AEROSOL OPTICAL THICKNESS RETRIEVAL FROM GOME DATA IN THE OXYGEN A-BAND

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Abstract

Backscatterd solar irradiance as measured by the GOME (Global Ozone Monitoring Experiment) on the ERS-2 satellite has been used in a new algorithm to obtain aerosol optical thickness and ground albedo simultaneously in the near infrared. The algorithm utilises an absorption band of oxygen around 762 nm (the oxygen A-band) which gives this method the advantage of obtaining some height information of the observed aerosol. The current status of this project is presented in this paper.
Keywords: GOME, Atmospheric Band, Aerosol, Oxygen

1. Introduction

Aerosols modify the radiative transport in the atmosphere directly by interacting with the radiation field. This has an impact on the earth's radiative budget. Indirectly, aerosols may also modify the radiative budget by interacting with a range of atmospheric properties such as cloud droplet number and size, cloud cover etc. The interaction of aerosols in a cloud free atmosphere may be observed by a space borne instrument such as GOME as an increased albedo due to the enhanced backscattering compared to a pure molecular atmosphere. Deducing the aerosol optical thickness from a measured backscatter spectrum is complicated by the nature of the GOME viewing geometry (nadir). The reflected radiation from the surface can totally swamp any backscattering from the atmosphere. Moreover the surface albedo is both spatially and seasonally variable making this signal difficult to predict. To minimise the impact of this we decided to use the oxygen A-band; a spectral region where the neutral atmosphere has significant absorption which reduces the ground reflected radiation. Also, since it is difficult to retrieve atmospheric albedo and/or ground albedo individually from a measured spectrum we developed an algorithm that retrieves both aerosol optical thickness and ground albedo simultaneously. Since the oxygen optical thickness in the A-band varies, the measured spectrum will also contain altitude information. This is seen in figure 1 which gives a initial indication of the potential for retrieval of aerosol optical thickness in the A-Band region. In this figure the height from which the majority of the backscatterd radiance is coming is shown at GOMEs spectral resolution for the spectral region of the A-band for a molecular atmosphere without ground reflection. One sees clearly that the backscattering height varies with wavelength which implies that altitude resolution can be obtained. Furthermore it is seen that the thickness of the reflecting layer is about 5 km which indicates the approximate height resolution we can expect to obtain. Around 761 nm, we see that the lower layers are effectively screened which also implies a reduction in the effect of backscattering from the ground.

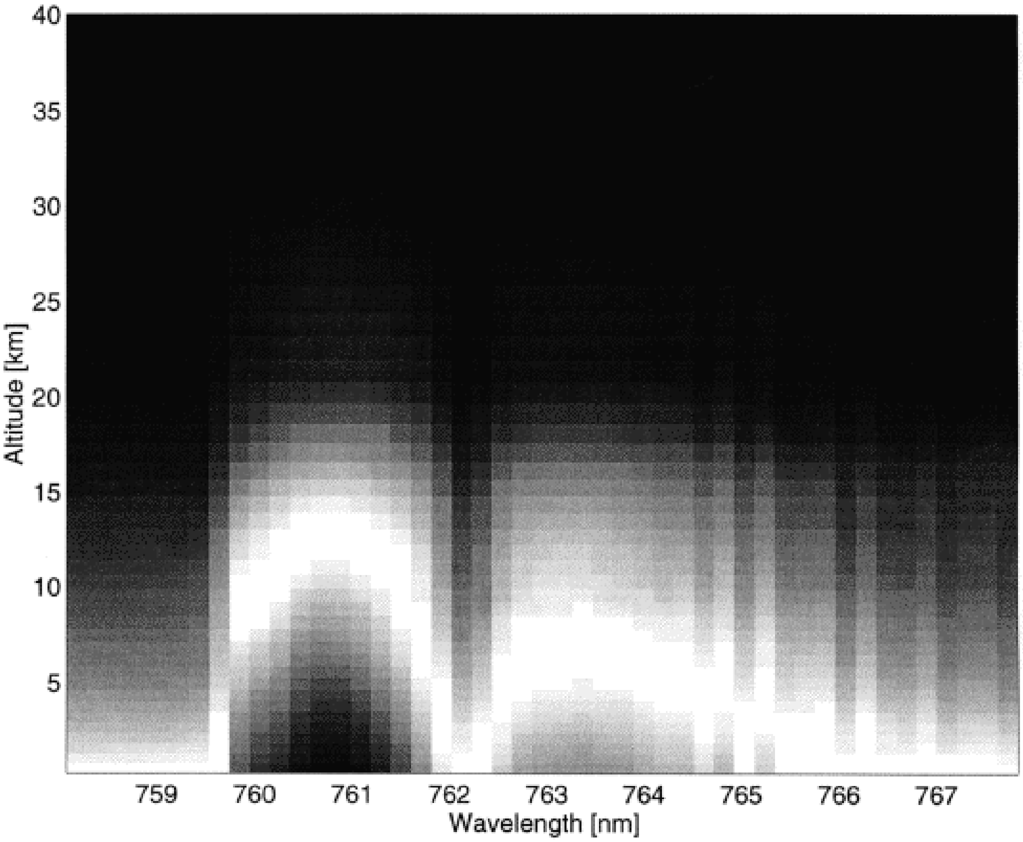

Figure 1. The altitude from which the majority of the backscatterd radiance is coming at GOME's spectral resolution is indicated with the lighter colours. The wavelength range is that is used for the retrieval .

The Optical Estimation Method (Rodgers 1976) has been used for the inversion. The single scattering model and inverse models that are part of this formalism will be presented in the next two sections. Section 4 will deal with the results and finally section 5 will conclude this paper.

2. THE FORWARD MODEL
2.1 SINGLE SCATTERING MODEL

The spectral region of the oxygen A-band (~762 nm) is seen by GOME at ~0.4 nm resolution. Figure 2 shows a synthetic spectrum of the A-band at the calculated resolution 0.01 cm-1, and the spectrum at the same resolution as the GOME instrument. To obtain the spectrum at GOMEs resolution, the high resolution spectrum is first convolved with the GOME instrument slit function (GOME Users Manual, 1995) and then sampled at the wavelengths at which GOME measures. The several hundred absorption lines of which the band consist are no longer resolved individually but the resolution is good enough to resolve the P and R branches. The convolved spectrum mainly sees the backscattered radiance coming from between the lines. Since the line density varies, the optical thickness between the lines, which consist of the contribution of all nearby lines, will also vary. This provides the altitude information in the measured spectrum that can be retrieval by an inversion algorithm such as the one presented in this paper (see Figure 1).

The MSIS 90e (Hedin *et al.* 1983) atmospheres are used for the atmosphere on a seasonal (1 month resolution) and latitudinal grid (variable resolution, depending on the solar zenith angle). At this point aerosol properties are uniform in all layers and taken from MODTRAN (Kneizys *et al.* 1988). The algorithm however is flexible and analysed fields could be used. Line strength are taken from HITRAN-92 (Rothman *et al.* 1992). We only include the first scattering event in the atmosphere of the incoming solar irradiance, and the reflection from the ground (treated as a lambertian surface), to determine the upwelling radiance. This will pose a severe limitation on the maximum surface albedo and maximum aerosol optical thickness for which we can attempt to perform an inversion. No attention is payed to polarisation. Since the GOME instrument is sensitive to polarisation and the correction for this is likely to be wrong in the A-band this may introduce an error which will be dependent on the amount of depolarisation in the atmosphere and is therefore difficult to estimate at this point.

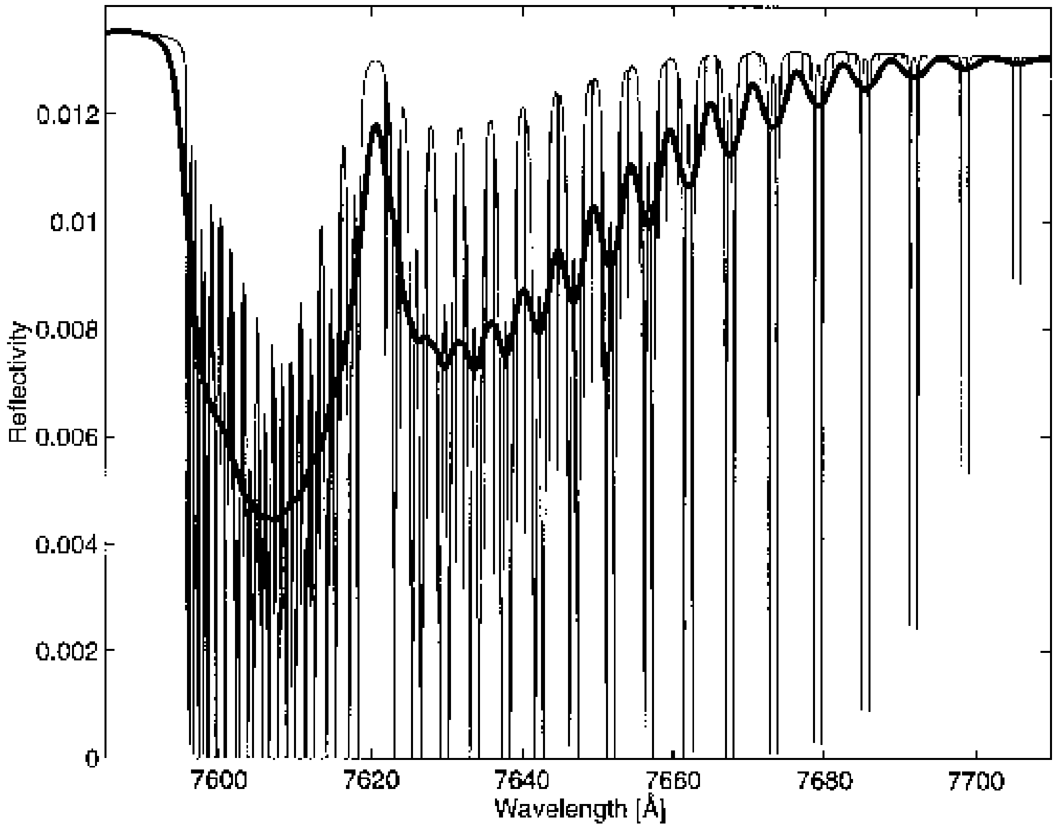

Figure 2. Synthetic reflectivity spectrum at the TOA in the oxygen A-band. Thin line: at 0.01cm-1 resolution. Thick line: convolved with the GOME instrument slit function.

Within the OEM formalism the measured bacscattered spectrum **y** can be related to the atmospheric state **x** through the forward model:

$$\mathbf{y}=\mathbf{F}(\mathbf{x},\mathbf{b})+\mathbf{e}_\mathbf{y}$$

plus the error ($\mathbf{e}_\mathbf{y}$ in the measurement. The forward model **F** is thus the single scattering model as described in the previous paragraph. the vector **b** contains all quantities included in the model but that will not be retrieved (e.g. line strength, temperature etc. see also table 1a). The true atmospheric state **x** that we intend to retrieve is the vector consisting of the ground albedo and optical thickness as function of altitude.

forward model	
Wavelength grid	758-768 nm at 0.01 cm-1 resolution, (Backscattered radiance is convoluted with GOME slit function)
Height grid	Exponential, 0-120 km. Smallest interval 0.5 km, Spherical atmosphere.
Atmosphere	MSIS 90e, seasonal and latitudinal dependent
O2 and H2O lines	HITRAN '92
Aerosols	MODRAN
Scattering	Single scattering with ground reflection (lambertian)

Table 1a. Properties of the forward model.

Inverse model	
Method	OEM (Rodgers 76)
Height Resolution	~5 km at 0 km
Retrieved parameters	Optical depth at 762 nm in 5 layers Ground albedo
Pixel rejection	Based on albedo (Rejection when the albedo > 15%)

	Based on column optical thickness (Rejection when t> 0.5)

Table 1b. Properties of the inverse model.

2.2 Monte-Carlo model

A second model was developed to study the effect of multiple scattering. This model was developed to validate the current single scattering forward model. A much-used method to investigate multiple scattering is the Monte Carlo approach in which photons are traced from the source throughout the multiple scattering process until they are lost to space. Loss of photons can be due to either backscattering or absorption (by the ground or by absorbing species in the atmosphere. The same atmosphere data and aerosol properties are utilised in the Monte Carlo model as in the single scattering model. The Monte Carlo model has a plane-parallel atmosphere which makes the comparison valid only for solar zenith angles of less than 60 degrees. The effect of polarisation of photons has not yet been incorporated into the model.

The results studied are the number of backscattered photons seen in the nadir direction in a small angular interval. This means that the result has a significant statistical error (which is evident in the results presented below). The Monte Carlo model can only be used for validation and not to replace the forward model because of the very large computation time needed for the Monte Carlo approach.

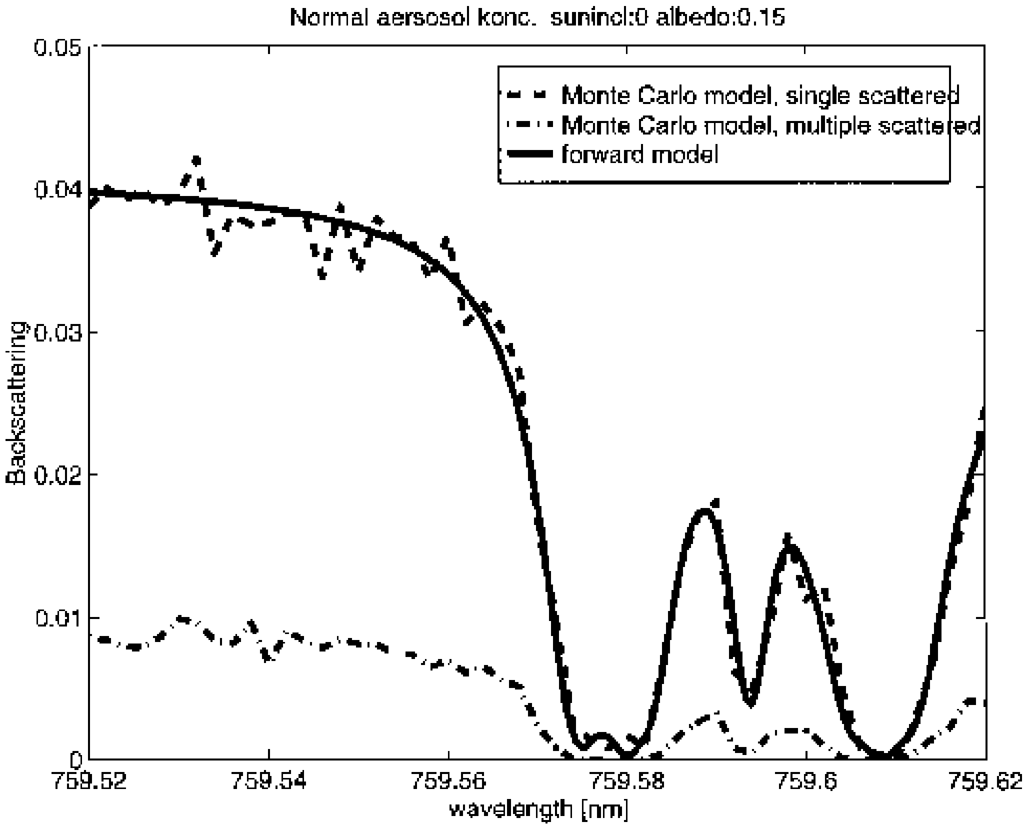

Figure 3: Comparison between the single scattering and Monte-Carlo model.

Figure 3 shows a comparison of the single scattering model with the Monte-Carlo model for a wavelength interval in the beginning of the A-band. The solar zenithangle was 0 degrees and the ground albedo 0.15. An background aerosol profile with a total optical thickness of 0.14 was used. As expected, the single scattered part of the backscattered radiation matches between the two models. The multiple scattered part was in the order of 20% of the single scattered part. However, 95% of the multiple scattered photons scattered from ground at some time so at lower ground albedos this contribution from multiple scattering decreases. Other aerosol profiles showed that the multiple scattered contribution becomes significantly important for aerosol profiles of optical thicknesses higher than about 0.4.

These results show that multiple scattering must be implemented in the forward model in order to correctly retrieve aerosol profiles of optical thickness of more than about 0.2

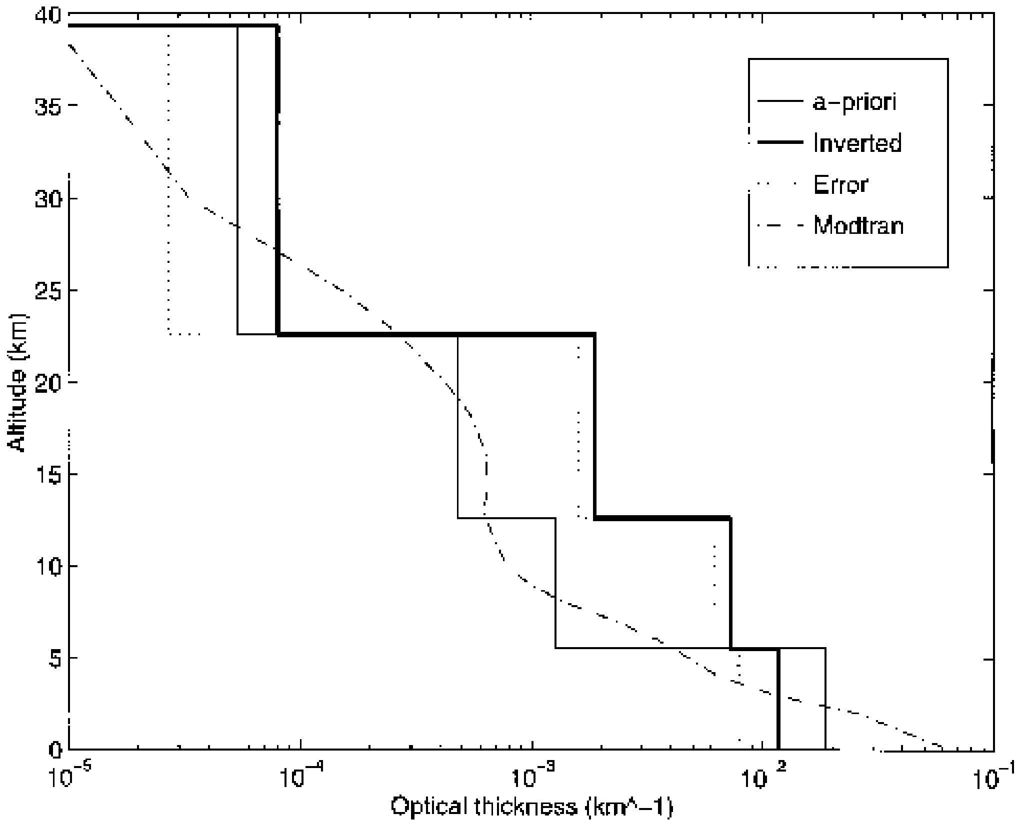

Figure 4a: A single aerosol retrieval, Aerosol optical thickness (km^{-1})

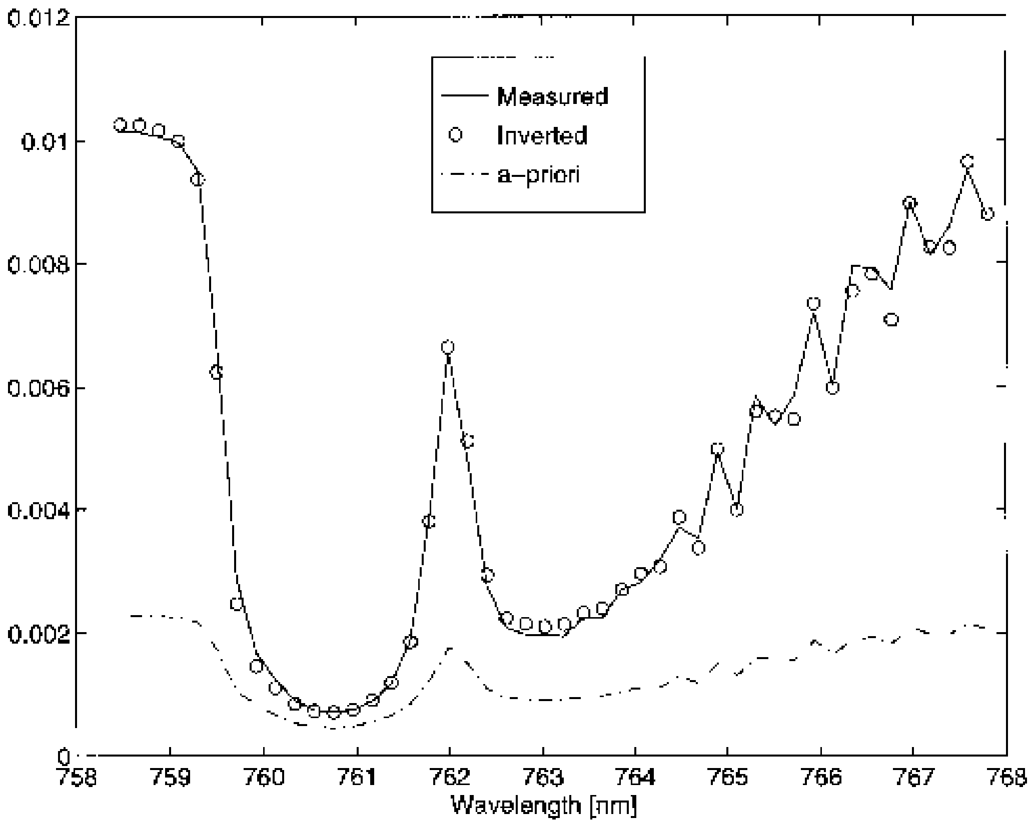

Figure 4b: A single aerosol retrieval. The measured and retrieved spectrum.

3. The inverse model

Similarly the retrieved vertical profile and ground albedo (together designated with $\mathbf{x_r}$as distinct from the true atmospheric state **x)** are related to the measured spectrum by the inverse or retrieval function R:

$$\mathbf{x=R(y,b,x_a)}$$

Where is a best estimate of the forward model parameters **b**. $\mathbf{x_a}$ is an a-priory estimate of the atmospheric state that we intent to retrieve. This might be aerosol optical thickness and ground albedo from a climatological database. Linearizing the forward model

F and inverse model **R** around an atmospheric reference state $\mathbf{x_0}$ the following equation can be obtained for the retrieval:

$$\mathbf{x=x_a+D_y(y-K_x x_a)}$$

$\mathbf{K_x}$ is the so called kernel matrix that is calculated by pertubating the aerosol optical thickness in the forward model around the reference state $\mathbf{x_0}$, $\mathbf{D_y}$ is a matrix that can be calculated from of the kernel matrix and the error matrixes. This equation is used for the retrieval of optical thickness and ground albedo.

Figures 4a and 4b show the results of a single retrieval. The a-priori and retrieved aerosol optical thickness (km^{-1}) in four of the five layers are shown. Note that due to the logarithmic scale the lower error limit is visually strongly exaggerated. Figure 4b shows the spectrum measured by GOME for this ground pixel with the a-priory spectrum (molecular atmosphere plus background aerosol without surface reflection) and the spectrum fitted by the retrieval method. The close match indicates that the forward model is capable of reproducing the atmospheric state for this particular ground pixel.

4. PRELIMINARY RESULTS

Figures 5a and 5b show preliminary results obtained by the inversion method as described so far. Figure 5a shows the retrieved ground albedo and figure 5b the total aerosol optical thickness on the 27 and 28 November 1995. Beneath these inverted parameters a infrared METEOSAT composite image is seen. The composite image is constructed such that it tries to follow the ERS-2 satellite in local time. The 4 eight's of a sphere that are shown correspond (from left to right) to 15UT, 12UT, 9UT and 6UT. The cloud rejection criteria applied here is clearly seen to disregard the high clouds seen above Africa but seems not to reject a low cloud region above the Atlantic, west of Angola. In this region the retrieval also sees a high aerosol optical thickness. At this point we have not yet used the PMD data to determine cloudy regions which might explain the confusion of low cloud regions with high aerosol optical thickness. Including PMD data in the retrieval will improve the cloud rejection. Specifically since the PMD data has higher spatial resolution we expect to be better able to deal with partial cloudiness. A problem that might seriously degrade the retrieval if not dealt with correctly. Operating GOME at the smaller swath width would also improve the aerosol retrieval.

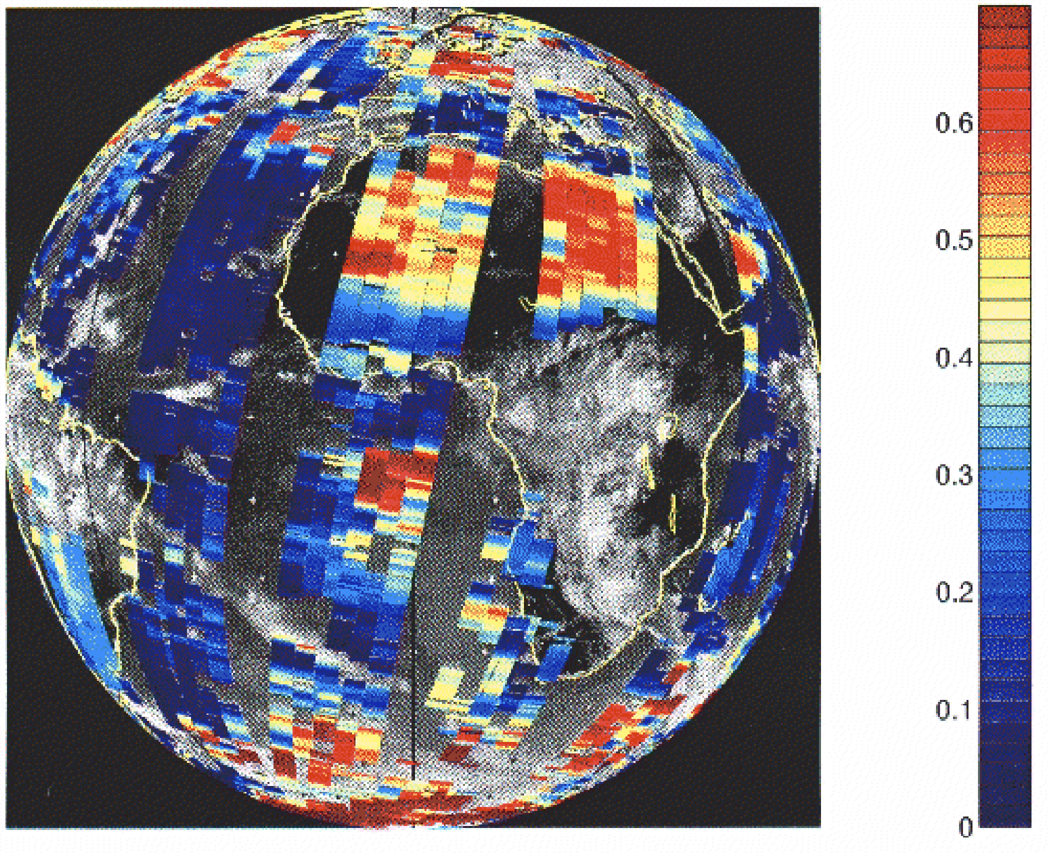

Figure 5a: Retrieved ground albedo on the 27 and 28 of November 1996. The rejection criteria stated in table 1 are loosened to obtain a global retrieval. The results are therefore preliminary and subject to changes with future improvements of the retrieval method

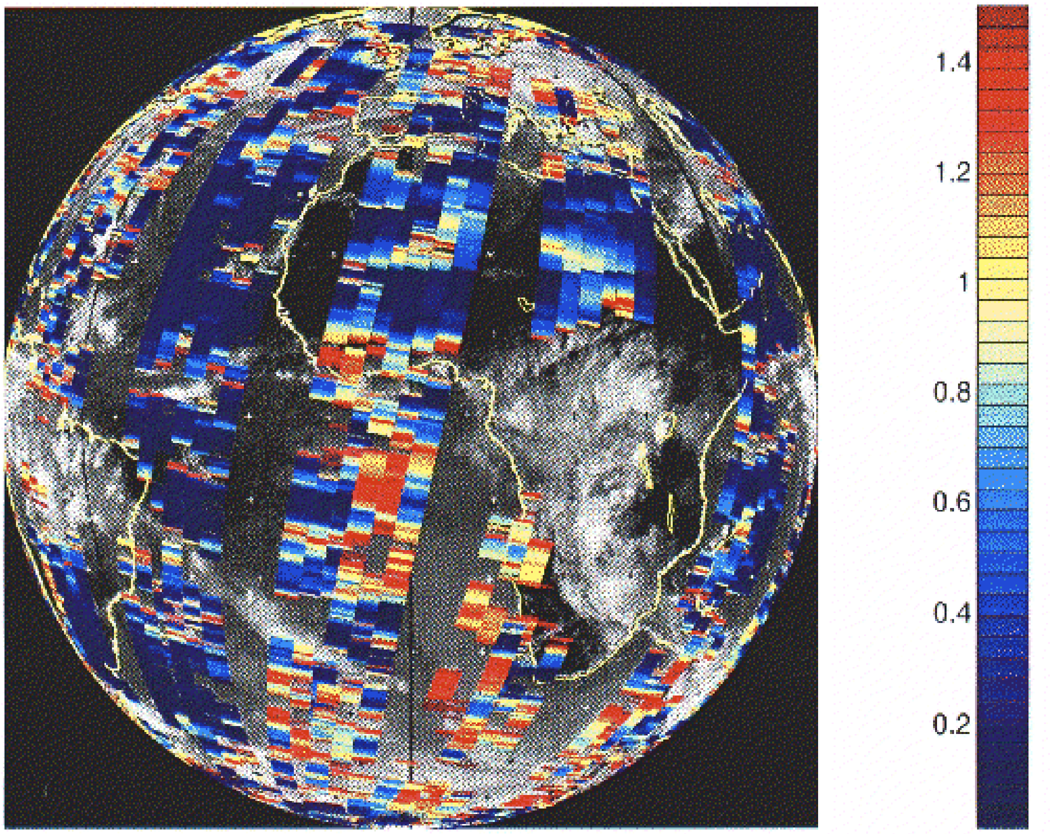

Figure 5b: Total optical thicknes on the 27 and 28 of November 1996. The rejection criteria stated in table 1 are loosened to obtain a global retrieval. The results are therefore preliminary and subject to changes with future improvements of the retrieval method.

5. CONCLUSIONS

A simple model has been used to retrieve aerosol optical thickness at 762 nm in 5 layers and ground albedo simultaneously from GOME data. At present the single scattering model is only valid at low aerosol optical thickness (<0.2) and low surface albedo (A<0.1). With these limitations the retrieval method with the single scattering model is capable of reproducing the measured spectrum to a high degree and we have confidence in the retrieved surface albedo and optical thickness. We will switch to a multiple scattering model and might use a non-linear retrieval. This will increase the ground albedo and the range of aerosol optical thickness we will be able to retrieve and global coverage seen in figure 5 will be obtained.

6. REFERENCES

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