DEVELOPMENT OF A POLARISED RADIATIVE TRANSFER MODEL IN THE OXYGEN A-BAND FOR SATELLITE RETRIEVAL OF CLOUD TOP PRESSURE

N. Fournier and P. Stammes
Royal Netherlands Meteorological Institute (KNMI)
De Bilt, 3730AE, The Netherlands (fournier@knmi.nl)

M. Eisinger
European Space Agency/ESTEC
Noordwijk, 2200 AG, The Netherlands

ABSTRACT

A monochromatic radiative transfer model that includes polarisation is extended with oxygen absorption in the O_2 A-band. Moreover, improvement in the model run-time is sought by developing a parallel implementation coded using Message Passing Interface. The model is then applied in the 755-775 nm window for several cloud types and geometries. The calculated radiances are used as input of a cloud retrieval algorithm to assess the accuracy of its retrievals from the O_2 A-band. Effective cloud fraction and cloud top pressure are retrieved with a respective accuracy of 0.05 and 50 hPa. As corroborated through a comparison with SCIAMACHY in-flight data, the cloud retrieval algorithm performs well but would be improved by taking into account Rayleigh scattering.

1. INTRODUCTION

As radiative scattering by clouds strongly influences retrievals of tropospheric gases and aerosols from satellite spectrometers (GOME, SCIAMACHY or GOME-2), accurate co-located cloud information is required. The O_2 A-band at 760 nm is the strongest band of O_2 in the Visible Near-Infrared and thus, is well suited to provide cloud information. Since oxygen is a well-mixed gas, the measured column amount of oxygen yields the cloud top pressure.

In this study, radiances from the DAK (Doubling-Adding KNMI) radiative transfer model are used as input to the FRESCO (Fast Retrieval Scheme for Clouds from the Oxygen A-band) cloud retrieval algorithm. The accuracy of FRESCO to retrieve cloud parameters is evaluated for different atmospheric scenarios. This required the extension of the DAK model with oxygen absorption in the O_2 A-band, its optimisation to allow faster simulations and its application for specific clouds and geometries for the case of the GOME-2 instrument on-board Metop (ESA/EUMETSAT).

Moreover, to investigate the influence of Rayleigh scattering on cloud retrieval in the O_2 A-band, SCIAMACHY in-flight data from a cloud-free scene are compared with DAK reflectances and the transmittances used by FRESCO.

2. FRESCO CLOUD ALGORITHM

The FRESCO method is a simple, fast, and robust algorithm to provide cloud information for cloud correction of ozone (Koelemeijer et al., 2001). FRESCO uses the reflectance in three 1-nm wide windows of the O_2 A-band: 758-759 nm, 760-761 nm, and 765-766 nm. The measured reflectance is compared to a modelled reflectance, as computed for a simple cloud model. In this model the cloud is assumed to be a Lambertian reflector with albedo A_c=0.8 below a clear atmosphere, in which only O_2 absorption is taken into account. To simulate the spectrum of a partly cloudy pixel, a simple atmospheric transmission model is used, in which the atmosphere above the ground surface (albedo A_s) or cloud (for the cloudy part of the pixel) is treated as a purely absorbing, non-scattering, medium. The retrieved parameters are the effective cloud fraction (between 0 and 1) and the cloud top pressure with an accuracy of 0.05 and 50 hPa, respectively. Besides the latter retrieval errors in cloud top pressure is most likely due to the fact that absorption by O_2 inside the cloud is neglected, both retrievals are particularly sensitive to errors in the assumed surface and cloud albedo (Koelemeijer et al., 2001). FRESCO is used in the fast-delivery processing of GOME ozone data and in the SCIAMACHY ozone processor TOSOMI, which provides ozone data from SCIAMACHY within the ESA TEMIS project (see http://www.temis.nl).

3. RADIATIVE TRANSFER MODELLING IN THE O_2 A-BAND

The DAK model is designed for line-by-line calculations of radiance, polarisation, and irradiance at top-of-atmosphere, and inside the atmosphere. It consists of an atmospheric shell around a monochromatic multiple scattering kernel, based on the polarised doubling-adding method (De Haan et al., 1987; Stammes, 2001). DAK is commonly used in the UV-visible spectrum. In this study, DAK is extended with O_2 absorption in the O_2 A-band, using the latest HITRAN 2001 database for the O_2 cross-sections (HITRAN, 2003). Figure 1 shows the calculated reflectance (R) at specific geometries for clear sky and a surface albedo of 0.05 for a Mid-Latitude Summer atmosphere. Figure 2 gives the degree of linear polarisation (P) showing that the wavelength dependence of P and R is opposite.

ISBN 0-937194-49-2

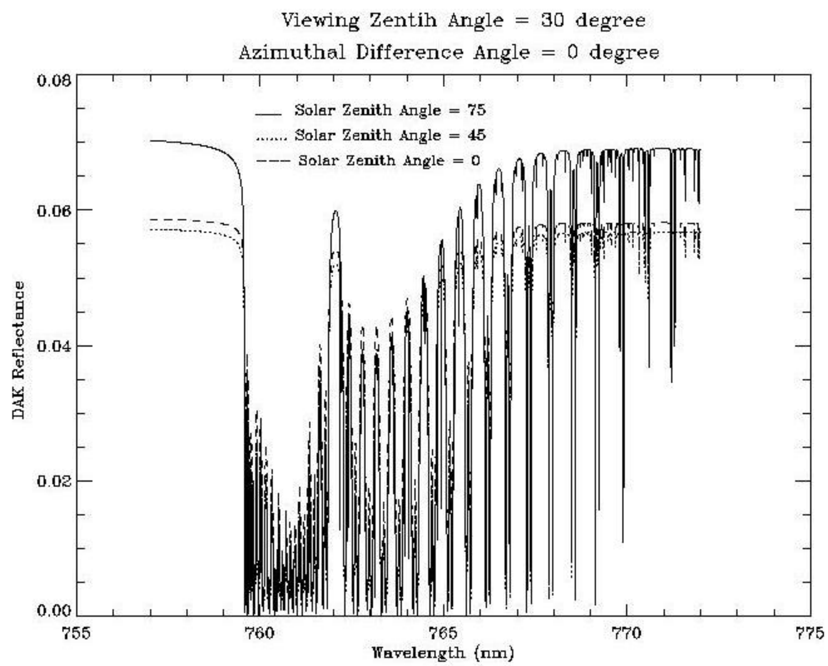

Fig. 1. Reflectance spectra at TOA (θ=30 and Φ- Φ_0=0) from the DAK model.

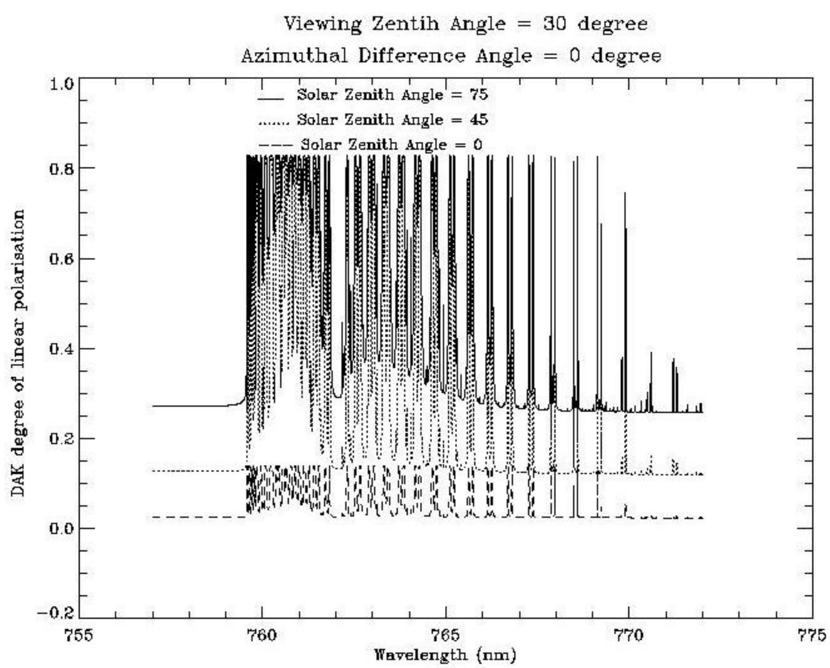

Fig. 2. Degree of linear polarisation at TOA (θ=30 and Φ- Φ_0=0) from the DAK model.

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3.1 DAK Optimisation

However, such calculations, together with the description of a Mie scattering cloud and linear polarisation impose a major computational requirement. Indeed, such simulation, at 0.01 nm resolution in the 757-772 nm region, is executed in 10 days with a classic 3.2 GHz workstation (8 Gbytes memory). Therefore, improvement in the model run-time was sought by developing a parallel implementation of DAK coded in a data-parallel approach using Message Passing Interface (Pacheco, 1996) on the KNMI Sun Fire 15K Platform (900 MHz, 48 Gbytes memory). The implementation distributes the calculations at the different wavelengths over multiple processors. For example, running the code on this machine with 30 processors led to a speedup by a factor of 22. However, an optimal speed-up can be reached by using the 68 available processors of the parallel Platform while no other codes are running simultaneously. However, as the number of processors increases, the communications increase and outweigh the advantages of distributing the code on a larger number of processors. Although the parallelisation's performance is limited by these communications, the speedup obtained with the parallel code is an important foundation for simulating, in a reasonable CPU time, scenarios including polarisation or explicit clouds at a fine spectral resolution.

4. FRESCO RETRIEVALS

FRESCO information on cloud top pressure and effective cloud fraction is derived from the reflectivity in and around the Oxygen A-band. In this particular study, the reflectivity will not be deduced from the radiance measured by a satellite instrument, but it will be calculated from the DAK model for specific scenarios and geometry. A pixel representative of a Metop test orbit is used with a viewing and solar zenith angle of 45 degrees and an azimuthal difference angle of 0 degree.

Table 1. FRESCO retrieval of effective cloud fraction (*c)* and cloud top altitude (z_c; km) for different input scenarios from DAK

Cases :		*NoCld*	*LR-8k*	*Mie-8k*
DAK	c	0.0	1.0	1.0
	z_c	0.0	8.0	8.0
FRESCO	c	0.05	1.0	1.0
	z_c	1.23	7.56	8.08
Cases :		***LR-2k***	***Mie-2k***	***MixCld***
DAK	c	1.0	1.0	0.4
	z_c	2.0	2.0	2.0
FRESCO	c	1.0	1.0	0.58
	z_c	1.59	2.03	1.98

Table 1 shows DAK prescribed and FRESCO retrieved values of effective cloud fraction (*c*) and cloud top altitude (z_c) for different scenarios. The scenarios considered are *NoCld* (no clouds and A_s=0.05); *LR-8k* (full cloud cover; cloud assumed to be a Lambertian Reflector at 8 km with A_c=0.8); *Mie-8k* (full cloud cover; Mie scattering cloud at 8 km with an optical thickness of 40.0); *LR-2k* (full cloud cover; cloud assumed to be a Lambertian Reflector at 2 km with A_c=0.8); *Mie-2k* (full cloud cover; Mie scattering cloud at 2 km with an optical thickness of 40.0) and *MixCld* (cloud cover of 40%; Mie scattering cloud at 2 km). The coefficients of the scattering matrix of the Mie cloud are calculated using the Meerhoff Mie code (De Rooij and Van der Stap, 1984) assuming a two-parameter gamma cloud droplet size distribution with an effective radius r_{eff}=10 μm and an effective variance v_{eff}=0.2 (Hovenier et al., 2004).

The retrievals from FRESCO are in good agreement with the cloud input conditions of the DAK scenarios. However, discrepancies arise between DAK and FRESCO in the case of low cloud fractions (cloud free or mixed cloud scenarios). As the major difference between both codes is the consideration of Rayleigh scattering, it would be worth taking this process into account in FRESCO. This would not affect significantly the fully cloudy pixels but would produce lower retrieved values of cloud top altitude in the case of low cloud fractions (inferior to 50%). Indeed, in the latter case, the Rayleigh effect is larger as most of the light is scattered before reaching the lower atmosphere where absorption is important and hence, the bands will be weaker.

5. RAYLEIGH SCATTERING INFLUENCE IN THE O_2 A-BAND

To demonstrate the usefulness of an accurate transmittance description in FRESCO, Figure 3 compares a clear-sky Sahara spectrum measured by SCIAMACHY (August 23, 2002) and the spectrum from the FRESCO transmission database and DAK, respectively (normalized at 758 nm). Both approaches compare well with SCIAMACHY in-flight data. The differences between DAK and SCIAMACHY are partly due to instrument calibration errors but, also, to aerosols and surface albedo effects.

The main difference between DAK and the transmittance used by FRESCO is the consideration of Rayleigh scattering. In DAK, Rayleigh scattering and O_2 absorption are included in 65 homogeneous layers between 0 and 100 km. However, this former process is not taken into account through the transmission database used by FRESCO to retrieve the cloud parameters. Thus, DAK produces bands slightly weaker (less absorption) which corroborates the fact that including Rayleigh scattering in the FRESCO Transmission database could

ISBN 0-937194-49-2

significantly improve cloud top altitude retrievals for scenes with low values of cloud fraction.

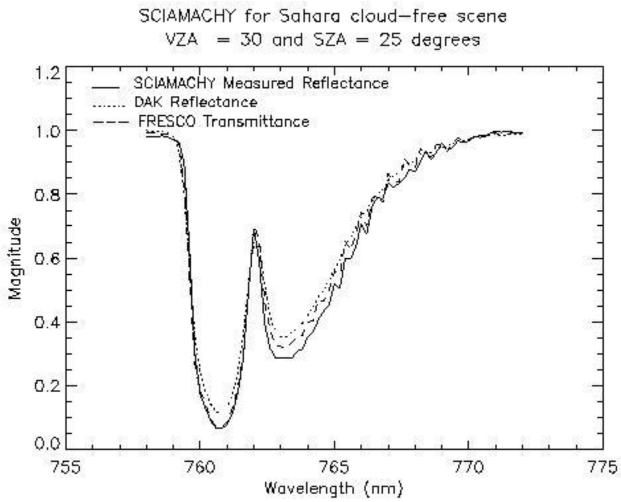

Fig. 3. Comparison between FRESCO transmittance and the in-flight measured reflectance of SCIAMACHY at a specific location of the Sahara in the O_2 A-band.

6. CONCLUSION

A radiative transfer model has been extended with the O_2 A-band using the latest HITRAN database for the O_2 cross-sections. The model has then been parallelised using MPI and applied in a line-by-line mode with multiple scattering in the 757-772 nm region. The obtained radiances have been combined with the SCIAMACHY slit function for different atmospheric scenarios and used as input of the FRESCO algorithm to retrieve the corresponding effective cloud fraction and cloud top altitude. This shows that FRESCO succeeds well to retrieve cloud information. However, for low cloud fraction, the cloud algorithm would benefit of taking into account Rayleigh scattering to retrieve cloud top pressure more accurately. This has been corroborated through the comparison with SCIAMACHY in-flight data.

ACKNOWLEDGMENTS

This work has been partly funded by ESA/ESTEC under the project *17332/03/NL/GS*.

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ISBN 0-937194-49-2