficient.

The assumption of a vertically homogeneous atmosphere would lead to unsatisfactory results if the suggested approach is utilized as is.

Then the contribution to the reflectance by radiation scattered only once is now analytically computed taking into account the vertical optical non-uniformity, caused by the presence of an aerosol layer bounded between two layers composed of molecules only ("Rayleigh layers").

On the contrary, some assumptions and approximations have been done in defining the higher order of scattering coefficient, following the Sobolev scheme:

- the scattering phase function is "smoothed" with a two-terms form (Legendre polynomial series);
- some approximations have been made on boundary conditions;
- approximations on the zenith dependence of the diffuse radiation have been introduced;
- the azimuth dependence of the reflection coefficient is due only to single scattering contribution.

Moreover, to take into account the atmospheric vertical non-uniformity, the following features have been added to the model computation of the higher order of scattering coefficient:

- an effective total (aerosol and molecules) scattering optical thickness is derived:

$$\tau_S = \tau_1^R + \tau_2^R + \tau^{AS}\exp\left(-\tau_1^R\alpha\right) + \tau_3^R\exp\left(-\frac{\tau^{AS}}{\mu_0}\right) \quad (2)$$

where:

τ_i^R is the Rayleigh optical thickness of the i-th layer, from top to down,

τ^{AS} is the aerosol scattering optical thickness,

α is the sum of the secants of the sun and line-of-sight zenith angles,

μ_0 is the cosine of the sun zenith angle;

- a two term scattering phase function, with a weighted (Mie and Rayleigh) asymmetry factor;
- aerosol absorption is parameterized by means of transmittance factors:

$$T^{AA} = \exp\left[-(1-\omega_0)\tau^A\alpha\right] \qquad (3)$$

where:

ω_0 is the aerosol single scattering albedo,

τ^A is the aerosol extinction, scattering plus absorption, optical thickness.

Gas absorption can be ignored since wavelength at which it occurs will be avoided, see (Guzzi et al, 1996).

This approach has the advantage of considering the multiple scattering effects preserving the high speed of computation thank to the use of a few physical parameters.

Prototypal GOME Aerosol Data Processor (PGADP)

The prototypal processor for the GOME Aerosol Optical Thickness product generation (PGADP) is a software package implementing a subset of the functions devised for the complete processing chain; it has been realized using the Interactive Data Language (IDL) and the FORTRAN language. It has been developed on a DEC ALPHA 3000 workstation under the Open VMS operating system. The main functions implemented by PGADP are:

- GOME Reflectance Calculation
- Cloud flag generation
- Spectral Window Selection
- Spectral Reflectance Fitting
- Ranking of the Aerosol Class
- Surface Reflectance Calculation
- Output Data Generation

Further details about the most significant aspects are given in the following subsections.

GOME Reflectance Calculation

The GOME instrument measures the following quantities:

- Earth-shine radiances
- sun irradiances

The reflectances calculation is performed using the formula

$$REF_{GOME} = \frac{\text{Earth - shine radiance} * \pi}{\text{sun irradiance} * \cos\theta_0} \qquad (4)$$

where θ_0 is the zenith angle of the sun

Cloud Flag Generation

In order to define the cloud detection algorithm of the AOT prototypal processor, the elaboration of the PMD data has been implemented following the line of the CCA algorithm (Deschamps et al, 1994).

A PMD pixel is declared cloudy if

$R3 > thre1$ or $thre2 < R3 < thre1$ and $R3/R2 > thre3$

where R1, R2, R3 are the reflectances measured respectively by PMD1, PMD2 and PMD3.

The values currently assigned to these parameters are:

$thre1 = 0.12$ $thre2 = 0.05$ $thre3 = 0.5$

Spectral Window Selection

GOME measurements cover the wavelength range from 240 nm to 790 nm. Nevertheless in order to properly use GOME data for aerosol retrieval the influence of two different phenomena have to be taken into account the absorption due to water, oxygen and ozone.

This can be done in PGADP selecting wavelength intervals in which gases absorption can be neglected and the spectral sensibility of the GOME can be fully exploited.

Spectral Radiance Fitting and Ranking of the Aerosol Class

The algorithm will be based on a fitting procedure of the GOME reflectances by the forward model GOMESIM. The maximum likelihood principle has been used in order to define the following objective function:

$$\min_{k\in\{1,\dots,20\}}\left\{\min_{\hat{\tau}_{ext}^{A_k}}\left[\sum_{i=1}^{m}\ln\left(REF\_ERR_{GOME}(\lambda_i)\right) + \frac{1}{2}\sum_{i=1}^{m}\left(\frac{REF_{GOME}(\lambda_i) - REF_{FM}^{A_k}(\lambda_i,\theta,\phi,\theta_0,\phi_0,\tau_{sj}^{a}(\hat{\tau}_{ext}^{A_k}),\omega_{0,i}^{A_k})}{REF\_ERR_{GOME}(\lambda_i)}\right)^2\right]\right\} \qquad (5)$$

where:

$\tau^{A_k}_{ext}$ the retrieval parameter, is the extinction aerosol optical thickness of the aerosol class A_k at the reference wavelength 0.55 μm;

$REF_{GOME}(\lambda_i)$ are the reflectances at the wavelength λ_i for i=1,...,m;

$\tau^{a}_{s,i}$ is the scattering optical thickness at the wavelength λ_i, for the aerosol class A_k;

$\omega^{Ak}_{0,i}$ is single scattering albedo at the wavelength λ_i, for the aerosol class A_k.

The process is based on two nested minimization procedures. The inner minimization is performed on the extinction aerosol optical thickness of the aerosol class A_k at the reference wavelength 0.55 μm using the NAG routine E04ABF (NAG) based on a one-dimensional inverse quadratic interpolation. This process is repeated more then once in different values intervals in order to avoid local minima. The outer discrete minimization will be made choosing the minimum among the least squared residuals computed for different aerosol classes.

Assuming that the aerosol particles can be modeled by equivalent spheres of known refractive index, we use the Mie's theory for the evaluation of the aerosol optical proprieties and aerosol phase function.

In the present version of PGADP the aerosol classes listed in Table 1 have been used.

Aerosol Class	Description
1 - 4	Rural (RH=0%, 70%, 80%, 99%)
5 - 8	Urban (RH=0%, 70%, 80%, 99%)
9 - 10	Maritime (RH=0%, 70%, 80%, 99%)
13 - 16	Tropospheric (RH=0%, 70%, 80%, 99%)
17	Background Stratospheric
18	Aged Volcanic
19	Fresh Volcanic
20	Desert Wind-Carry

Table 1: Aerosol classes description

Surface Reflectance Calculation

In order to introduce surface albedo in the aerosol retrieval scheme a parametrization of its spectral dependence is required. To this aim 5 spectral signatures have been used in PGADP relative to the different surface types (Bowker et al., 1985), that is:

snow

vegetation

sand

soil

water

Morover for each pixel the following steps are performed in order to assign an albedo profile:

minimization of the objective function (5) using the each of the 5 spectral albedo profiles with a fixed troposheric aerosol class;

selection of the surface spectral albedo profile corresponding to the minimum residual value of the objective function.

Output Data Generation

The PGADP gives as output the geolocation information of the pixel processed and the following aerosol information:

Aerosol class: that is a code for aerosol class identification, Table 1

Aerosol Optical Thickness (at the reference wavelength 0.55 μm)

Surface Albedo type: that is a code for the surface albedo identification

Relative Retrieval Residual, that is:

$$\text{Relative Retrieval Residual} = \frac{\left[\sum_{i=1}^{m}\left(REF\_GOME(\lambda_i) - REF\_REC(\lambda_i)\right)^2\right]^{\frac{1}{2}}}{\left[\sum_{i=1}^{m}\left(REF\_GOME(\lambda_i)\right)^2\right]^{\frac{1}{2}}} \quad (6)$$

Real GOME Data Processing Results

The prototypal processor PGADP has been tested on a data set of real GOME data relative to 4 orbits in the period 29-31/01/97 covering the geographical area depicted in Figure 1. In the same figure the aerosol optical thickness values obtained by PGADP are shown regardless to the cloud information provided by the CCA algorithm. The albedo map Figure 2 shows some problems with cloud over the sea, while it recognizes clearly and not surprisingly snow over the Antarctic. Figure 3 shows the results of considering as valid only the pixels over which no PMD is declared cloudy by the CCA algorithm. The results of this filtering can be checked by looking at Figure 4 where only water albedo has survived over ocean. Morover the effectiveness of the CCA in Cloud detection over Ocean has been also qualitatively tested against full disk Meteosat Image

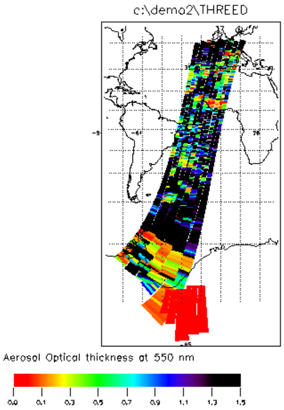

Figure 1

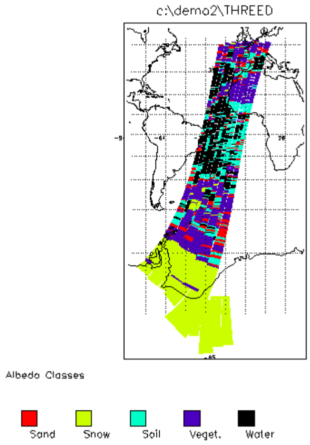

Figure 2

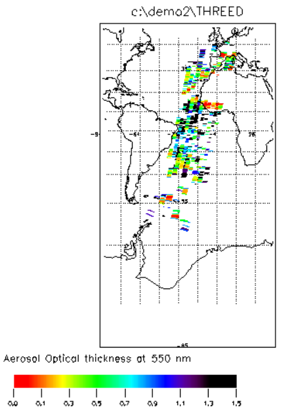

Figure 3

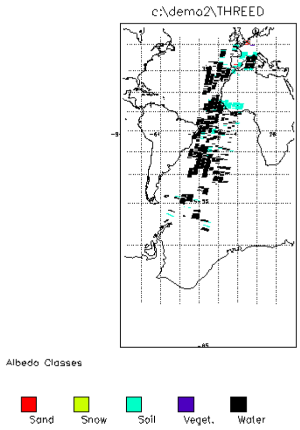

Figure 4

Conclusions

The first results obtained on real GOME data show that the application of the CCA algorithm for the cloud flag generation seems to work over the Ocean where reasonable AOT values (<1) are calculated over a significative amount of pixels (65%). Nevertheless a more quantitative and sophisticated validation exercise has to be done in order to clearly establish the CCA effectiveness and to explain the presence of too high AOT value over clear open Ocean pixels. In conclusion the PGADP software is a useful tool for the assessment of the aerosol optical thickness retrieval algorithm from GOME data and we think that more problems and hopefully solutions will be found processing larger amount of data.

References

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