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Utilization of AERONET polarimetric measurements for improving retrieval of aerosol microphysics: GSFC, Beijing and Dakar data analysis ☆

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ABSTRACT

The study presents the efforts on including the polarimetric data to the routine inversion of the radiometric ground-based measurements for characterization of the atmospheric aerosols and analysis of the obtained advantages in retrieval results. First, to operationally process the large amount of polarimetric data the data preparation tool was developed. The AERONET inversion code adapted for inversion of both intensity and polarization measurements was used for processing. Second, in order to estimate the effect from utilization of polarimetric information on aerosol retrieval results, both synthetic data and the real measurements were processed using developed routine and analyzed. The sensitivity study has been carried out using simulated data based on three main aerosol models: desert dust, urban industrial and urban clean aerosols. The test investigated the effects of utilization of polarization data in the presence of random noise, bias in measurements of optical thickness and angular pointing shift. The results demonstrate the advantage of polarization data utilization in the cases of aerosols with pronounced concentration of fine particles. Further, the extended set of AERONET observations was processed. The data for three sites have been used: GSFC, USA (clean urban aerosol dominated by fine particles), Beijing, China (polluted industrial aerosol characterized by pronounced mixture of both fine and coarse modes) and Dakar, Senegal (desert dust dominated by coarse particles). The results revealed considerable advantage of polarimetric data applying for characterizing fine mode dominated aerosols including industrial pollution (Beijing). The use of polarization corrects particle size distribution by decreasing overestimated fine mode and increasing the coarse mode. It also increases underestimated real part of the refractive index and improves the retrieval of the fraction of spherical particles due to high sensitivity of polarization to particle shape. Overall, the study demonstrates a substantial value of polarimetric data for improving aerosol characterization.

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1. Introduction

Atmospheric aerosol studies are important for different environmental applications. Thus the development of corresponding observational capabilities is in continuous progress. One of the main objectives of aerosol observations is to decrease the estimation uncertainty of the impact of aerosol on radiation balance and to enrich our general knowledge about aerosol properties. Remote sensing provides global information about characteristics of aerosols and clouds. Remote sensing methods could be divided into active (lidars) and passive (radiometers) techniques. The measurements can be carried out either from space (space-borne instruments) or ground (ground-based instruments). Each technique and instrument has specific scope and limitations. For example, space-borne imagers implement global monitoring of large areas and produce the data over large regions or over the entire world. At the same time, such satellite observations generally provide information with limited accuracy. Detailed review of the satellite systems could be found in Kaufman et al. [22], Mishchenko et al. [34], Li et al. [30], and Kokhanovsky et al. [23].

The satellite observations are validated by the measurements of solar photometers from ground. Such ground-based measurements provide information of high quality about columnar aerosol properties. Frequent measurements by the sun/sky-scanning radiometers allow for obtaining a detailed dynamic picture of local aerosol loading.

Due to the high spatial and temporal variability of the aerosols distribution, ground-based observations are needed. The AErosol RObotic NETwor (AERONET, [21]) program, initiated by NASA (National Aeronautics and Space Administration) and LOA (Laboratoire d'Optique Atmosphérique-LOA, University of Lille) in the 90s, is the most extended network deployed on ground in the form of stations for monitoring atmospheric aerosols. AERONET provides aerosol characterization, satellite data validation, and synergy with other instrumentation (lidars, in-situ, radars, etc.). The interpretation of the measurements relies on complex inversion procedures. The AERONET operational algorithm [10,14] inverts a combination of direct-sun and diffuse sky-scanning measurements and provides detailed information on aerosol properties integrated over the atmospheric column such as particle size distribution, complex refractive index, and some information about particles shape and lidar ratio.

Highly standardized AERONET observations rely mainly on intensity measurements registered at several wavelengths: the total direct solar radiation and angular diffuse radiation transmitted through the atmosphere. Nevertheless, the use of polarimetric observations in addition to the observations of total atmospheric radiance is widely expected to improve aerosol characterization from remote sensing measurements. Therefore, there are significant efforts for development and utilization of polarimetric observations from space for remote sensing of aerosol. For example, several multi-viewing polarimetric POLDER (POLarization and Directionality of the Earth's Reflectances) imagers have been already operated in space. The high potential of space polarimetry was demonstrated by interpretation of POLDER/PARASOL [47] data using recently developed enhanced algorithms [18,19,8,13]. As a result, several new polarimeters have being developed [4,6] and a few polarimetric missions are projected (for example, 3MI mission [31] and Global Change Observation Mission (GCOM-C) with Second generation GLobal Imager (SGLI) [39], see also [23]). Correspondingly, the availability of ground-based polarimetric observations for validation of the satellite data is highly desirable. It is expected that addition of such polarimetric observations significantly increases the information content of data provided by a single photometer and therefore should be highly beneficial for improving quality of aerosol products provided by AERONET [29]. Moreover, the utilization of detailed polarimetric observation was identified by several comprehensive sensitivity analyses [32,33] as very promising approach for improving accuracy of monitoring aerosol from satellite. However, the polarimetric observations from ground have not yet been as widely developed as in satellite remote sensing and, at present, there is rather limited experience in using ground-based measurements of polarization for aerosol characterization (some studies are [3,51,1,28,57,55,56]). Namely, although some polarimetric measurements of diffuse sky radiation were also performed (at only one wavelength of 870 nm), these observations are not used in generation of AERONET products.

In order to explore the potential of ground-based passive polarimetry for aerosol remote sensing, a new sun-photometer CIMEL CE318-DP enabling multi-wavelength polarization characteristics of the downward radiation has been developed. Such instruments were already deployed at several AERONET sites. The main enhancement of the new CIMEL Double Wheel Polar (DWP) sun-photometer is a new scheme of a measurement acquisition. It is designed as a system of two paired independently rotating wheels: one with a set of polarizers and the other one with the set of spectral filters. It provides a possibility to measure the polarized radiance at all available wavelengths. At the same time, the measurements of the new radiometer are substantially more complex than the measurements provided by standard CIMEL radiometer employed by AERONET. The measured data from DWP-photometer need to be systematically processed and used for operational aerosol retrieval. It requires development of several complex procedures for standardizing and processing the polarimetric measurements within AERONET. Therefore, at present there are only few examples of using ground-based polarimetric measurements, and the potential of such measurements for aerosol characterization remains unexploited and not fully clarified.

In this paper we present an effort to evaluate the importance of new polarimetric observations as part of large network observation and we analyze extended series of the DWP polarimetric data. With that purpose, we have developed data preparation and processing tool for the retrieval. In order to estimate a contribution of polarimetric data for improving aerosol characterization we have compared the results of data inversions obtained with and without utilization of the additional polarization