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Limitations of AERONET SDA product in presence of cirrus clouds

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ABSTRACT

The paper discusses certain limitations on applicability of Spectral Deconvolution Algorithm (SDA) to aerosol optical depth spectral measurements contaminated by cirrus clouds. Analysis of the synthetic data demonstrates that application of SDA to cloud contaminated measurements can produce significant errors in the apparent optical depth fine mode retrievals. Such application can produce results that just look reasonable and physically admissible but in fact can be relatively far from the truth and therefore can be misleading.

1. Introduction

Cirrus clouds are important for correct estimations of the Earth radiation budget. Optical properties of cirrus clouds are highly variable in size and shape. Therefore a proper optical modeling of cirrus cloud particles is very difficult. Aerosol-cloud interactions remain a big unknown in the weather forecast and climate models. Unlike ground-based aerosol optical measurements, which are well established by the worldwide Aerosol Robotic Network (AERONET) [26], cirrus clouds lack ground based measurement techniques and consequently validation opportunities of the space-based sensors [19].

Spectral deconvolution algorithm (SDA) developed by Norm O'Neill in the beginning of the 2000s [16,18] proved to be a useful tool in aerosol optical depth analysis. Spectral curvature allowed a partition of AOD into two parts associated with the fine and coarse aerosol fractions. Comparison with aerosol retrievals based on AOD and sky brightness measurements in the solar almucantar [6] showed a very good agreement [8]. SDA has certain advantage because AOD measurements are taken more frequently and do not require fulfillment of numerous thresholds that vastly depend on sky condition. The algorithm was successfully applied to analysis of various aerosol types, i.e. dust [14], biomass burning [15,17], urban/industrial [7], and their mixture [8]. The utility was used for validation of satellite products; in particular of the MODIS fine mode fraction retrieval [13]. SDA advantages come with a price of the need to have highly accurately measured AODs as an input within specific wavelength spectral range (380–870 nm).

Recently, there were attempts to apply SDA retrieval algorithm to atmospheric conditions it was not designed for, namely to the analysis of cloud contaminated (i.e. aerosol+cloud) direct sun measurements [2]. Because sunphotometers have a finite field of view, in the presence of clouds we have to account for the diffused light that is scattered into the instrument's aperture. This extra light will cause extra transmission and therefore the computed optical depth will be underestimated (it is called "apparent optical depth"). It is obvious that in case of cloud-free sky, we can still get some diffused light within instrument's field of view, however, for typical aerosol effective radii (Reff), this contribution will be small (see e.g. [5,20,22]). Cirrus clouds may have a wide range of particles, of various shapes and forms, with effective diameter (Deff) ranging from several microns to hundreds of microns. Underestimation of cloud+aerosol optical depth can be significant and to correct properly the scattering within field of view [1,9,12,21,23] we should know cirrus cloud particles shape, effective diameter and optical properties, i.e. phase function and single scattering albedo. Neither parameter is usually known at any given point of space and time. Correction factors will be a function of particle size, shape

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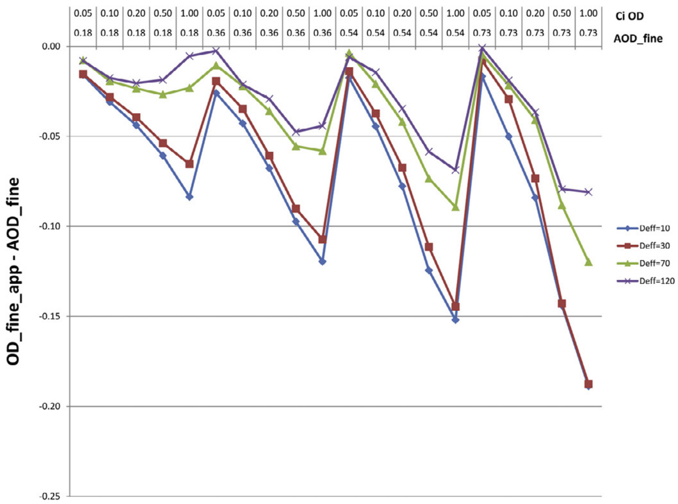

Fig. 1. SDA derived differences between fine components of apparent optical depth (OPAC Continental aerosol model with relative humidity of 80% and Aggregated columns Ci cloud model) and aerosol optical depth (OPAC Continental aerosol model with relative humidity of 80% only).

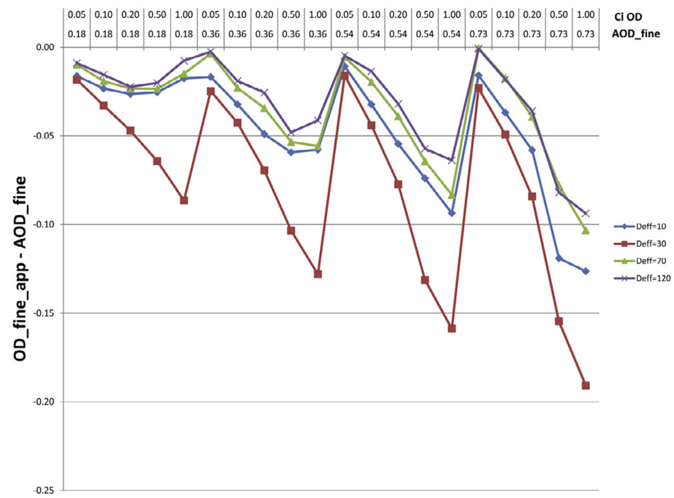

Fig. 2. SDA derived differences between fine components of apparent optical depth (OPAC Continental aerosol model with relative humidity of 80% and severely roughened mixed habits Ci cloud model) and aerosol optical depth (OPAC Continental aerosol model with relative humidity of 80% only).

and spectral wavelength (see, for example, Fig. 1 in [9]). Therefore, by measuring the apparent (cloud + aerosol) optical depth and partitioning it into fine and coarse parts we can attribute the coarse part to clouds and fine part to aerosols from urban/industrial or biomass burning origin and/or any mixtures with the fine mode dominance. However as we will show below this simple hypothesis requires careful assessments and certain limitations based not only on the empirical evidence [2] but also on direct computations of the diffuse light contribution.

2. Illustrative example

We simulated total irradiance (direct plus diffuse) at the sea level for a sun/sky radiometer with the full field of view of 1.2° that corresponds to AERONET instrument. For simplicity solar zenith angle was zero (Sun in the zenith). Spectral range 380–870 nm had five narrow spectral channels: 380, 440, 500, 675, and 870 nm. Atmospheric aerosol optical properties were based on the OPAC continental model [10] with aerosol optical thicknesses 0.20; 0.40; 0.60; 0.80 at 500 nm. Cloud optical properties were adopted from Baum et al. [4] and Yang [24] with optical thicknesses 0.05; 0.10; 0.20; 0.50; 1.00 for MixSR (mixed habits, severely roughened) and Aggregates (aggregate of solid columns). Molecular scattering and gas absorption used 1976 US Standard Model. Radiative transfer computations were done according to Zhuravleva [25] and Segal-Rosenheimer et al. [21]. Spectral deconvolution algorithm was applied to computed spectral aerosol only and to the apparent (aerosol plus cloud) optical thicknesses to retrieve AOD_fine and apparent OD_fine. Then we computed differences (OD_fine_app-AOD_fine) for each atmospheric aerosol and cloud ODs, cloud particles effective diameter, and cloud model.

Fig. 1 presents differences between fine components of apparent optical depth and aerosol optical depth for the aggregate of solid columns and OPAC continental model with relative humidity of 80%. Deff span covers full available range of cirrus cloud phase functions [3]. The graph shows that in general with the cloud optical depth increase underestimation of the fine component of the apparent optical depth is getting larger. It is valid for all aerosol loadings considered. This effect is getting bigger while AOD increases, however differences diminish with increase of cloud particles effective diameter.

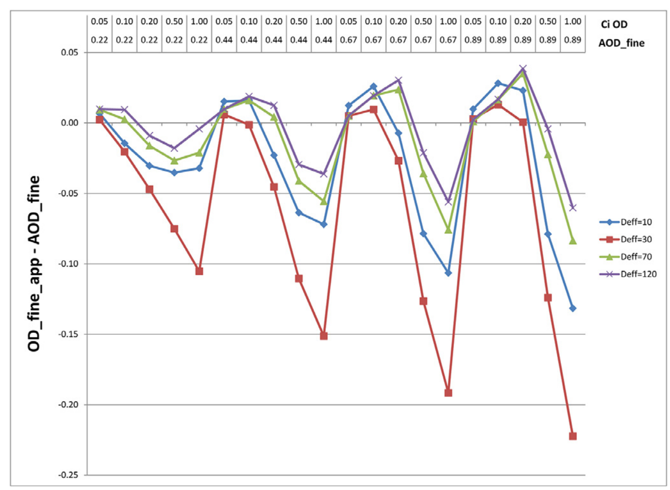

Fig. 3. SDA derived differences between fine components of apparent optical depth (ARCTAS Smoke aerosol model and Severely roughened mixed habits Ci cloud model) and aerosol optical depth (ARCTAS Smoke aerosol model only).

Fig. 2 presents OD_fine_app minus AOD_fine differences for severely roughened mixed habits (MixSR) and same OPAC continental model with relative humidity 80%. Generally underestimation of the OD_fine_apparent is evident however a non-monotonic dependence on cirrus cloud Deff is obvious for all cloud ODs and AODs.

Fig. 3 shows computations for MixSR and smoke aerosol model from the ARCTAS mission [11] following Segal-Rosenheimer et al. [21]. The ARCTAS smoke model was derived from averaging multiple AOD spectra below the smoke plumes under clear skies. Slightly different from OPAC continental model (higher Angstrom parameter) smoke aerosol model produced a variable pattern with positive and negative OD_fine_app minus AOD_fine differences. We would like to note that for computational convenience nominal AODs (0.20; 0.40; 0.60; 0.80) were taken at 550 nm (not at 500 nm as in Figs. 1 and 2).

Fig. 4 displays results for MixSR and OPAC urban model with the relative humidity of 50%. Presented in Fig. 4 differences do not differ much from Fig. 2 and are presented to show consistency for two computational methods of Zhuravleva [25] (Figs. 1 and 2) and Segal-Rosenheimer et al. [21] (Figs. 3 and 4).