RETRIEVAL OF STRATOSPHERIC AEROSOL PROPERTIES FROM SCIAMACHY LIMB OBSERVATIONS

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ABSTRACT

In this study we present a new technique to retrieve aerosol extinction profiles from SCIAMACHY measurements in limb geometry using the Monte Carlo Atmospheric Radiative Transfer Inversion Model (McArtim). Our retrieval algorithm follows the Onion-Peeling approach: Starting at a reference tangent height the aerosol extinction is varied for each subsequent tangent height until the simulated intensity profile is in agreement with the measurement. In self validation studies the retrieval algorithm performed well showing errors below 5 % for an altitude range of 13 to 30 km. In addition we investigated the effect of gradients in aerosol extinction along the line of sight. Using the standard homogeneous approach for aerosol plumes can lead to strong underestimations in extinction and plume altitude.

1. INTRODUCTION

Since the start of the Stratospheric Aerosol Measurement program in 1975 satellites have improved our understanding of the global distribution of clouds and aerosols. Satellite observations in occultation and limb geometry contain information on profiles of different types of particles in the stratosphere. Retrieval algorithms for aerosol extinction profiles generally use an homogeneous approach, assuming that there are no horizontal gradients along the line of sight of the instrument. This assumption might hold for investigations of the background aerosol layer, well aged volcanic plumes or large persistent polar stratospheric clouds (PSCs). However, such gradients can be found especially for lee wave PSCs, young volcanic plumes or strong pyro-convective events. For example a lee wave event over the Ellsworth Mountains in mid-June 2003 caused the formation of a NAT belt that persisted for several days [1]. Also, the formation H_2SO_4 droplets after a volcanic eruptions can take from hours [2, 3, 4] to several weeks [5]. Local events like these can have a strong influence on the heterogeneous chemistry and the radiation budget in the stratosphere.

This work will be structured as follows: First a brief description of the aerosol extinction retrieval algorithm and the results of the self-validation study will be shown. Then, a comparison study between SCIAMACHY and SAGE-III will be presented. In the third part the effect of horizontally inhomogeneous aerosol distributions will be discussed.

2. RETRIEVAL DESCRIPTION

The basic principle of this retrieval is to reproduce a measured intensity profile with radiative transfer simulations by varying the aerosol extinction β (see Eq. 1). In this work the full spherical, three dimensional Monte Carlo Atmospheric Radiative Transfer Inversion Model (McArtim) [6] is used. Since the variation of aerosol extinction with wavelength contains information about the aerosol size distribution, the retrieval will be performed for several wavelengths λ individually. In addition, the profile is normalized using the intensity at a reference tangent height $\mathrm{TH}_{\mathrm{ref}}$ of about 35 km [7] in order to reduce the dependency on ground albedo [8] and to simplify the comparability between simulation and measurement without using an absolute calibration.

$$\frac{I_{\mathrm{sim}}(\lambda, TH, \beta)}{I_{\mathrm{sim}}(\lambda, \mathrm{TH}_{\mathrm{ref}}, \beta)} \stackrel{!}{=} \frac{I_{\mathrm{meas}}(\lambda, TH, \beta)}{I_{\mathrm{meas}}(\lambda, \mathrm{TH}_{\mathrm{ref}}, \beta)} \quad (1)$$

In limb geometry the intensity at lower tangent heights strongly depends on the aerosol extinction at altitudes above the tangent height TH. In contrast, the effect of optically thin layers below the tangent height on the intensity is negligible. This motivates an onion peeling approach: Starting at the layer below $\mathrm{TH}_{\mathrm{ref}}$, the intensity of each subsequent tangent height is used to retrieve the aerosol extinction β of the corresponding altitude layer. However, this approach introduces an error for optically thick aerosol layers which have an increased probability of multiple scattering events. To account for this effect an iterative approach is used for the retrieval algorithm where the whole top-down retrieval process is repeated using the aerosol profile retrieved in

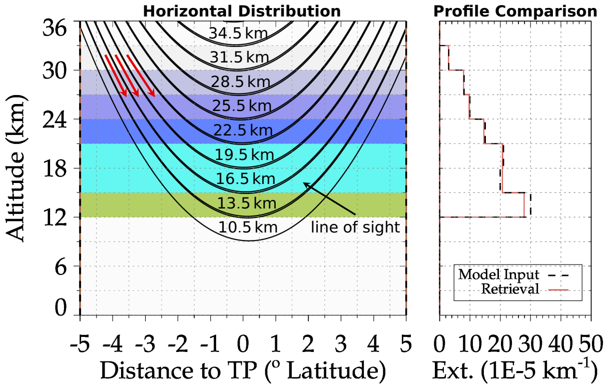

Figure 1. Self-Validation of the onion-peeling retrieval algorithm at a wavelength of 750 nm: In the left panel the black lines show the edges of the line of sight (LOS) for the satellite geometry of SCIAMACHY. Black numbers indicate the altitude of the LOS at the tangent point (TP), also called the tangent height (TH). The colors indicate the position of the aerosol layers. The right panel shows the quantitative comparison between model input (black, dashed) and retrieval output (red, solid).

the previous iteration.

In order to check the consistency of the retrieval algorithm several self-validation studies were performed using an extinction profile in 3 km boxes between 10 and 33 km. Simulated intensity profiles were used to retrieve the extinction profile. The Comparison between the retrieved and assumed aerosol extinction profiles indicates the precision of the retrieval method. As shown in Fig. 1 the algorithm can retrieve the extinction profile with relative errors below 5 %. The same result was also found for different viewing and solar geometries. The precision of the retrieval algorithm is decreasing for altitudes below 13.5 km and for wavelengths below 500 nm.

3. SAGE-III/SCIAMACHY INTERCOMPARISON

In order to perform the radiative transfer simulations using measurement data some approximations have to be used: The effective albedo, representing the upward influence of optically thick layers of clouds and/or aerosols, is determined from collocated SCIAMACHY nadir measurements. Here, a unique feature of the SCIAMACHY instrument is used: The instrument provides measurements in nadir and limb geometry for the same location within a few minutes enabling a combined use of both measurement geometries. In addition, optical properties of the aerosol like the phase function and the single scattering albedo have to be derived from assumed aerosol size distributions and refractive indexes. For this study the Henyey-Greenstein function with an

SAGE-III	SCIAMACHY
Covering similar wavelength ranges (UV to NIR)	
high latitudes only	global information
2002 to 2005	2002 to 2012
Occultation Geometry	Limb Geometry
Mie Phase Function	Henyey Greenstein
$\Delta z = 0.5$ km	$\Delta z = 3.0$ km

Table 1. Short comparison between instrument and algorithm properties of SAGE-III and SCIAMACHY

asymmetry parameter of 0.6 is used and the single scattering albedo is set to 1.0 representing a non-absorbing background aerosol.

For the intercomparison the SAGE-III 755 nm aerosol extinction product was chosen. Tab. 1 lists the instrumental and algorithmic properties of the SAGE-III data set and the SCIAMACHY aerosol extinction retrieval. The spatial and temporal overlap, the similar viewing geometry and covered wavelength range improve the comparability between both data sets.

For a first, preliminary intercomparison study a polar stratospheric cloud (PSC) event in the arctic stratosphere on the 22$^{\text{nd}}$ January 2005 was chosen. The ECMWF reanalysis temperature data in Fig. 2 show the area of possible PSC formation at an altitude of 19.5 km. On this day the temporal and spatial difference between SCIAMACHY and SAGE-III is small for the chosen measurements. The intercomparison was performed 1) for a location outside the area of possible PSC formation showing the aerosol extinction profile under background conditions in the polar stratosphere and 2) a location inside the area of possible PSC formation that shows an enhanced aerosol extinction signal due to the presence of a PSC around 20 km.

For the background case a good agreement with relative errors below 30 % was found (see Fig. 3). A qualitative agreement can also be found for the PSC case, but the relative error is larger than 50 % for all altitudes. Nevertheless the PSC case shows a strongly enhanced aerosol extinction signal for both instruments. Since PSCs in the arctic usually have a small horizontal extent, small differences in location and time might already cause a significant difference for the aerosol extinction. In addition the Henyey-Greenstein approximation can also cause large deviations: While it is a good approximation for small particles like the background aerosol, the phase function of larger particles is much more complex. Finally, the vertical sampling of the atmosphere is different for both instruments. In this comparison the SAGE-III data set was averaged over 3 km boxes in order to improve the comparability.

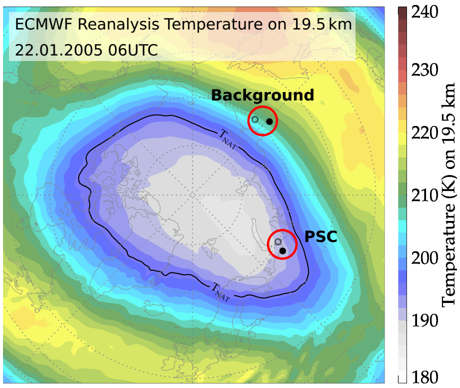

Figure 2. Temperature on 19.5 km for 22nd January 2005 at 6 UTC provided by ECMWF. The black contour line indicates the area of possible PSC formation. The filled black circles show the approximate location of the SCIAMACHY measurement. The empty black circles show the corresponding SAGE-III measurement location. The red circles mark the two locations used for the intercomparison: One within the area of possible PSC formation and one representing background conditions in the polar stratosphere.

4. INHOMOGENEOUS AEROSOL LAYERS

Another problem that affects aerosol extinction retrievals for all measurements in limb and occultation geometry are gradients that can occur along the line of sight of the instrument. Since the ranges for spatial variability of particles in the stratosphere are usually larger than 1000 km, this problem does not occur for retrieving the extinction of the background aerosol. But especially localized stratospheric events like volcanic eruptions, lee wave PSCs, tropospheric intrusions or pyro-convective plumes show strong gradients well within the line of sight of all common instruments that measure in limb of occultation geometry. Those localized events can have a major influence on the stratospheric chemistry and radiation budget by seeding the formation of aerosols and clouds and/or speeding up chemistry processes.

In this study extinction profiles are used to simulate intensity profiles for aerosol plumes with a small horizontal extent. Like in the self-validation study, these intensity profiles are put into two types of the retrieval algorithm: 1) Retrieving the aerosol extinction assuming horizontal homogeneity and 2) performing the retrieval at the correct location of the plume. Fig. 4 shows that the homogeneous assumption leads to underestimations for the aerosol extinction. In addition for a plume that is not located at the tangent point (Fig. 5) the homogeneous approach also leads to a downward shift of the aerosol extinction profile. Both effects however can be accounted for by using the correct horizontal distribution. At

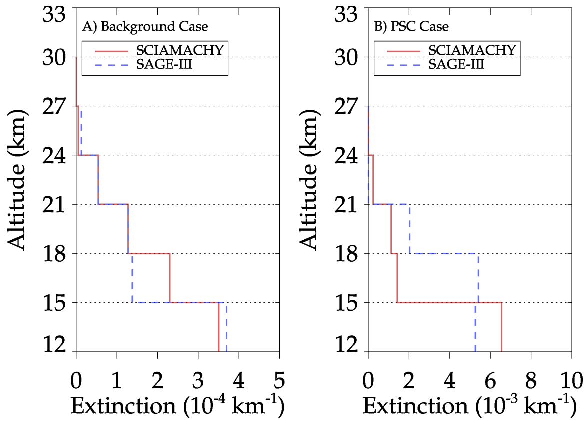

Figure 3. Retrieval result for the SCIAMACHY measurements at 750 nm (solid, red) in comparison to the SAGE-III 755 nm aerosol extinction (dashed, blue). The figure shows the background case on the left panel (A) and the PSC case on the right panel (B).

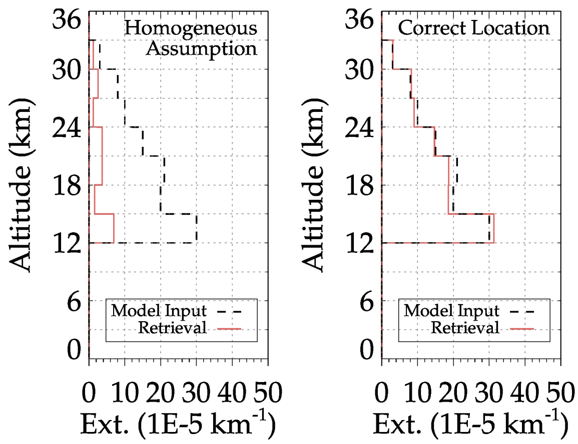

Figure 4. The effect of inhomogeneous layers: In this case an aerosol layer is put symmetrically around the tangent point coordinate with an extent of about 100 km. The left panel shows the underestimation caused by the homogeneous approach. With the correct location of the plume the algorithm is able to retrieve the correct extinction profile.

the same time the precision of the retrieval algorithm is reduced for narrow plumes and even more for those that are not located around the tangent point.

Here, the unique property of the SCIAMACHY instrument of having measurements in nadir and limb geometry for the same location within a few minutes can be used: The horizontal position and extent of a plume can be obtained from proxy data retrieved from measurements in nadir geometry. For example the SO_2 vertical column density can be used as a proxy for location and extent of a volcanic aerosol plume that is then retrieved from measurements in limb geometry.

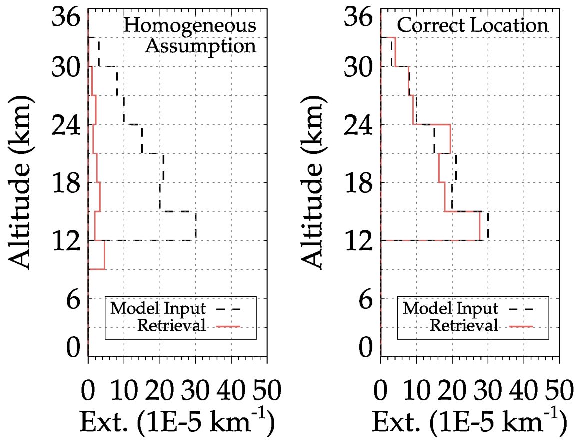

Figure 5. Analogous to Fig. 4 but for an aerosol layer that is located about 200 km north of the tangent point using the same horizontal extent. In addition to the underestimation of the aerosol extinction the profile is shifted by about 3 km.

5. CONCLUSION

Our work shows that an onion peeling approach is sufficient to retrieve aerosol extinction profiles from SCIAMACHY measurements in limb geometry. Furthermore a first, preliminary comparison with the SAGE-III aerosol product shows a good agreement. Larger deviations found for measurements in the presence of polar stratospheric clouds indicate small scale horizontal variations for this type of stratospheric events. The assumption of a representative scattering phase function also has an influence on the retrieval result. Using the Henyey Greenstein approximation holds for typical background aerosol types, but in order to retrieve larger aerosol particles a Mie phase function has to be considered. In the second part of this study the effect of inhomogeneous aerosol layers on retrievals that use a homogeneous approach is shown: Depending on the extent and the position of the aerosol layer with respect to the tangent point, the aerosol extinction profile can be underestimated and shifted downwards. To account for this effect proxy data (e.g. from nadir measurements) can be used to identify the horizontal position of the plume.

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