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A-Train satellite measurements of dust aerosol distributions over northern China

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ABSTRACT

Horizontal and vertical distributions of dust aerosols over northern China were investigated for the period June 2006 to May 2011 using A-Train satellite constellation data and ground-based measurements. Surface observations at 675 meteorological stations showed that dust events occurred most frequently in the Taklamakan and Gobi deserts. In the Taklamakan Desert, the dust aerosol content was high throughout the year, as seen from the distributions of the Moderate-Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) and the Ozone Monitoring Instrument (OMI) UV-absorption aerosol index (AAI). In the Taklamakan and Gobi deserts, the AOD and AAI reached maxima in spring and minima in winter. In the eastern part of northern China, AOD reached a maximum in summer and a minimum in fall, whereas AAI was high in winter and spring and low in summer and fall due to seasonal differences in the main aerosol type. The dust observations revealed strong seasonal variations in dust coverage area and height, with maxima in spring and summer and minima in fall and winter. The transportation of dust aerosols in all seasons was confined largely between 35°N and 45°N. The mean height of the dust layer top varied and showed strong seasonal variation in all regions, with values higher than 4 km in spring and about 2 km in winter. The Taklamakan Desert experienced higher occurrence of dust events than other regions throughout the year. Dust occurrence decreased dramatically over the eastern part of northern China in summer because of surface vegetation and precipitation. Simulation results by the HYSPLIT model were similar to the distribution of dust aerosols observed by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) during the same period.

1. Introduction

Airborne mineral dust is one of the major components of atmospheric aerosols and plays an important role in modulating regional and global climate via a number of complex processes. Dust aerosols affect the radiation budget of the Earth-atmosphere system directly by scattering and absorbing incoming solar radiation and outgoing infrared radiation [1–3] and indirectly by modifying cloud optical properties and lifetimes [4–7]. The absorption of ultraviolet (UV) radiation by dust aerosols may modulate photochemical processes [8]. Deposition of dust in the ocean supplies iron, which in turn affects the ocean biogeochemistry [9].

In northern China, desertification has occurred and strong winds often lift large amounts of dust into the atmosphere, causing dust phenomena such as floating dust (FD), blowing dust (BD), and dust storms (DS). The Taklamakan Desert is one of the largest deserts in the world. It is located in the Tarim Basin, which covers 300,000 km^2 and is bounded on three sides by high mountains, including the Tianshan in the north and

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Kunlun Mountains in the south. This area and the Gobi Desert are major sources of dust in northern China. Dust from the Taklamakan and Gobi deserts can be transported long distances, including to the northern Pacific Ocean, North America, [10,11], and globally [12–14]. Huang et al. [15] analyzed a dust case over the Taklamakan Desert in summer using the Fu–Liou radiative transfer model and satellite observations. They estimated the average daily mean net radiative effects of the dust to be 44.4, -41.9, and 86.3 $\mathrm{W\,m^{-2}}$, respectively, at the top of the atmosphere (TOA), surface, and in the atmosphere.

Most previous studies of dust over northern China were numerical simulations or case studies, the latter of which often have limitations of shorter time scales and smaller observational areas. To estimate dust effects accurately, extensive measurements of dust transport altitudes, patterns, and lifetimes are urgently required. Many polar-orbiting passive satellite instruments can measure dust aerosols, such as the Moderate-Resolution Imaging Spectroradiometer (MODIS), the Multiangle Imaging Spectroradiometer (MISR), and the Ozone Monitoring Instrument (OMI). These observations can provide useful information on dust horizontal distribution and transportation. However, observation of the vertical structure of dust using these passive measurements is rather difficult. Thus, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data are used to acquire the vertical distribution of dust aerosols. All satellite data used for this study were obtained from the Atmospheric Date Center of the NASA Langley Research Center (LARC).

2. Satellite and surface data

2.1. MODIS/Aqua and Terra

The MODIS aerosol optical depth (AOD) product has been evaluated and validated for both regional [16,17] and global [18–20] scale with high accuracies. The MODIS Dark Target Collection 5 algorithm provides information about the global distribution of aerosols, but not over bright surfaces such as deserts [21–23]. The MODIS deep-blue algorithm has higher sensitivity to aerosols over bright surfaces because it employs two blue channels (0.412 and 0.470 μm), for which surface reflectances are relatively small, to infer aerosol properties [24]. The MODIS Deep-blue products were thus useful for our study of desert areas. Aerosol Deep-blue products are not available for Terra after December 2007 due to unavailability of the required polarization corrections to the L1B data. We analyzed 5 years (June 2006 to May 2011) of Aqua and Terra MODIS AOD and Aqua MODIS Deep-blue AOD and Ångström exponent $\alpha_{412/470}$ product (Level 2).

2.2. OMI/Aura

The OMI onboard NASA's Aura satellite is a wide swath, nadir-viewing, near-UV and visible spectrometer that provides daily global coverage of clouds, aerosols, and surface UV irradiance with a high spatial resolution of $13\times24\ \mathrm{km}^2$. It is also part of the A-Train constellation. The OMI measures solar reflected and backscattered light in the spectral range from 270 to 500 nm with high spectral resolution (0.5 nm). This makes OMI especially suited for distinguishing UV-absorbing aerosols, such as dust and biomass-burning aerosols, from weakly absorbing aerosols and clouds. In this study, 5 years (June 2006 to May 2011) of the OMI absorbing aerosol index (AAI) data were used. The AAI represents the error in estimating the satellite radiance at 354 nm from the radiance at 388 nm, assuming a purely molecular atmosphere bounded by a spectrally varying Lambertian surface. The AAI takes near-zero values for clouds and weakly absorbing aerosols and positive values for dust and biomass burning aerosols [25,26]. In addition to the aerosol physical and optical properties, the AAI also depends on the height of the aerosol layer above the ground [25]. Absorbing aerosols above the boundary layer yield positive AAI values (>1), but they in the boundary layer may produce small AAI (<0.5) that make it difficult to separate their signal from the background noise [26].

2.3. CALIOP/CALIPSO

The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is the primary instrument on the CALIPSO satellite. The CALIOP is designed to acquire vertical profiles of elastic backscatter at two wavelengths (532 nm and 1064 nm) from a near-viewing geometry during both day and night phases of the orbit. In addition to the total backscatter at these two wavelengths, the CALIOP also provides linear depolarization at 532 nm. Dust aerosols have a large linear depolarization ratio (ratio of perpendicular to parallel polarization component) due to the nonsphericity of dust particles. This makes them different from other types of aerosol. Dust aerosols can therefore be identified in a given altitude range of a lidar profile using the volume depolarization ratio (VDR) [27]. The CALIPSO lidar L2 5 km aerosol and cloud layer products (version 3.01) were used here for all available nighttime data during the period June 2006 to May 2011 because they allowed a better signal to noise ratio. Two classes of aerosols were used from the L2 product: desert dust and polluted dust. The cloud data were used to screen for clouds.

We used the frequency of dust aerosol occurrence (OCC) defined by Liu et al. [27] as

$$\mathrm{OCC_i}=\frac{N_{\mathrm{i,dust}}}{N_{\mathrm{cf}}}$$

where $N_{\mathrm{i,\,dust}}$ and N_{cf} are the number of dusty profiles in the vertical range (i) and the number of cloud-free profiles, respectively, in a $1^\circ\times1^\circ$grid.

2.4. Surface observations and HYSPLIT trajectories

Surface meteorological data were taken from the CMA (China Meteorological Administration) and included standard surface observations. Dust days are those days in which floating dust (FD), blowing dust (BD), or dust storms (DS) were observed. In the FD category, dust particles are suspended in the air under calm or low-wind conditions, with horizontal visibility usually less than 10 km. In the BD category, dust and sand particles