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Detection of Asia dust storms using multisensor satellite measurements

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Abstract

Observations from visible, infrared and microwave satellite instruments are integrated to detect dust storm over northwestern China. Microwave measurements are used to detect the dust storm underneath ice clouds, while visible and infrared measurements are utilized for delineating the cloud-free dust systems. Detection is based on microwave polarized brightness temperature differences ($\Delta T_b = T_{bv} - T_{bh}$) among two channels of 89 GHz and 23.8 GHz and infrared brightness temperature difference (BTD) between channels at 11 and 12 μm. It is shown that the integrated approach is better than the method solely based on infrared BTD in storm detection, especially for those dust systems covered by ice clouds. This approach is applied for the Asia dust storms cases using the data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Advanced Microwave Scanning Radiometer (AMSR-E) onboard Aqua satellite.

Keywords: Multisensors; Infrared measurements; Microwave measurements; Asia dust storm

1. Introduction

Mineral dust plays an important role from a climate study point of view, as do anthropogenic aerosols, especially when we consider the global trend of desertification caused by land development (Sokolik & Toon, 1996; Tegen & Lacis, 1996). The Asia dust storms most frequently originate in the regions of the Taklamakan Desert of China and the Gobi Desert of Mongolia and peak in late winter and early spring. The dust aerosol layers are capable of traveling thousands of kilometers at high altitude and outflow from the continent to the open sea near Korea and Japan under prevailing westerly conditions (Haywood et al., 1999; Higurashi & Nakajima, 2002; Takemura et al., 2002). Dust aerosol has a significant effect on the atmospheric radiation budget because of a large emission amount (Albrecht, 1989; Bréon et al., 2002; DeMott et al., 2003; Huang et al., 2006a,b; Rosenfeld & Nirel, 1996; Rosenfeld et al., 2001; Twomey et al., 1984). Such dust storms can also pose a serious health risk for people with respiratory disorders. Thus it is imperative to be able to monitor dust storms and predict their evolution.

Several techniques have been proposed for detecting mineral dust and volcanic ash using thermal–infrared observations (Ackerman, 1997; Legrand et al., 2001; Prata, 1989; Prata & Grant, 2001). Detection is based on the brightness temperature differences (BTD) either in two or three channels. Ackerman (1997) argued that a combination of three IR channels near the 8, 11, and 12 μm bands is likely to provide a more robust way to identify dust. Using satellite observations of AVHRR and HIRS/2 of dust outbreaks over the Arabian Peninsula and adjacent Arabian Sea in July 1985, Ackerman (1997) demonstrated that analyzing BTD between the 8 and 11 μm channels against BTD between the 11 and 12 μm channels enables to discriminate dust from the clear sky over both oceans and lands. However, the most common dust storms in East Asia are those caused by strong winds behind a cold front and generally coexist with cirrus. Because the visible–infrared radiance is primarily sensitive to the upper cirrus cloud layer, especially when the upper-layer cirri are thick, the BTD approach is nearly useless to detect dust under cirrus areas. The microwave radiation, however, is not significantly scattered or absorbed by ice clouds. Microwave can penetrate the ice cloud, so the change of microwave radiation caused by the dust below the cirrus can be received by the microwave sensors on satellite and finally converted to the change of brightness temperature. Consequently, it is possible to combine

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both visible–infrared and microwave techniques to determine the presence of a dust storm.

Little work has been done on integrated multisensors detection of dust storms. El-Askary et al. (2003, 2006) have analyzed several remote sensing instrument capabilities in monitoring dust storms and developed the multisensor approach for detecting dust storm. They have studied the behavior of dust particles at different wavelengths and found that the technique based on a combination of optical and microwave sensing is particularly useful for detecting dust storm and suggested to use scattering index (SI) which was developed by Ferraro and Grody (1994) for monitoring dust storm at microwave length.

In this paper, we proposed to use microwave polarized brightness temperature differences ($\Delta T_\mathrm{b} = T_\mathrm{bv} - T_\mathrm{bh}$) combining with thermal–IR BTD approach for dust detection. The "polarization temperature difference" (PTD) at microwave frequencies was used by Greenwald et al. (1997, 1999) to estimate cloud liquid water path (LWP). It was also shown that PTD has small magnitudes over land, which is believed to be associated with land polarization, and is much less sensitive to cloud vertical location, surface temperature variability, and systematic instrumental errors. The microwave PTD is suggested to detect cloud over dust system while infrared BTD is used to monitor cloud-free dust system.

2. Data

The data used in this study are from microwave, visible and infrared measurements which are taken by Aqua satellite. Aqua is an Earth observation satellite that monitors from space various kinds of physical phenomena related to water and energy circulation. The AMSR-E is a conical scanning total power passive microwave radiometer sensing (brightness temperatures) at 6 frequencies ranging from 6.9 to 89.0 GHz. Horizontally and vertically polarized radiations are measured separately at each frequency. The AMSR-E antenna temperatures were converted to brightness temperatures T_b with the method of Wentz (1998). The MODIS has 36 spectral bands ranging in wavelength from 0.4 to 14.4 μm and is designed to remotely sense atmospheric temperature, moisture profile, clouds, aerosols, and surface properties. Fig. 1 shows an image from MODIS data for an example of dust storm cases over northwestern China. To compare the infrared and microwave brightness temperature of dust aerosol and cloud, three regions are selected to represent the dust and clouds in different environments. Box 1 (hereafter DUST) in Fig. 1 represents the cloud-free dust region. Box 2 (hereafter, CLD) denotes an area where clouds occurred in a dust-free atmosphere. Box 3 (hereafter, COD) represents overcast clouds in dusty conditions. The CLD and COD regions are selected based on observations from 701 surface meteorological stations in China and Mongolia (Wang et al., 2003). The surface stations report dust in four categories at 3-hour intervals: dust storm, wind-blown sand, floating dust, and no-dust. For a cloud region observed by satellite, if the surface observation is no-dust, this region is defined as CLD, and if the surface observation is dust storm, this region is defined as COD. For the period of 2003 to 2004, we have identified and collected six dust storm cases (see Table 1) over northwest China.

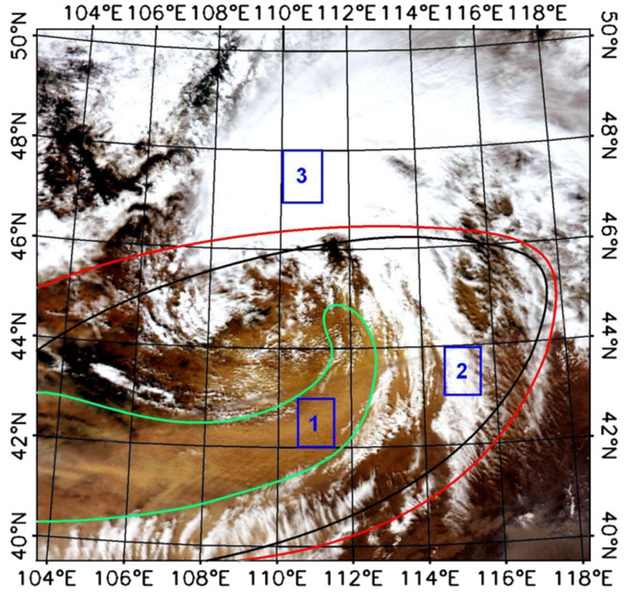

Fig. 1. Example of six dust outbreaks of the true color composite over northwest China, in which channels 0.65 μm, 0.56 μm and 0.47 μm are associated with red, green and blue colors, respectively. Box 1 is the pure dust region (DUST), box 2 the clouds over dust region (COD), and box 3 the cloud in dust-free cloud region (CLD). The regions covered by green, black, red curves are the dust areas that were decided by BTD, surface meteorological stations and multisensors method, respectively.

Table 1
Six dust cases used in this study

Image	Date	GMT	Latitude (°N)	Longitude (°E)	SAT
1	2003/03/26	04:20	38.0–48.0	118.0–132.0	Aqua
2	2003/04/09	06:15	35.0–45.0	72.0–86.0	Aqua
3	2003/04/17	07:00	35.0–45.0	73.0–87.0	Aqua
4	2004/03/09	05:30	40.0–50.0	102.0–116.0	Aqua
5	2004/03/27	05:15	40.0–50.0	104.0–118.0	Aqua
6	2004/05/08	04:15	40.0–50.0	118.0–132.0	Aqua

3. Method and results

Since channels at 11 and 12 μm lie in the thermal–IR window, absorption by other atmospheric gases is negligibly small and dust has a higher emissivity at 12 μm than at 11 μm, the BTD between the 11 and 12 μm channels (BT_{45}) can be used to detect the dust storm. Ackerman (1997) showed that the BT_{45} for dust is negative because dust has a higher albedo at 12 μm than at 11 μm. In this case, the clouds are distinct from the dust in the BT_{45} image (Fig. 2). The average BT_{45} is less than -2.0 K in the pure dust region and larger than 0 K in the cloudy regions. Using a threshold of BTD $= -2$ K would identify 80% of the dust. However, it can only identify 5% of pixels in the cloud over the dust region. It is because the infrared radiance is primarily sensitive to the upper cloud layer. If the threshold of -1.0 K is used for the BT_{45}, 98% of the dust can be identified and 15% of the cloud over dust can be discriminated. But in dusty areas with clouds, the BT_{45} signals tend to cancel each