

FUB

**MERIS
ESL**

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ALGORITHM THEORETICAL BASIS DOCUMENT

ATBD 2.16

CLOUD REFLECTANCE

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1. Introduction

This document introduces an algorithm producing cloud reflectances for all MERIS channels. The proposed algorithm is not implemented in the MERIS operational processing.

2. Algorithm Overview

The cloud reflectance $\rho_{\text{cloud}}(\lambda)$ will be estimated for all MERIS channels. An adequate algorithm has to be established to correct the radiance measurements according to the atmosphere above the cloud. The bidirectionality of cloud reflectance, the multiple scattering in the atmospheric layer above the cloud and the multiple scattering between the cloud and the atmospheric layer above the cloud have to be taken into account. The algorithm suggested here accounts for the angular distribution of reflected solar radiation and all kinds of multiple scattering by radiative transfer simulations. The radiative transfer model MOMO (Matrix Operator Model) is used to solve the forward problem, i.e. the derivation of satellite sensor signals and the radiance at cloud top level. The difference is stored as the **atmospheric correction term** $L_{\text{corr}}(\lambda)$. The atmospheric correction term $L_{\text{corr}}(\lambda)$ is a function of all input parameter that determine the physics of the atmosphere. The most important properties that determine $L_{\text{corr}}(\lambda)$ are the cloud optical thickness (and therewith the cloud albedo at 753.75nm because it is highly correlated to cloud optical thickness, see ATBD 2.1, 2.2) and the cloud top pressure. So inferring the atmospheric correction term $L_{\text{corr}}(\lambda)$ from cloud top pressure and cloud albedo at 753.75 nm is the inverse problem. This problem will be tackled by the use of a Lookup Table (LUT) technique. Additionally a polynomial approach will be researched.

The influence of stratospheric aerosols must be considered by using a separate LUT.

3. Algorithm Description

3.2. Theoretical Description

3.2.1. Physics of the problem

3.2.1.1. Cloud reflectance and atmospheric correction term

The reflectance at cloud top level ρ_{cloud} is defined by:

$$\rho_{\text{cloud}}(\lambda) = \frac{\pi L_{\text{cloud}}(\lambda)}{\cos\theta_{\text{sun}} F_{\text{sun}}(\lambda)}$$

where L_{cloud} is the upward radiance at cloud top level.

The coherence between L_{cloud} and L_{TOA} measured by MERIS can be expressed by :

$$L_{\text{cloud}} = L_{\text{TOA}} - L_{\text{corr}},$$

where L_{corr} is called the atmospheric correction term. If L_{corr} is known L_{cloud} and therewith ρ_{cloud} can be evaluated. Despite of the equation is looking simple L_{corr} is not simple. It contains all information about scattering and multiple scattering and can not be expressed analytically. However L_{corr} can be evaluated by radiative transfer calculations for all possible and reasonable combinations of physical input parameter. The essential parameters are:

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- the Rayleigh and aerosol optical thickness above the cloud, which determine scattering and multiple scattering,
- and the cloud reflectance, which influence L_{corr} due to multiple scattering.

The Rayleigh and aerosol optical thickness above the cloud are determined by the cloud top pressure. The cloud reflectance is determined by cloud optical thickness, surface albedo for low cloud optical thickness and again by the Rayleigh and aerosol optical thickness above the cloud. Therefore L_{corr} is mainly determined by cloud top pressure, cloud optical thickness and surface albedo. The cloud albedo at 753.75nm is highly correlated to the cloud optical thickness (see ATBD 2.1, 2.2). Variations of the surface albedo influence the cloud reflectance in a range of a few percent by a increasing influence with increasing optical thickness. So the cloud reflectance is determined in a first order of accuracy by the cloud albedo at 753.75 nm and by the cloud top pressure. Therefore finally the atmospheric correction term L_{corr} is determined mainly by the cloud albedo at 753.75 nm and by the cloud top pressure. The procedure of deriving the atmospheric correction term L_{corr} consist of building up and using an look up table, where cloud albedo and cloud top pressure are the dimensions.

A iterative process that use a first order derived cloud reflectance as an input to find a more precise atmospheric correction term is conceivably. But the influence of the cloud reflectance to L_{corr} is only of second order and the improvement seems negligible. A precise statement can be made after a sensitivity test.

The influence of stratospheric aerosols must be considered by using separate LUT.

3.1.2. Mathematical Description of the Algorithms

3.1.2.1. Radiative transfer simulations

The radiative transfer model MOMO (Fell and Fischer, 1995) uses cloud optical properties as calculated from a Mie-program (Wiscombe, 1980). For a given droplet size distribution and optical constants of water and ice (complex refractive index from Hale and Querry (1973), Palmer and Williams (1975) and Irvine and Pollack (1968)) this code returns extinction and scattering coefficients and the scattering phase function, which describes the angular distribution of scattered light in a single scattering event. A modified gamma function has been adopted for cloud droplet size distribution (Hansen, 1971). The influence of tropospheric aerosol scattering is almost negligible. Therefore, the simulations need only to distinguish between the *maritime* and *continental* aerosol types with an optical thickness of $\delta_{\text{aero}}=0.125$ at $\lambda=550\text{nm}$ (Toon and Pollack, 1973). The aerosol optical properties are calculated from a Mie-program (Wiscombe, 1980) too. Air molecules are small compared to the wavelength of the incoming sunlight. Hence, molecular scattering can be described with Rayleigh theory. The scattering coefficient of all atmospheric constituents are direct input parameter of the radiative transfer model MOMO. The scattering phase function has to be expanded into a Fourier series in order to calculate azimuthally resolved radiances. Since MOMO calculations include the full information of the angular dependencies of scattering due to cloud particles, the BRDF can be simulated for any illumination and observation geometry as well for arbitrary atmospheric conditions.

The radiative transfer model MOMO uses the data of Neckel and Labs (1984) as input for the solar irradiance.

The most important cloud feature that influenced L_{corr} are the cloud optical thickness and the cloud top pressure. The cloud optical thickness varies between 1 and 300 in the calculations. The cloud top pressure varies between 1013 hPa and 100 hPa in steps of 12.5 hPa.

Because it is not possible to do radiative transfer calculations for all permutations of input parameters 1000 cases are considered where the input parameters: cloud type (\cong effective radius), optical thickness and cloud top pressure are chosen randomly and independently from each other. In figure 1 below the process of radiative transfer simulations is shown.

In case of volcanic eruptions stratospheric aerosols should be introduced in the model atmosphere. Sulphuric acid particles are then placed in the model layer between 20km and 30km (WCP-report No. 112, 1986).

3.1.2.2. Inversion

Figure 1 below describes the inversion process. The TOA radiance is processed with the atmospheric correction term $L_{\text{corr}}(\lambda)$. The cloud albedo and cloud top pressure will be used for a preselection to find the appropriate atmospheric correction term table. The atmospheric correction terms belongs to discrete points and have to be interpolated to observation and sun geometry.

A stratospheric aerosol flag is set, if volcanic eruptions with emissions in the stratosphere are reported. In such cases the algorithm selects the coefficients (or matrices) derived with the simulations containing sulfuric acid particles in the upper atmosphere.

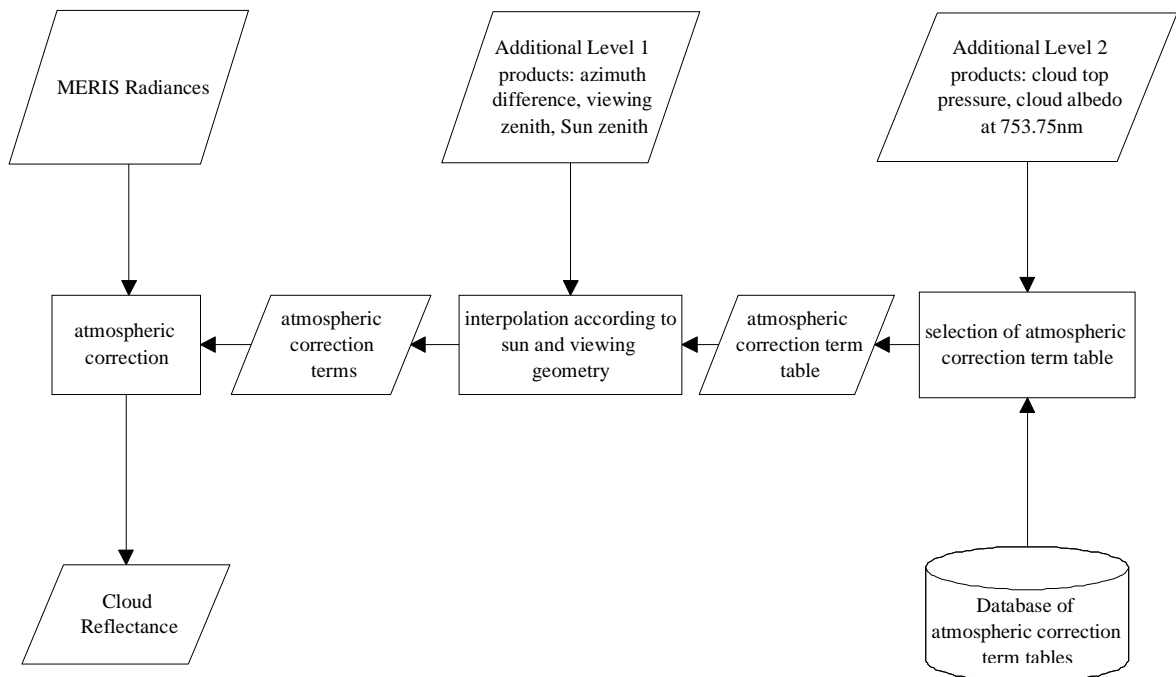


Figure 1 : Inversion process flow chart

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3.2. Practical Considerations

3.2.1. Numerical computation considerations

TBD

3.2.2. Calibration and Validation

TBD

3.2.3. Quality Control and Diagnostics

TBD

3.2.4. Exception Handling

The algorithm will only be applied to pixels, which was indicated as cloudy by the cloud screening algorithm.

If the algorithm retrieves parameters, that lies outside realistic boundaries, a quality flag will be raised, indicating, what bond was exceeded. For that specific pixel, no cloud parameter will be estimated.

3.2.5. Output product

- cloud reflectance

3.3. Error budget estimates

TBD

4. Assumptions and Limitations

The algorithm will be derived from radiative transfer calculations for which a plane parallel atmosphere is assumed. There are no 3-dimensional radiative transfer codes (except Monte-Carlo methods) available which could describe the shapes of the clouds in a realistic way. The plane parallel atmosphere assumption is not valid for low sun elevations and high observation angles.

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ATBD 2.16 — MERIS DATA PRODUCT SUMMARY SHEET

Product Name: Cloud Reflectance
Product Code: MERIS.RRGCREF
Product Level: Level 2
Description of the product: Cloud reflectance

Product Parameters:

Coverage: global
Packaging: Half-orbit
Units: [1]
Range: 0.0-1.00
Sampling: pixel by pixel (300*300m² pixel should also be recorded to detect small cumulus clouds - important to atmospheric correction)

Resolution: radiometric: 0.2 Wm⁻²sr⁻¹μm⁻¹
spatial: 1.2km (0.3km)

Accuracy: radiometric: 2-4% (within precision of calibration)
geophysical product: **TBC**

Geo-location Requirements: 1-4 pixels, depending on use of cloud-top pressure
Format: 16 bits / sample (**TBC**)
Appended Data: Earth location, Quality mask (i.e. residual of inversion process)

Frequency of generation: 1 product per orbit
Size of the Product: **TBC**