RETRIEVAL OF AEROSOL OPTICAL PROPERTIES AND ESTIMATION OF AEROSOL FORCING BASED ON MULTI-SPECTRAL SUN PHOTOMETER OBSERVATIONS

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ABSTRACT

We discuss an inversion method to retrieve aerosol optical properties based on direct and diffuse multi-spectral observation of solar radiation at the Earth's surface. These radiation quantities are measured by a sun photometer with CCD spectrometer. The spectral range of the instrument detector is between 350 and 1100 nm and includes 255 channels. This instrument is operated with two modes; one with active solar tracking, which allows measuring direct solar radiation and the second with almucantar or principle plane scans, which are used to measure spectral sky radiance. We retrieve following parameters: spectral aerosol optical thickness, columnar single scattering albedo, asymmetry parameter and total water vapor. Finally basing on these parameters and radiative transfer calculations the aerosol direct radiative forcing was estimated.

1. INTRODUCTION

Knowledge of aerosol optical properties plays an important role in estimation of the direct aerosol forcing. Precise information about these quantities enables computing based on radiative transfer models the reduction of solar radiation at the Earth's surface and change of planetary albedo at the top of the atmosphere. Models calculations require information about spectral aerosol optical properties and its variability with altitude. Much of the recent work has been devoted to improve observational networks such as the Aerosol Robotic Network (AERONET) (Holben et. al, 1998), a European Aerosol Research Lidar Network (ERLINET), and the micro-pulse lidar network (MPLNET). In spite of this fact there is no technique to measure remotely aerosol optical and physical properties required by radiative transfer models. For instance lidar observation is usually limited to measure profiles of extinction and backscatter coefficients only. In addition, aerosol lidar retrieval requires strong assumptions, which introduce significant uncertainties (Welton et al., 2002).

The sun and sky radiance observation (AERONET) is used to retrieve vertically averaged quantities such as single scattering albedo (SSA), scattering phase function. However these aerosol optical properties are limited only to a few spectral data points. Wavelength variability of the aerosol optical properties is important for the aerosol

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radiative forcing but also for the identification of aerosol type.

In this paper we discuss new observational technique to measure and retrieve multi-spectral aerosol optical properties. We present results obtained during SAWA experiment, which took place in Warsaw, Poland in 2005.

2. AUTOMATIC SUN AND SKY SCANNING MULTI-SPECTRAL SUN PHOTOMETER

In this section we describe Multi-Spectral Sun Photometer (MSSP), which is used to measure spectral: direct and diffuse solar radiance. The main part of this instrument is a CCD spectrometer with 256 channels. We use the MMS1 UV-VIS Zeiss spectrometer with the spectral range between 320 and 1100 nm. Resolution of this detector is about 3 nm and wavelength accuracy is about 0.2 nm. The measurement time (integration time) can be adjusted from 1.5 to 6500 ms. Noise of this detector is small and does not exceed 3 digital number (DN). Although, the dynamic range of the MMS1 spectrometer is determined by 15 Bit A/D converter (33 768 DN) it is too small to measure direct solar and sky radiance. Therefore we measure these radiance components with different field of view (FOV). The direct solar radiance is measured by 1^{o} FOV and sky radiance with 2^{o} FOV. To reduce the direct solar radiance (in the case of the smallest FOV) we use 10% of transmission gray filter. In addition the integration time for sky radiance is about 10^{3} larger if compared to direct solar radiance. We use two fiber shutters to block one channel (sun or sky) or to block two channels and perform dark measurement.

Both tubes limiting the FOVs were mounted on two-axis sun tracker. This tracker allows to follow up the sun with precision about 0.01^{o} and it performs sky scans (almucantar, principle or others). The MSSP instrument is controlled by MatLab software by USB2 and RS232 ports.

The MSSP is calibrated according to the Langley method. We are using this technique for the SUN channel. For the SKY channel the Langley method cannot be applied because direct solar radiation saturates the MMS1 spectrometer. In order to calibrate SKY channel we compare it with the SUN one in the region of sun aureole.

3. RETRIEVAL OF SPECTRAL AEROSOL OPTICAL PROPERTIES

The AOT measurements have been made for many years with two general techniques. One approach uses a narrow field of view radiometer pointed directly at the sun (Volz, 1959) and the second one uses a shadow band radiometer that measures the total and diffuse solar radiations. The MSSP instrument uses the first approach, where the AOT is calculated from Beer-Lambert law. For this purpose we use observation of the direct solar radiance. For significant part of detector pixels simple Beer-Lambert relationship cannot be applied because of oxygen, ozone, and water vapor absorption bands. Correction for these gasses requires radiative transfer calculations of the spectral transmittance as a function of solar zenith angle and total amount of gases in the vertical column.

Based on the differential absorption technique the total water vapor is estimated. For this purpose we use the water vapor absorption band at 936 nm and radiative transfer model. We use MODTRAN, ver. 4.1, which was run in the transmittance mode with 20 cm^{-1} spectral resolutions.

Retrieval of the SSA and scattering phase function or the asymmetry parameter is more complicated. Distribution of downward diffuse sky radiance for almucantar scan can be described by

$$I(\Theta,\lambda) = F_o e^{-m_o\tau} m_o \tau[\omega P(\Theta) + MS(...)] \qquad (1)$$

where, Θ is scattering angle, m_o is the air mass factor, τ total optical thickness, F_o is the direct flux at the top of the atmosphere, and MS(…) term describes multiple scattering. Thus ratio of diffuse to direct solar radiance is a function of aerosol and molecular optical properties

$$R(\Theta,\lambda) = \frac{I(\Theta,\lambda)}{F_{dir}(\lambda)} = m_o \tau[\omega P(\Theta) + MS(...)]\,. \qquad (2)$$

In the case of the single scattering approximation angular variability of the diffuse to direct ratio $R(\Theta,\lambda)$ is only function of the scattering phase function.

Fig. 1 shows calculated sky radiance ratio for different aerosol optical properties as a function of the scattering angle (for almucantar scan). Sky radiance changes significantly larger due to variability of the asymmetry parameter (red lines) than for the SSA (blue lines). Note the model calculation was performed for the AOT of 0.2 and for this value difference between the single scattering approximation (open circles) and multiple scattering model (dotted squares) is not negligible.

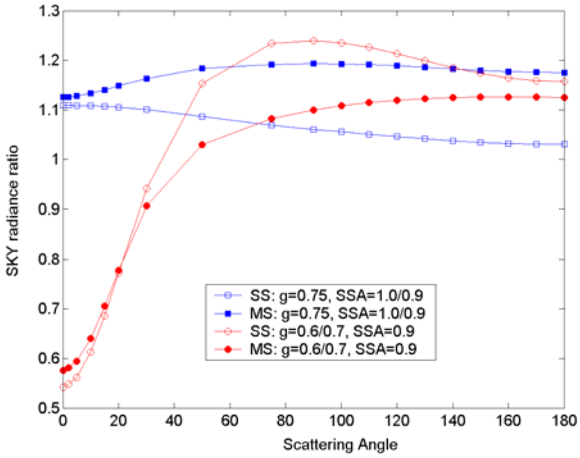

Fig.1 Calculated sky radiance ratio for different aerosol optical properties based on single scattering approximation (opened points) and DISORT included multi-scattering (dotted points). Blue pointes correspond to the sky radiance ratio for two aerosol optical models. Both models have the same asymmetry parameter (0.75) but different value of the SSA (1.0 for the first model and 0.9 for second). Similar for red points but in this case the SSA is constant and set to value 0.9 and the asymmetry parameter is equal 0.6 for the first model and 0.7 for second model.

In order to calculate the distribution of sky radiance we use the same radiative transfer model. Modtran uses DISORT solver, which enables multi-scattering calculation up to 16 radiance streams. As the input data we use standard atmospheric profiles, however we scale the input profiles: the total water vapor and total ozone according to the observation. MODTRAN requires information about spectral aerosol optical properties such as the aerosol extinction coefficient, the SSA and the asymmetry parameter. These spectral aerosol quantities are constant with altitude (MODTRAN allows to set four different aerosol models). However, profiles of the aerosol extinction coefficient at 550 nm can by applied independently. In this study we assume exponential decreasing of the aerosol extinction coefficient with the altitude. The assumption for typical profile, for most of the atmospheric conditions does not influence critically the retrieval quantities (Dubovik et al., 2000).

In this paper we assumed values of spectral surface albedo concerning the surface type. Because surface albedo has significant influence on the multiple scattering (especially over the surface with large albedo) in the future we will attempt to measure spectral albedo by the MSSP instrument.

Based on the MODTRAN we developed large 5D look-up table. This table includes following independent variables: AOT, SSA, asymmetry parameter, solar zenith angle and relative azimuth angle. By minimizing the difference between modeled and observed sky almucantar radiances at each wavelength we retrieve the SSA and the asymmetry parameter.

The aerosol radiative forcing is estimated from the aerosol optical properties and radiative transfer calculation of total downward and upward fluxes. For this purpose the aerosol optical quantities are spectrally extended up to 4 μm. The Angstrom relationship for the AOT and the SSA is assumed.

4. RESULTS AND CONCLUSION

In this section we present the results obtained during SAWA experiment, which took place in Warsaw, Poland in April and in May 2005. The main goal of this campaign was to estimate the aerosol forcing of the nonspherical Saharan dust. Saharan dust over Central Part of Europe can be observed several times a year, especially during springtime. Therefore, we decided to carry out this experiment between end of March and May.

To the objectives we estimated the AOT of spherical and nonspherical particles using 3 wavelengths lidar, MSSP, MICROTOPS, and Multi Filter Rotating Shadow Band Radiometer. The contribution of the nonspherical AOT to the total AOT was determined from analysis of lidar depolarization at 532 nm. The comparison of the observed radiative fluxes during the days with and without Saharan dust events gives an evidence of the aerosol forcing caused by nonspherical aerosol.

The mean reduction (during SAWA) of the solar radiation at the surface due to aerosol is about 6% and the mean aerosol forcing is about -18 Wm^{-2}. The aerosol forcing efficiency was estimated between -70 and -77 Wm^{-2} and these values are characteristic for the moderately absorbing aerosol. The change of aerosol forcing due to nonspherical particles is small however the difference of radiative forcing between spherical and nonspherical particles strongly depends on the aerosol size and the aerosol shape. The results of this study are discussed by Markowicz et al. (2005).

Fig. 2 presents spectral variability of the AOT (Fig. 2a) and the SSA (Fig. 2b) obtained using the MSSP observation as described above in section 3. Different slope of the AOT in the visible range indicates different particles effective size. The mean (defined for the entire measured spectrum) Angstrom exponent in April 20 is 1.17 while in May 20 is 0.78. The wavelength variability of the SSA for these two days is similar, but values of the SSA are significantly different.

This method makes possible analysis of the spectral variability of the aerosol optical properties which are function of the particles size distribution, shape, and refractive index. Thus our retrieved parameters may be used in inversion methods in order to estimate the aerosol size distribution.

Uncertainties of the retrieval of the SSA and the scattering phase function or the asymmetry parameters are reduced due to observational technique. Estimation of these quantities requires only relative calibration between SUN and SKY channels. Absolute calibration is needed only for the AOT retrieval. However, the AOT includes usually smaller errors than others optical properties due to simpler methodology.

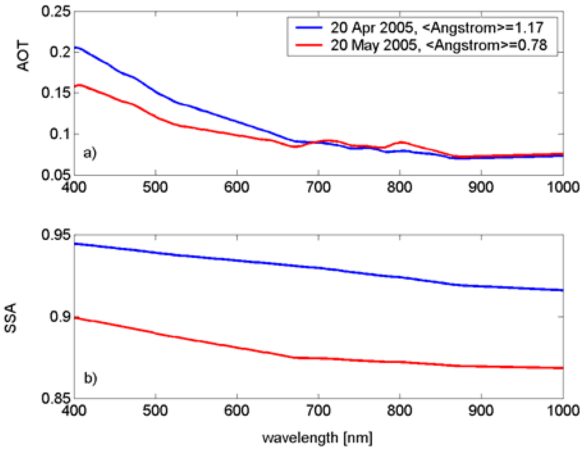

Fig. 2 Spectral variability of the AOT (a) and the SSA (b) retrieved from observation performed in April 20 and May 20, 2005.

5. BIBLIOGRAPHY

Dubovik, O., M. D. King, 2000: A flexible inversion algorithm for retrieval of aerosol optical properties from Sun and sky radiance measurements, *J. Geophys. Res.,* **105**, D16, 20673-20,696.

Holben, B. N., T. F. Eck, I. Slutsker, D. Tanr&eacute, J. P. Buis, A. Setzer, E. F. Vermote, J. A. Reagan, Y. J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, A. Smirnov, 1998: AERONET – A federated instrument network and data archive for aerosol characterization. *Remote Sensing of Environment*, **66**(1), 1-16.

Markowicz, K. M, A.E. Kardas, C. Hochherz, K. Stelmaszczyk, A.Rozwadowska, T. Zielinski, G. Karasinski, J. Remiszewska, M. Witek, S. Malinowski, T. Stacewicz, L. Woeste, 2005: Observation of optical properties and radiative forcing of nonspherical particles over Poland, *Accent symposium, Sep 2005 – Aerosol: air quality and climate*.

Welton, E. J., J. R. Campbell, 2002: Micro-pulse Lidar Signals: Uncertainty Analysis,
J. Atmos. Oceanic Technol., **19**, 2089-2094.

Volz, F. E., 1959: Photometer mit Selen-photoement zurspektralen Messung der Sonnenstrahlung und zer Bestimmung der Wallen-langenabhangigkeit der Dunsttrubung (in German). *Arch. Me-teor. Geophys. Bioklimatol.,* **B10**, 100–131.

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