Novel aerosol retrieval algorithms for SCIAMACHY for application over water and land

J. Kuśmierczyk-Michulec & G. de Leeuw
TNO Physics and Electronics Laboratory, The Hague, The Netherlands

Abstract

Two aerosol retrieval algorithms of the SCanning Imaging Absorption SpectroMeter for Atmospheric ChartographY (SCIAMACHY) are developed for application over water and over land. The one for application over water uses IR spectral channels taking advantage of the common assumption of a black surface to obtain information about optical properties of aerosols. Next, this information is combined with data in the visible channels to benefit from the full spectral range offered by SCIAMACHY. The IR-derived aerosol properties are used as a first guess for the retrieval in the visible range where the surface properties are accounted for on the basis of the measured surface reflectance spectra.

In contrast, for the retrieval of aerosol properties over land the starting point is the UV spectral range where the surface is dark. Next, the UV-derived aerosol properties are used for the retrieval in the visible and IR channels.

Look-up tables were prepared for the following aerosol types: sea-salt, dust-like particles, black and organic carbon and water-soluble particles. The aerosol mixtures were constructed in such a way that the values of the resultant Ongström coefficients cover the whole range of possible values as found e.g. in the AERONET databases [1].
1 Introduction

The total radiance $L$ received by a sensor at the top of the atmosphere can be presented as the sum of the contributions from aerosols, molecules, and the surface. Instead of radiance $L$, this dependence can be also presented in terms of reflectance $\rho = \pi L/F_\odot \cos \theta$, where $\theta$ is the solar zenith angle and $F_\odot$ is the extraterrestrial solar irradiance. In both representations the molecular contribution is assumed to be well known. The problem is how to separate the aerosol and surface reflectance. Because the spectral properties of the water surface and land surface differ, two different methods are applied to properly describe them.

SCIAMACHY is a high-resolution (0.2-0.4 nm) spectrometer, which is scheduled for launch on ENVISAT on 1st of March 2002. It will observe transmitted, reflected and scattered light from the atmosphere in the UV, visible and near infrared wavelength regions over the range 240-1750 nm, and in 2 selected regions between 1900 nm and 2400 nm. Taking advantage of this wide range of wavelengths, two novel aerosol retrieval algorithms are developed for SCIAMACHY.

To achieve this, a number of wavelength bands were selected based on the atmospheric transmission properties. Preferably they are free (or with negligible amount) of absorption by water vapour, ozone and other trace gases.

2 Application over water

The aerosol retrieval algorithm of SCIAMACHY for application over water uses the infrared bands, where the surface can usually be considered as black, to estimate the atmospheric effects and extrapolate them into the visible.

The total upward reflectance measured at the top of the atmosphere can be decomposed into five components:

$$\rho(\lambda) = \rho_r(\lambda) + \rho_d(\lambda) + \rho_{ra}(\lambda) + t(\lambda)\rho_{wc}(\lambda) + t(\lambda)\rho_w(\lambda)$$

where:
- $\rho_r(\lambda)$ is the reflectance resulting from multiple scattering by air molecules in the absence of aerosols (Rayleigh scattering);
- $\rho_d(\lambda)$ is the reflectance resulting from multiple scattering by aerosols in vacuum;
- $\rho_{ra}(\lambda)$ is the multiple-interaction term between molecules and aerosols (e.g. [2]);
- $\rho_w(\lambda)$ is the water-leaving reflectance;
- $\rho_{wc}(\lambda)$ is the reflectance at the sea surface that arises from sunglint [3] and skylight reflecting from whitecaps on the sea surface (e.g. [4]);
- $t(\lambda)$ is the atmospheric-diffuse transmittance that accounts for the effects of propagating water-leaving reflectance and whitecap reflectance's from the sea surface to the top of the atmosphere (TOA), e.g. [5], [6].
2.1 The water-leaving reflectance

In 1988 Morel distinguished Case I and Case II waters [7]. To the first case belong waters in which phytoplankton and their immediate derivatives play a predominant role in determining the optical properties of oceanic waters. Case II includes water surfaces for which the contribution of sediments or dissolved yellow substance to the optical properties is significant.

The knowledge of the spectral characteristics of the water-leaving reflectance for Case I and Case II waters is crucial in constructing algorithms for application over water. Both versions of the SCIAMACHY algorithms for Case I and Case II waters are based on the same principles, the difference is in the parameterisation of the water-leaving reflectance and in the infrared bands taken to establish the atmospheric effects.

As an example of Case II waters the Baltic Sea was chosen. The typical behaviour of the water-leaving reflectance for the open Baltic Sea is presented in Fig. 1, based on data from [8]. In total 887 spectra of the water-leaving reflectance were collected during 27 research cruises on the Baltic Sea from June 1992 to September 1997. The water-leaving reflectance was measured by the spectrophotometer MER2040, in 10 spectral channels: 412, 443, 490, 510, 550, 589, 625, 665, 683 and 710 nm (for more details see [8]).

![Baltic Sea, open waters](image)

Figure 1: The mean values of the water-leaving reflectance and their standard deviations for 4 seasons, for the open Baltic Sea.
For application of the SCIAMACHY algorithm for Case 2 waters, the variations of the reflectance with the wavelength in the range between 665-710 nm and 412-443 nm are the most important. The experimental data show that the values of the water-leaving reflectance in the spectral range between 412-443 nm and 665-710 nm are smaller than 0.15% for open waters (see Fig. 1). The ratio of the reflectances in these two bands

\[ \varepsilon_w(\lambda_i/\lambda_j) = \rho_w(\lambda_i)/\rho_w(\lambda_j) \]  

(2)

is fairly constant. Thus the reflectance in the 665-710 nm band can be used to derive the one for the 412-443 nm range. Similarly, the water leaving reflectance at 412 nm, 443 nm, 665 nm, 683 nm and 710 nm are estimated. Although strictly the ratios between the reflectances in the various band pairs are not fixed, the errors introduced by this method are relatively small.

2.2 The atmospheric reflectance

Defining the atmospheric reflectance \( \rho_{\text{atm}}(\lambda) \) as the sum of \( \rho_t(\lambda) \), \( \rho_d(\lambda) \) and \( \rho_{\text{ra}}(\lambda) \), eqn (1) can be rewritten as

\[ \rho_t(\lambda) = \rho_{\text{atm}}(\lambda) + t(\lambda)\rho_{\text{wc}}(\lambda) + t(\lambda)\rho_w(\lambda). \]  

(3a)

The component \( \rho_{\text{wc}}(\lambda) \), which is assumed to be dominated by reflectance from whitecaps (tilting the sensor avoids sun glitter), is calculated from an empirical wind speed formulation [4]. In the IR spectral range both terms \( \rho_w(\lambda) \) and \( \rho_{\text{wc}}(\lambda) \) [4] can be neglected and eqn (3a) becomes:

\[ \rho_t(\lambda) = \rho_{\text{atm}}(\lambda), \]  

(3b)

with \( \lambda = 990 \text{ nm}, 1015 \text{ nm}, 1020 \text{ nm} \) and \( 1250 \text{ nm} \) for Case II waters, and \( \lambda = 670 \text{ nm}, 683 \text{ nm}, 710 \text{ nm}, 800 \text{ nm}, 865 \text{ nm}, 990 \text{ nm}, 1015 \text{ nm}, 1020 \text{ nm} \) and \( 1250 \text{ nm} \) for Case I waters. Selection of these bands has the additional advantage that in the spectral range between 670 nm and 1250 nm the single scattering approximation approach can be used and eqn (3b) can be rewritten as

\[ \rho_t(\lambda) = \rho_t(\lambda) + \rho_d(\lambda). \]  

(3c)

Because the term \( \rho_t(\lambda) \) is known, the aerosol reflectance can be calculated and the \( \text{Ongstr\"om} \) coefficient can be determined. The \( \text{Ongstr\"om} \) coefficient contains information about the aerosol composition [9], which is used as a first guess for the further retrieval. Next, correcting for the water-leaving reflectance (see section 2.1, eqn (2)), the aerosol reflectance values in other wavelength regions can be determined and used to extend the information on the aerosol properties over a wider range of wavelengths.

In the look-up tables the following aerosol types were taken into account: sea-salt, dust-like particles, black and organic carbon and water-soluble particles. The aerosol mixtures were constructed in such a way that the values of
the resulting Ongström coefficients would cover the whole range of possible values as obtained e.g. from the AERONET data [1].

3 Application over land

Also for the retrieval over land some assumptions about the surface reflectance have to be made in order to obtain information about the aerosol reflectance and next about the aerosol optical thickness and the Ongström coefficient. First, in the range of wavelengths from 313 nm to 391 nm the surface reflectance can be neglected. Second, to define the surface reflectance in the range of wavelengths between 410 nm and 1015 nm, assumptions are made about the variation of the reflectance with the wavelength, based on ground measurements of surface reflectance of 14 types of surfaces [10]. The results were also tested with the surface albedo data derived from GOME [11]. Similarly to SCIAMACHY, GOME is a high-resolution (0.2-0.4 nm) spectrometer, but with a smaller wavelength range from 240 nm to 800 nm, and its data are available since April 1995. The look-up tables including the different aerosol mixtures were constructed in the same way as described in section 2.2.

4 Discussion

The ideas presented in this paper are further implemented in algorithms. The values of the surface reflectance are tested with GOME data in the proper wavelength regions. The algorithm will be tested with SCIAMACHY data in the calibration phase.

References

450 Air Pollution X


