Observed Dust Storm in the Taklimakan Desert on April 13, 2002

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Abstract

Analysis results of data from lidar and AWS observations performed in the northwestern part of the Taklimakan Desert show a sudden increase in the backscattering ratios in the lower troposphere on 13 April 2002, with strong easterly winds. The Terra satellite reveals that the sudden increase is caused by the outbreak of an extensive dust storm. Numerical simulations, using a regional model, reproduce the strong easterly winds prevailing in a wide area of the desert, originating from north of the Tienshan Mountains. These conclude that the strong easterly winds lift a large amount of sand particles off the ground and results in the dust storm. In addition, a nose-shaped profile of the increased backscattering ratios indicates passage of a gravity current.

1. Introduction

Dust storm outbreaks are annually reported from several areas around the world, for instance, Afghanistan, Iraq, Niger, Sudan, the Gobi Desert, the Sahara Desert, the Taklimakan Desert, and Arizona State, USA. There are some studies for dust storms happening in the Gobi Desert, the Sahara Desert, and Arizona State (e.g., Nickling and Brazel 1984; Pauley et al. 1996). In addition, dust storms on Mars have been also investigated (Toigo et al. 2002; Wang et al. 2003).

The structure and dynamic mechanism of dust storms occurring in the Taklimakan Desert have not been investigated yet, although the climatological aspects were already researched by previous studies (Sun et al. 2001; Qian et al. 2002). The present study is the first investigation into that structure and mechanism, by analyses of lidar observation data and detailed surface wind distributions using a regional numerical model. This study is expected to contribute to the forecast of dust storm outbreaks in the Taklimakan Desert. A large amount of sand particles lofted by dust storms in the Taklimakan Desert can be transported far to the east by westerlies (e.g., Kai et al. 1988), bringing about visibility obstruction and health hazard to East Asia.

2. Lidar observations in April 2002

The Lidar observations were performed in the northwestern part of the Taklimakan Desert, Aksu (40.62°N, 80.83°E, 1028 m above sea level (ASL); see Fig. 1), in April 2002. The observations were conducted by a research group of Prof. Kenji Kai of Nagoya University, Japan, as part of a project called the Aeolian Dust Experiment on Climate Impact. The lidar system can measure backscattering and depolarization of aerosol particles from near the ground up to the lower stratosphere. Specifications of the lidar system are listed in the paper of Kai et al. (2002). Figure 2 shows the lidar observation result, which is presented as a time-height cross section of backscattering ratios calculated by lidar equations following Sakai et al. (2003), and surface winds observed by an automatic weather station (AWS) beside the lidar, from 2200 UT 12 April to 0800 UT 13 April 2002. The backscattering ratios were not calculated well after 0800 UT 13 April because photomultiplier tubes installed in the lidar system were saturated with strong backscattering light. In this figure, the backscattering ratios reveal that many aerosol particles regularly exist at altitudes below 2 km ASL through the period. Just before 0600 UT 13 April, the ratios suddenly increase to higher than 15. The wind velocities also increase to faster than 6 m/sec at that time with
their easterly directions. The top of the high backscattering ratios is gradually growing from 1.5 km ASL up to nearly 2.5 km ASL during 0600–0800 UT. Interestingly, a profile of the high ratios is in the shape of a nose, as discussed later.

3. Simulated surface wind distributions

Figure 3 shows surface wind distributions around the Taklimakan Desert at 0000 UT and 0600 UT on 13 April 2002. These wind vectors were reproduced by the Regional Atmospheric Modeling System (RAMS; Pielke et al. 1992). This study used a modified RAMS produced by the Terrestrial Environment Research Center of University of Tsukuba, Japan (TERC-RAMS; Sato and Kimura 2003). This model is based on compressive non-hydrostatic equations and a terrain-following coordinate. In this study, intervals of a coarse grid system (150x75) and a fine grid system (101x101) are set at 60 km and 20 km, respectively. The fine grid system is nested into the coarse grid system using a two-way interface condition. These horizontal calculation domains are presented in Fig. 1. The number of vertical layers is 40, and the lowest level (surface level) is $Z^* = 53$ m. The initial time is 0000 UT 11 April 2002. The 6-hourly NCEP/NCAR reanalysis data (Kalnay et al. 1996) are used for the initial and boundary conditions of this calculation.

The wind velocities are under 5 m/sec over most of the desert at 0000 UT (Fig. 3a). However, strong easterly winds faster than 10 m/sec appear in a wide area of the desert between $Y = 800$ and 1200 km 6 hours later (0600 UT; Fig. 3b), and the front reaches the northwestern part of the desert including the lidar observation site, as identified also in the observed winds (Fig. 2). The strong winds originate from north of the Tien Shan Mountains, and then blow across the mountains or along the eastern rim of the mountains toward the desert.

4. Discussions

An image by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra satellite, which is taken at 0525 UT 14 April 2002 (Fig. 4a), shows that almost all parts of the Taklimakan Desert have very dusty conditions, therefore it is hard to recognize the surface ground, except for the southwestern rim of the desert where the surface is clearly seen (see a sketch of the satellite image; Fig. 4b). This image demonstrates that the high backscattering ratios observed on the previous day, 13 April (Fig. 2), are caused by a dust storm. A sudden decrease of visibility (less than 1 km), after 0600 UT 13 April at the observation site, also indicates that a dust storm made an attack on the site.

Some previous studies mention that the front of dust storms corresponds to the head of gravity current (e.g., Idso et al. 1972; Mitsuta et al. 1995). The observation results (Fig. 2) also suggest passage of a gravity current, which is recognized as the nose-shaped profile of high backscattering ratios and the appearance of strong surface winds after 0600 UT 13 April. Figure 3b reveals the current to be part of the strong easterly winds prevailing in the wide area of the desert. Sun et al. (2001), from their investigation into moving directions of sand
dunes, states that dust storms in the Taklimakan Desert tend to break out by strong easterly winds. This indicates that the extensive dust storm, shown in Fig. 4, occurs under the typical pattern of air flows for outbreaks of dust storm in the desert.

However, not only the easterly air flow but also any other local wind systems may contribute to the dust storm outbreaks. More field observations and numerical simulations including diffusion experiments on sand particles should be helpful in the clarification of the relationship between dust storms and local winds in the Taklimakan Desert.

5. Conclusion

Just before 0600 UT 13 April 2002, lidar and AWS measurements in the northwestern part of the Taklimakan Desert observed a sudden increase in the backscattering ratios ($\geq 15$) and strong easterly winds ($\geq 6$ m/sec) simultaneously. A nose-shaped profile of the high backscattering ratios indicates passage of a gravity current. Numerical simulations performed using TERC-RAMS reveal that strong easterly winds originating from north of the Tienshan Mountains prevail in a wide area of the desert, at that time. The front of the easterly winds reaches the northwestern part of the desert, resulting in the observed easterly winds. A satellite image taken by MODIS/Terra on the following day, 14 April, shows very dusty conditions in almost all parts of the desert, namely an outbreak of an extensive dust storm in the desert. This image demonstrates that the increased backscattering ratios are caused by a dust storm attack. From the simulation result, the strong easterly winds appear to induce the dust storm, lifting a large amount of sand particles off the surface ground. This is a typical air flow pattern for outbreaks of dust storm in the desert, as described in the previous climatological investigation.

The present study first succeeded in illustrating the front structure of a dust storm of the Taklimakan Desert from the observation data, and found that the dust storm had occurred under the typical pattern, by the numerical simulations.

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References

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Fig. 4. Satellite image of the Taklimakan Desert at 0525 UT 14 April 2002 by MODIS/Terra: (a) large image, (b) sketch of the large image. Dusty conditions prevail over the desert. The gray and thick solid lines in (b) indicate the dusty area and borders of the desert, respectively. This image was obtained from a web page, ‘MODIS Rapid Response System’ (http://rapidfire.sci.gsfc.nasa.gov/).