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Simultaneous retrieval of aerosol and surface optical properties using data of the Multi-angle Imaging SpectroRadiometer (MISR)

Johannes Keller [a,*], Stephan Bojinski [b], André S.H. Prevot [a]

[a] *Paul Scherrer Institute, Laboratory of Atmospheric Chemistry (LAC), CH-5232 Villigen PSI, Switzerland*
[b] *World Meteorological Organization (WMO), Global Climate Observing System Secretariat (GCOS), 7bis, Avenue de la Paix, Case Postale 2300, CH-1211 Geneva 2, Switzerland*

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Abstract

An algorithm for retrieving simultaneously aerosol and surface optical properties from radiance data of the Multi-angle Imaging SpectroRadiometer (MISR) was developed. It uses MISR subregion radiance data of the 9 cameras and 4 spectral bands (spatial resolution 1.1 km) to generate characteristic functions $\rho_{surf}=f_{\lambda,cam}$ (β_e (550 nm)), where β_e (550 nm) and ρ_{surf} are the ground level aerosol extinction coefficient at 550 nm, and the surface reflectance, respectively. The analysis of the mutual intersections of those functions yield optimum values for β_e (550 nm), aerosol optical depth (AOD) at 550 nm and ρ_{surf}. MODTRAN 4 v3r1 was used to create radiance look-up tables. The algorithm was tested for MISR paths covering the complex terrain of Switzerland and northern Italy. Results of 2 days (low and high aerosol loads on May 14 and June 17, 2002, respectively) were analyzed and compared with sun photometer measurements. First, ground level aerosol extinction coefficients and optical depth over water were derived. From those data it was possible to retrieve a best-fit aerosol mixture. AOD (550 nm) over water is in satisfactory agreement with both sun photometer data and the operational aerosol product of MISR. Second, the Ross–Li approach for the bidirectional reflectance factor (BRF), supported by MODTRAN 4, was applied to simulate the radiance over vegetation surfaces. In this case, the retrieved aerosol extinction coefficients and optical depths over vegetation are significantly lower than the values derived over water. We assume that the incomplete coupling of BRF and radiation in MODTRAN 4 is at least partly responsible for this discrepancy.

Keywords: MISR; MODTRAN 4; Aerosols; Aerosol optical depth; Surface reflectance

1. Introduction

Aerosols affect mankind mainly in two ways. First, they modify the radiation balance of the earth in a direct (increased backscattering of solar radiation to space) and in an indirect way (cloud formation activated by particulates). These effects may significantly contribute to climate change. The radiative forcing of these contributions, however, is still fraught with high uncertainties (Houghton et al., 2001). Second, epidemiological studies showed that respiratory symptoms, lung function and mortality are significantly correlated with the mass density of the particulate matter below 10 μm (Dockery et al., 1993; Fischer et al., 2004; Stedman, 2004). Hence it is desirable to obtain information on aerosol properties both globally as well as on a local or regional scale.

Satellite sensors have the potential of measuring the spatial and temporal distribution of aerosol properties from space. The retrieval of these properties is based on the measurement of scattered sunlight. The angular pattern and the wavelength dependence of the scattered radiation strongly depend on characteristic quantities of aerosols such as particle size distribution, single scattering albedo, non-sphericity and refractive index. The radiance measured by downward looking remote sensing instruments is a mixture of scattered and reflected radiation. A review of approaches to derive aerosol optical properties is given by King et al. (1999).

During the last few years, novel instruments have been developed and launched. Multi-angle viewing sensors are particularly suited for the retrieval of aerosol optical properties. Along-track angular variations of radiance measurements, for

* Corresponding author. Tel.: +41 56 3102065; fax: +41 56 3104525.
E-mail address: johannes.keller@psi.ch (J. Keller).

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instance, may be exploited to retrieve the scattering phase function. The most powerful instrument for multi-angular observations currently in orbit is the Multi-angle Imaging SpectroRadiometer (MISR) aboard Terra (Diner et al., 1998). MISR observes the earth at 9 different view angles and 4 spectral bands at a pixel resolution of 275 m and averages the radiance data onboard over subregions of 1.1 km. An operational aerosol product from MISR is available at a 17.6 km resolution. This resolution, however, is too coarse to be meaningful for complex topography such as Switzerland. Hence, we developed a novel retrieval algorithm that yields information on both surface reflectance and aerosol optical properties on the subregion resolution. Details about MISR and its use for the operational retrieval of aerosol properties are given in Section 2. Section 3 describes the retrieval algorithm. Finally, Section 4 reports the application of the algorithm and the results for low and high aerosol load in Switzerland and the Po Basin in northern Italy.

2. MISR instrument and aerosol related data products

The Multi-angle Imaging SpectroRadiometer (MISR) onboard the NASA Terra satellite has 9 pushbroom cameras (An, Af, Aa, Bf, Ba, Cf, Ca, Df, Da) pointing at 9 different view angles. They look at nadir (n), forward (f), and afterward (a) directions (nominal zenith angles: 0, 26.1, 45.6, 60.0 and 70.5^0). Each camera has 4 spectral bands (blue: 446 nm, green: 557 nm, red: 672 nm and near infrared (NIR): 866 nm). A detailed description of the instrument is available from Diner et al. (1998). The Level 1B2 product includes calibrated top of atmosphere (TOA) radiances geo-rectified either on the World Geodetic System 1984 (WGS84) ellipsoid or on the terrain. Radiance measurements are taken at a pixel resolution of 275 m and averaged onboard over subregions of 1.1 km before being transmitted to ground. Data of the nadir camera An (all bands) and of the red band (all cameras) are transmitted at the pixel resolution. On request, local mode data are taken with 275 m resolution for all bands and cameras. Geometric parameters such as altitude, solar and view angles for each subregion may be extracted from the data sets for further processing.

Terra follows 233 paths covering the entire globe. The satellite revisits the same path every 16 days. Due to the MISR swath width of 380 km, the effective repetition period for a given ground location varies between 2 and 7 days. The data of one semi-orbit is split into 180 blocks. Blocks 52 to 54 of paths 193 to 197 cover Switzerland.

An operational aerosol product is available on regional grids with a resolution of 17.6 km × 17.6 km. The product is calculated with an algorithm developed by Martonchik et al. (1998). This product is based on a set of climatological aerosol mixtures. Each of them consists of 3 components (called aerosol models) selected from a number of possible aerosols. These mixtures are supposed to cover the most likely maritime, rural and urban conditions. Phase functions for each component are included as well. Since the launch of MISR, the composition of aerosol mixtures has been modified at least twice. The most recent version is V3.3 (January 2006). For the investigation described in this publication, version V2.2 was used (see Tables 1 and 2). Pre-calculated radiances are compared with the measured values of each camera and wavelength. The output contains, among other quantities, the regional mean (or best estimate) AOD in the green band and the corresponding mixture. Aerosol properties are computed for both water and land surfaces. Cloudy and mountainous areas are masked out.

A research version of the aerosol algorithm software is currently being developed for non-operational use that is

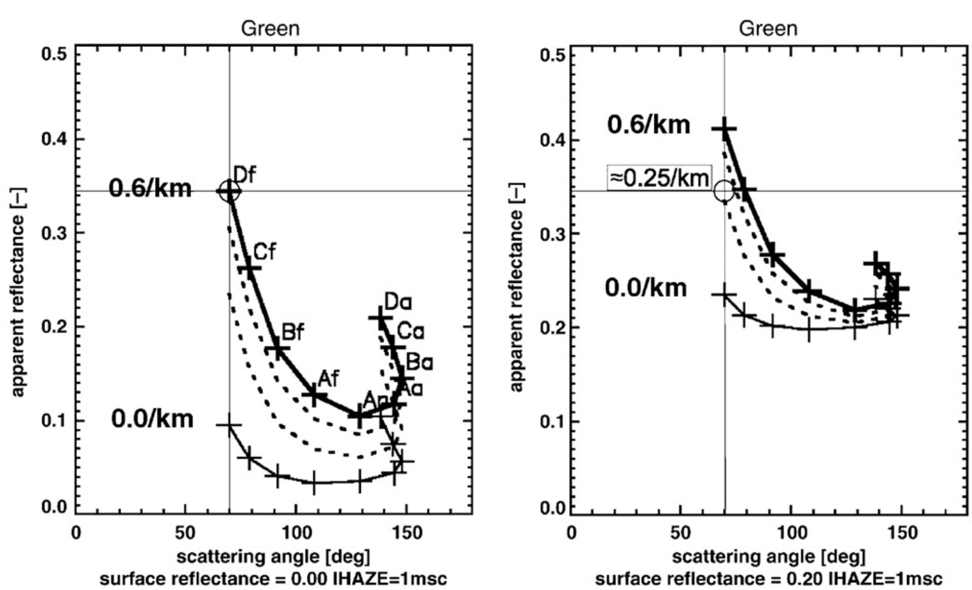

Fig. 1. Simulated apparent reflectance ρ_{app} measured by the 9 MISR cameras vs. scattering angle for the green spectral band (557 nm). Af to Df: forward looking cameras, Aa to Da: aftward looking cameras, An: nadir looking camera. Ground level extinction coefficients β_e (550 nm) are set to 0 (thin solid line), 0.2, 0.4 (dotted lines, not labeled) and 0.6 km^{-1} (thick solid). Surface reflectances ρ_{surf} are set to 0 (left panel) and 0.2 (right panel). The surface is assumed to be Lambertian. Example: ρ_{app} = 0.345 is observed by camera Df (crosshair) for ρ_{surf} = 0.0 and β_e (550 nm) = 0.6 km^{-1} (left) as well as for ρ_{surf} = 0.2 and β_e (550 nm) = 0.25 km^{-1} (right). See text for details.