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Aerosol type over east Asian retrieval using total and polarized remote Sensing

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ABSTRACT

Satellite observation in East Asia is important because aerosols of this region are very complex, not only from anthropogenic but also from natural sources, which have been recognized as a major source of regional and global air pollution. However, retrieving aerosols properties over land is difficult because of surface reflection, complex aerosol composition, and aerosol absorption. In this study, a new aerosol retrieval method including two steps was developed to invert AOT and aerosol type using PARASOL TOA measurements. Both reflectance (490 nm) and polarized reflectance (670 nm and 865 nm) are used in the algorithm to improve the accuracy of retrieved AOT and aerosol type. AOT was determined by comparing the aerosol reflectance and polarized reflectance with pre-calculated LUTs of six aerosols clustered from the inversion products of AERONET sites in East Asia. The comparison between PARASOL and AERONET showed improvement in total AOT using the suggested methodology. Three case studies show inverted aerosol AOT and types agreed well with specific aerosol types.

1. Introduction

Atmospheric aerosols originate either from natural sources (dust, volcanic, or sea salt, etc.) or from anthropogenic sources (fires, sulfates, soot, etc.). Due to their very high spatio-temporal variability and various optical properties, they are one of the main sources of uncertainty in climate change caused by human activities [1]. Observation from satellites, being global and quasi-continuous, has been a major tool for aerosol studies. Various satellite remote sensing techniques in the visible wavelengths range have been widely used to characterize aerosols and their effect on solar radiation [2–4]. Not only the knowledge of the microphysical and optical properties of aerosols on the radiative transfer but also the accurate estimation of surface reflectance is needed to retrieve reasonable aerosol characteristics. The uncertainties and discrepancies among different retrieval algorithms have been studied [4–7] and some insights ware obtained [8–10]. However major improvements in the accuracy and spatial resolution of the satellite products are still required for air quality applications in urban areas [11].

Aerosol optical thickness (AOT) is a basic optical property derived from many Earth observation satellites such as the Advanced Very High Resolution Radiometer (AVHRR) [12,13], the Moderate resolution Imaging Spectro-radiometer (MODIS) [14], the Multi-angle Imaging Spectro-Radiometer (MISR) [15], and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) [16,17], etc. The spectral and angular variation of upwelling total radiance is currently used to derive aerosol optical properties.

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However the brightness of the surface and its angular variability, as well as it spatial heterogeneity, make the differentiation of aerosol and surface contributions in the upwelling total radiance a challenging problem.

Retrievals of aerosol properties from multi-angular, multi-spectral, and polarized measurements can take advantage of the different angular and polarized reflectance signatures of the contributions from the surface and the aerosols. Taking advantage of these features of polarization, Deuzé et al. [18] have developed a method based on polarized radiance measurements provided by the Polarization and Directionality of the Earth Reflectance (POLDER) instrument to derive the aerosol optical depth over land from the total and polarized radiance. Waquet et al. [19] have used airborne polarized measurements to retrieve optical and microphysical aerosol properties. However, because polarized light is mainly sensitive to scattering by small particles and cannot detect coarser modes of aerosols (such as dust and sea salt), AOT is underestimated in the case of bimodal size distribution of the particles. The algorithm developed by [20] could consider a continuous parameter space for aerosol microphysical properties (size distribution and refractive index) and properly account for land or ocean reflection by retrieving land and ocean parameters simultaneously with aerosol properties. Overview by Tanré et al. [21] is very detailed and comprehensive about the products and algorithms of PARASOL. Algorithms over land [18] and ocean [22] are reviewed. Validations provided by several papers [23–25] are listed and the factors influencing the retrieval accuracies are analyzed. Except for the two above algorithms for processing POLDER and PARASOL data adopted by CNES, further developments considering altitude and absorption, statistical optimization principles [26] are also introduced. Within the algorithms inverting aerosol properties using multi-angle satellite observations, the algorithm developed by Dubovik [26] emphasizing statistical optimization is the most advanced and sophisticated. Over land the algorithm is able to retrieve parameters of the land surface reflectance together with detailed information about aerosol sizes, shape, absorption and composition (refractive index) and aerosol layer elevation. Although Dubovik's algorithm can overcome the limitation of existing algorithms [18,22], the speed of the inversion by a factor 50–100 is still required for applying the method operationally to the PARASOL archive [21].

From the analysis of optical of aerosol from the AERONET inversion products over the East Asia, it is found that various types of aerosol result in very broad optical properties in this region. This study presents an aerosol retrieval algorithm retrieving aerosol optical depth and type of East Asia based on interactive look-up tables (LUTs). We developed LUTs by means of statistical classification method, which is defined in previous work [27]. In this classification, aerosol optical properties were obtained from AERONET sun-sky radiometer data archive. Aerosol retrieval is then processed by a step forward from the classified aerosol models and has the advantage of representing more accurate aerosol properties in the retrieval. The retrieved AOT from the 6 km resolution PARASOL Level 1 calibrated reflectance data using this method is compared with AERONET AOT measured from the ground for validation.

This paper is organized as follows. Section 2 describes the aerosol models with cluster analysis. Section 3 describes the construction of LUTs used to invert aerosol AOT and type. In Section 4, we present the retrieval algorithm including two steps using non-polarized reflectance of 490 nm and polarized reflectance from 670 nm and 865 nm separately. The results of aerosol retrievals from PARASOL and their consistency with AERONET data are discussed in Section 5. Finally, conclusions are given in Section 6.

2. Aerosol models

Aerosol retrieval based on LUTs highly depends on the aerosol models used in the radiative transfer code. Aerosol models can be acquired from well known global climatology [28,29]. Nevertheless, aerosol microphysical and optical properties based on in-situ measurement or sun photometry describe real atmospheric conditions [30]. Since aerosol are mainly originated from transport of local air masses and nonsystematic events such as biomass burning (BB), re-suspension, and human activities, these variations lead to diverse aerosol characteristics. The representative aerosol type at a region of interest can be found by the occurrence of a typical type of aerosol at that location if an adequately large sample is used for calculations. However, assigning of typical aerosol microphysical and optical properties to a given location based on a long tern average has significant shortcomings [31].

In East Asia, atmospheric aerosols from human activities are recognized as an important source of regional and global pollution [32,33]. Furthermore, long-range transport of aerosols depends on meteorological conditions and affects air quality over downwind areas. These transported pollutants contain mineral dust as well as aerosol pollution consisting of sulfate, nitrate, and carbonaceous particles [34]. To develop type-specific aerosol models that include aerosol microphysics and optical properties over East Asia, the AERONET database [30,35] having very fine temporal resolution was used. A detailed description of the products is found in the documents of description [36,37].

Six aerosol types are clustered based on products from AERONET in Asia [38] and an algorithm for retrieval of aerosol was developed using MODIS L1 data. These six aerosol types are adopted in our algorithm. Compared to the four wavelengths used in AERONET which are 441 nm, 675 nm, 869 nm and 1018 nm, only three wavelengths are used in our algorithm based on PARASOL: 490 nm, 670 nm, and 865 nm. So we made interpolations to calculate the refractive index of 490 nm, 675 nm and 865 nm. Table 1 shows the aerosol and microphysical properties for each cluster.

Fig. 1 compares the size distribution for the six clustered aerosol models. Size distributions show that the values of $dV/d\ln r$ varied significantly for different categories. Omar generated six clusters using AERONET data set all over the world described by the column optical and physical properties. He also found that the properties of the medoids along with the geographic locations of the