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New dust aerosol identification method for spaceborne lidar measurements

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ABSTRACT

Classification is a critical step in the backscatter lidar data processing to accurately retrieve extinction and backscatter profiles of atmospheric aerosols and clouds. Different schemes, such as the probability distribution functions (PDFs) method, have been used in the cloud and aerosol classification. In this paper, we attempt to use the *support vector machine* (SVM) to discriminate aerosols from clouds, with a focus on dust aerosol classification in China. To demonstrate the feasibility of the SVM classifier, we chose dust storms that occurred in the Gobi and Taklimakan deserts and observed by the CALIPSO lidar in spring time 2007. The results show that the SVM can correctly identify the dust storms.

1. Introduction

Over East Asia, soil and mineral dust aerosols dominate aerosol loading during dust active seasons [1]. Many researches have been carried out to observe Asian dust. These researches include ground-based observations such as the NIES lidar network using active instrumentations, and AERONET (AErosol RObotic NETwork) using passive instrumentation (sun-photometer). These ground-based networks can obtain more accurate and continuous observation data. However, the coverage of these networks is limited mainly to land. It is difficult to obtain dynamic information of the dust transport on a large scale [2]. On the other hand, spaceborne observations provide a global coverage that enables the track of the dust transport on a global scale. The MODerate resolution Imaging Spectroradiometer (MODIS) aboard the NASA's TERRA and AQUA satellites has been widely used in aerosol and climate studies [3]. However, these spaceborne remote sensors are passive facilities and hard to provide vertical distribution of clouds and aerosols. In addition, these passive measurements are strongly impacted by the surface conditions and, for the measurements in the visible regime, limited to day time only.

The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) is an active instrument [4]. The CALIOP's high-resolution vertical profiling ability and accurate depolarization measurements make it a superb platform for the study of dust aerosols [5]. Therefore, the CALIOP measurements have been used to characterize the dust occurrence over the Tibet Plateau and the surrounding area (e.g. [5]) and validate the dust transport model (e.g. [1]).

In the CALIOP production data processing, the classification between aerosols and clouds is the first step of the scene classification algorithm (a detailed description will be given in Section 3). The parameters used in the classification do not include the depolarization ratio in the version 2 algorithm. This parameter is used as an additional dimension of the probability density functions

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(PDFs) of clouds and aerosols in the version 3 algorithm. The depolarization ratio is calculated from the ratio of the perpendicular channel and the parallel channel signals at 532 nm [6]. It is a useful indicator that can be used to identify irregular particles (such as dust particles and ice crystals) from spherical particles. In the current version of the algorithm described in this paper, however, the depolarization ration is not used. This parameter will be used in future. In this study we use the SVM classifier to perform the scene classification. The observation object chosen is the dust storms that occurred in spring (March 30 and May 10) 2007 in the Gobi and Taklimakan deserts in China (40–45°N, 109.16–107.47°E, 37–42°N, and 86.91–85.35°N), respectively.

Section 2 below describes the data we use. Section 3 introduces the new dust aerosol classification method. Section 4 presents the test results of the classification and the corresponding discussions. Conclusions are summarized in Section 5.

2. Data

The CALIPSO satellite is one of the Afternoon satellite constellation (A-Train) which consists of several Earth observation satellites maintained in sun-synchronous orbits at an altitude of ~700 km [4]. They are spaced a few minutes apart from each other so they are considered as providing synchronous observations. The CALIPSO lidar (CALIOP) is an active instrument; the signal it receives is the profile of the atmosphere. The SVM algorithm studied in this paper is applied to the atmospheric features detected by the CALIPSO lidar to classify their type (cloud vs. aerosol). The CALIOP version 2 products are used. To assist select the required training samples and test the SVM algorithm, we use the CloudSat data. CloudSat is another satellite in the A-Train constellation that is ahead of CALIPSO by ~15 s. It carries a cloud profiling radar (CPR) that can penetrate optically thick clouds and profile the clouds consisting of large particles. In this study, the MODIS imagery data acquired on the Aqua satellite is also used to identify the horizontal distribution of clouds and dust. The Aqua satellite leads the A-Train constellation and is ahead of CALIPSO by ~ 1 min.

2.1. CALIPSO

The CALIPSO payload consists of three nadir-viewing instruments: the two-wavelength polarization-sensitive backscatter lidar (CALIOP), wide field camera (WFC), and imaging infrared radiometer (IIR) [4]. The CALIOP level 1 major data products is a set of calibrated profiles of total attenuated backscatter at 532 nm and its perpendicular component and attenuated backscatter at 1064 nm. The CALIOP level 2 data products include aerosol and cloud layer and profile products. The parameters reported in these products include, for example, vertically resolved aerosol and cloud layers, extinction, optical depth, aerosol and cloud type, cloud water phase, cirrus emissivity, and particle size, and shape [7]. In this paper, we use the Level 1B data. We first search the total attenuated backscatter profiles to find the location (top and base heights) of each layer. Then, the mean attenuated backscatter, total color ratio, and volume depolarization ratio of each layer are calculated. To improve the signal-to-noise ratio (SNR), the L1B CALIOP data are averaged for 15 profiles, corresponding to a horizontal resolution of 5 km. The vertical resolution still remains the same as the original ones (i.e., 30, 60, 180, and 300 m in the different altitude ranges) as described in Table 1.

2.2. CloudSat

Onboard the CloudSat payload is a 94-GHz, nadir-pointing Cloud Profiling Radar (CPR). The purpose of the CloudSat mission is to measure the vertical structure of clouds from space and simultaneously observe cloud and precipitation. It provides vertically resolved information on cloud location, cloud ice and liquid water content (IWC/LWC), precipitation, cloud classification, radiative fluxes, and heating rates. The vertical resolution is 480 m with 240 m sampling, and the horizontal resolution is approximately 1.4 km (cross-track) × 2.5 km (along-track) with sampling roughly every 1 km [8].

A unique feature that CloudSat brings to the constellation is the ability to fly a precise orbit enabling the fields of view of the CloudSat radar to be overlapped with the CALIPSO lidar footprint and the other measurements of the constellation. The precision of this overlap creates a unique multi-satellite observing system for studying the atmospheric characteristics. In this paper, we use the 2B-GEOPROF data files. A cloudy range bin in 2B-GEOPROF is associated with a confidence mask value that ranges from 0 to 40. Values ≥ 30 are confidently associated with clouds and a value of 6 suggests clouds approximately 50% of the time. CloudSat can measure the location of thick clouds and find the total attenuated area, providing additional information that can be used to identify the cloud signals measured by CALIOP and select training samples.

2.3. Aqua

Aqua-MODIS views the entire Earth's surface every 1–2 days and acquires data in 36 spectral bands (see the MODIS Technical Specifications). These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated global interactive Earth system models that is able to predict global changes and accurately assist

Table 1
The horizontal and vertical resolution of data after averaging.

Altitude range (km)	Horizontal resolution (km)	Vertical resolution (km)
30.1–40.0	60	0.3
20.2–30.1	25	0.18
8.2–20.2	15	0.06
0.01–8.2	5	0.03