VERTICAL STRUCTURE OF THE DUST LAYER AND HIGH- AND MIDDLE- LEVEL CLOUDS OVER THE TAKLAMAKAN DESERT, CHINA BY LIDAR

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1. Introduction

In spring, dust storms raise up a large amount of mineral dust in the atmosphere, which is known as the Asian dust or Kosa in East Asia. The Taklimakan desert and Gobi desert are considered as important sources of the Asian Dust (Kurosaki and Mikami, 2003). The Asian dust, if lifted up to the free troposphere, can be transported long distances and affect the global scale (Duce *et al*., 1982; Iwasaka *et al*., 1983; Kai *et al.,* 1988). Satellite imagery does not provide information on the aerosol's height distribution. One of the most important parameters which are crucial to the understanding of aerosol transport is the vertical structure of the Asian dust over the source regions.

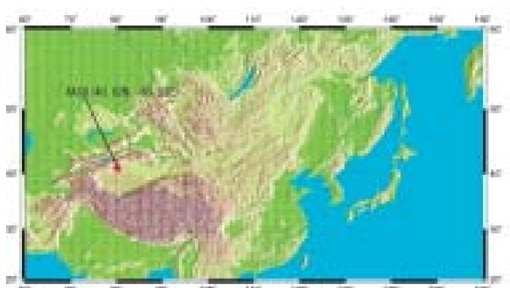


Figure 1: Observation site. Aksu, Xinjiang, China.

The Japan-China Joint Studies on Origin and Transport of Aeolian Dust and its Impact on Climate (ADEC) has started since 2000 (Mikami *et al*., 2002). The purpose of ADEC is to figure out the mechanism of mineral dust outbreaks from arid regions into the atmosphere and to evaluate its annual variability. As a part of ADEC, a newly developed lidar has been operated since 2001 at the Aksu oasis (40 37'N, 80 50'E, 1028 m above the sea level) in the northern fringe of the Taklimakan Desert, Xinjiang, China (Fig.1). The lidar is a Nd:YAG depolarization lidar designed to measure the vertical profiles of backscatter and the depolarization of the aerosol particles from near the ground and up to the stratospheric aerosol layer. The present paper shows the vertical structure of the dust layer and high- and middle-level clouds over the Taklamakan Desert, using the lidar observations at Aksu during the spring of 2002 - 2004.

2. Lidar system

Photographs, illustrations, and a block diagram of the lidar system are shown in Figures 2. The preliminary test observations using the lidar in Japan have been presented in Kai *et al*. (1997). The lidar system is a single wavelength Nd:YAG laser-based system designed to measure the vertical profiles of backscatter and the depolarization of aerosol particles from the layer near the ground up to the stratospheric aerosol layer.

A pulsed Nd:YAG laser was employed as the transmitter. The green line in the illustration is the laser beam transmitted from the Nd:YAG laser. The pulse energy of the laser was 300 mJ at 532 nm, and the pulse frequency was 10 Hz. To expand the receiving range and signal strength, two telescopes were used: one with a diameter of 200 mm to measure the lower atmosphere, and another with a diameter of 355 mm used to measure the upper atmosphere. The smaller telescope and transmitting laser light were aligned coaxially, in order to measure the aerosol layer in the lowest altitude range. The larger telescope was set parallel to the smaller telescope. In the

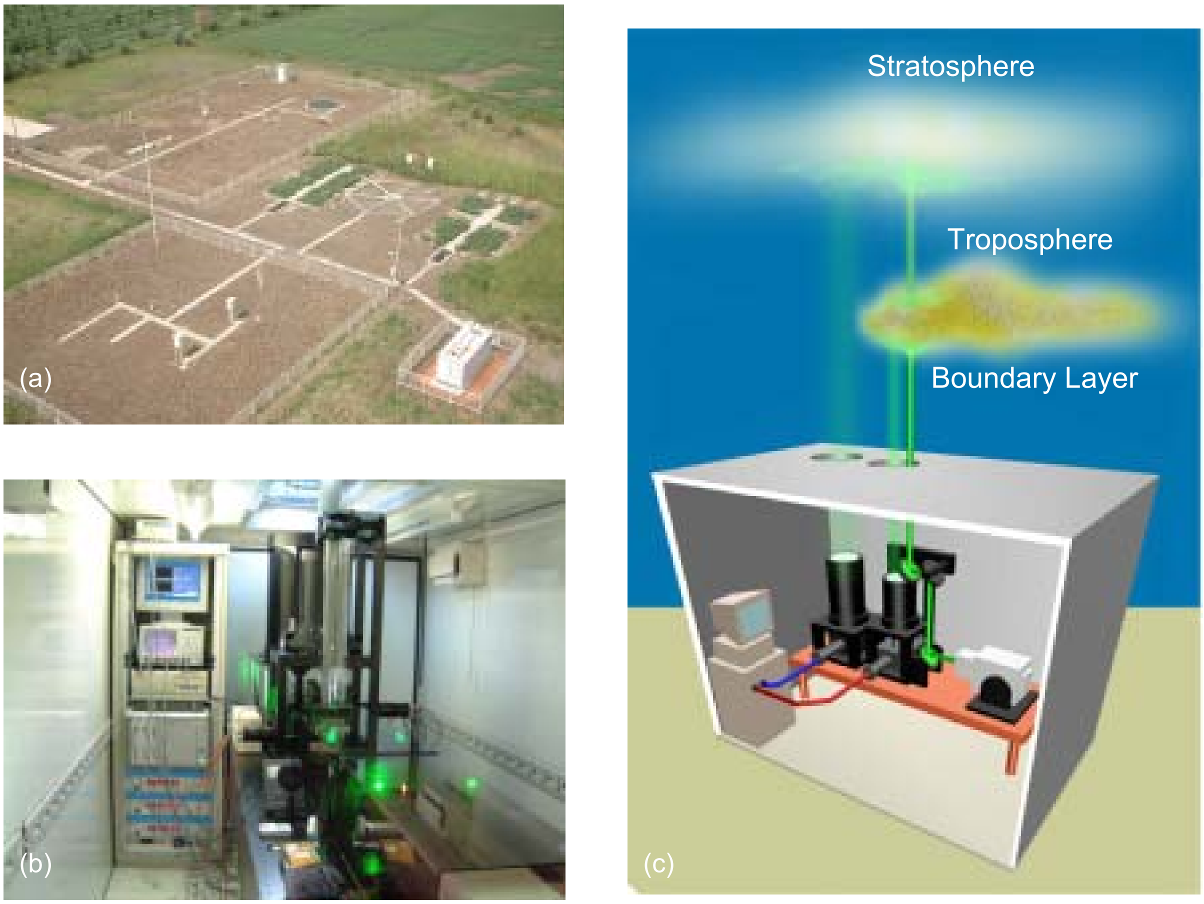


Figure 2: Photographs Illustration and of the lidar system. (a) Aksu Water Balance Experimental Station, Xinjian Institute of Ecology and Geography, CAS. (b) Inside of the lidar container. (c) Illustration of the lidar system.

small telescope, two photomultiplier tubes were used as detectors to receive the parallel (P) and perpendicular (S) components needed to measure the depolarization ratio, S/P. The light received by the larger telescope was separated into parallel and perpendicular components. An electrical gate circuit was added to the higher altitude channel P to remove noise from strong ground signals. A 12-bit A/D converter and a photon counting system were also used in the upper receiver to expand the dynamic range of the signals. The lidar system can measure a range of altitudes from close to the surface all the way up to the stratosphere (30 km and above).

All the instruments, including the optical components, data processing instruments, and electronics, were housed in an environmental shelter. Two optical windows were set in the ceiling of the shelter to protect the field of view of the two telescopes. Each optical window had 2 coated optical glass plates to prevent the formation of dew or frost.

The definitions of the backscattering ratio (R) and the depolarization ratio (δ) in the present study are the same as those used by Sakai et al. (2003). The values of R and δ are given by

$$\delta = \frac{P_\perp}{P_\perp + P_\parallel}\ , \qquad (2)$$

$$R = \frac{\beta_m + \beta_a}{\beta_m} \qquad (1)$$

where β_m and β_a are the molecular backscattering coefficient and the aerosol backscattering coefficient, and $P_\perp$ and $P_\parallel$ represent the perpendicular and parallel components of the intensity of backscattering light. β_m is calculated from molecular number density listed in the U.S. Standard Atmosphere (U.S. Standard Atmosphere, 1976). β_a is calculated by an equation of $\beta_a = \beta_m(R - 1)$ on the assumption that R equals 1 in the lower stratosphere. The aerosol extinction-to-backscatter ratio is assumed to be 50 in the present study.

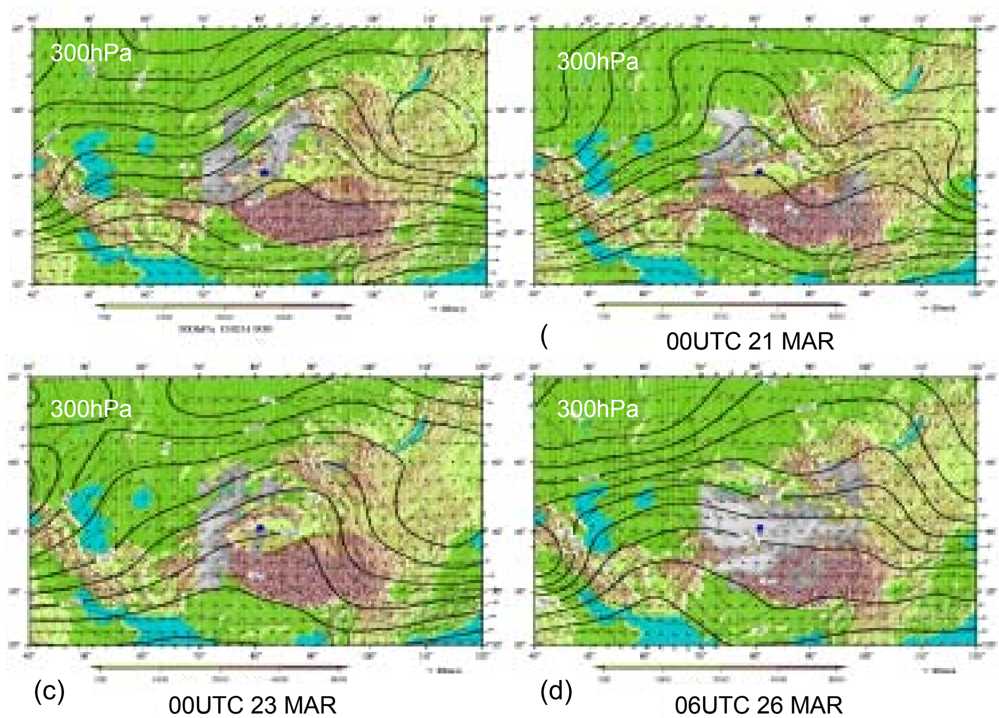


Figure 3: Geopotential height, wind and clouds for the 300 hPa winds from 0000 UTC on13 March 2003 to 0600 UTC on 26 March 2003. A blue dot shows the location of Aksu. Cloud cover, obtained using GMS, is shown for the region between 70°E to 100°E and 30°N and 50°N.

3. Results

The second intensive period of observation (IOP-2) in ADEC was conducted from 15 – 26 March 2003. During this period, surface winds were weak, and the soil moisture was higher than average. The dust storm activity was weak during IOP-2.

Figures 3(a) - (d) show the geopotential height, wind, and clouds for 300 hPa. In the figure, a blue point shows the location of Aksu. The cloud cover, obtained using GMS, is shown for the region 70°E to 100°E and 30°N to 50°N. A trough passed over Aksu during 18 – 19 March. Clouds from the Pamir Plateau developed over the Tarim Basin. The height of these clouds varied from 8 to 12 km. A ridge prevailed from 20 – 22

March which led to clearing over the Tarim Basin. Another trough passed over Aksu during 25 – 26 March 2003.

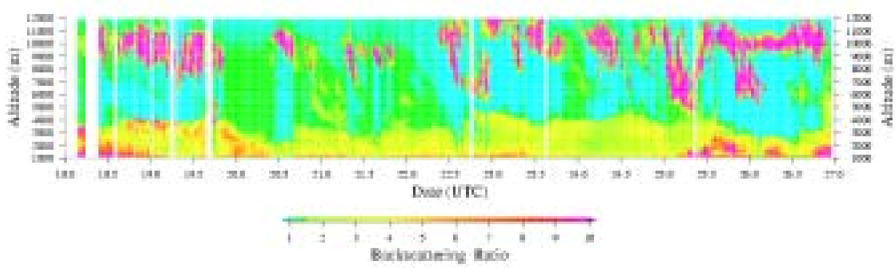
Figures 4(a) and (b) show the time-altitude cross sections of the backscattering ratio R(z) and the depolarization ratioδ(z) during IOP-2. The steady dust layer that developed during IOP-2 is shown in profile from ground level to a height of 2.5-4 km in Figures 4(a) and (b). The mineral dust layer had high values of δ(z) because this layer is largely composed of particles which are largely non-spherical. The δ(z) values accurately indicate the type of dust layer present. The lowest hundred meters of the dust layer had depolarization ratios of more than 20%. This means that a large amount of mineral dust was generated from the ground. The dust layer was optically thick during the passage of troughs (18 – 19 March and 23 – 26 March) and thin during the passage of a ridge (20 – 22 March).

A small dust storm occurred on March 25 UTC and on March 25.3 UTC after clouds descended from about 10 km to the surface. The large number of particles present absorbed the laser beam during the dust storm event from March 25.3 UTC to March 25.5 UTC, therefore there is an absence of a backscattering ratio in Figure 8(a). The backscattering ratio could not be obtained for several hours, but the profile of the depolarization ratio clearly shows the vertical structure of the dust layer during the dust storm. This is because the depolarization ratio is simply the ratio between the parallel and perpendicular components with respect to the polarization plane of the emitted laser.

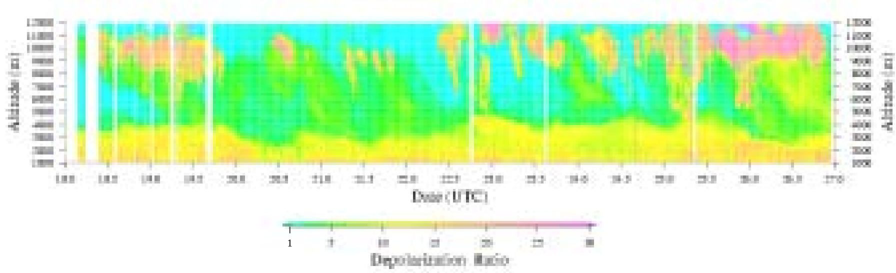
The height of the dust layer showed a meso-scale variation due to circulation in the Tarim Basin, as well as a synoptic variation due to the passage of troughs and ridges. The top of the dust layer abruptly increased on March 22.7 UTC. The meteorological analysis showed this increase was due to local circulation in the Tarim Basin (Tsunematsu and Kai, 2004).

The top of the dust layer at 3 - 4 km is capped by an inversion layer, which suppressed the vertical exchange of dust. Above the dust layer, the free troposphere had low values of backscattering and depolarization ratios.

Due to the Tianshan Mountains to the north, the Pamir Plateau to the west, and the Kunrun Mountains to the south, the upper clouds in the Tarim Basin appear at an altitude of about 10 km. Some clouds had high depolarization ratios, which indicate the presence of cirrus clouds with ice nuclei.



(a) Backscattering Ratio (R)



(b) Depolarization Ratio (δ%)

Fig. 2

Figure 4: Backscattering ratio (a) and depolarization ratio (b) over Aksu from 18 - 26 March 2003.

4. Characteristics of the dust layer over the Taklamakan Desert

In Figure 5, 4 histograms show the number of particles with a given depolarization ratio for the following altitudes: from 0 km to 0.2 km; from 0 km to 5 km; from 5 km to 10 km; and from 10 km to 15 km. At the surface, the dust had a modal depolarization ratio of 19 %, with values ranging from 10% to 25%. A higher depolarization ratio indicated the presence of dust originating from desert soil. The dust layer had two peaks: one at the depolarization ratio of 5% – 6 % and another at the depolarization ratio of 17% – 18 %. In the free troposphere between 5 km and 10 km, most of the depolarization ratios were less than 10 %. However, there was a broad tail that extended from 10% to 35%. The free troposphere between 10 km and 15 km had features similar to the free troposphere between 5 km and 10 km. Of interest, there are double peaks in the histogram that shows the dust layer between 5 km and 10 km. This result suggests that the mixing of dust of different origins occurs primarily in the dust layer. We assumed that the higher depolarization ratio peak 18-20% corresponds to soil dust, while the smaller depolarization ratio peak 5-8 % corresponds to aerosols in the free troposphere.

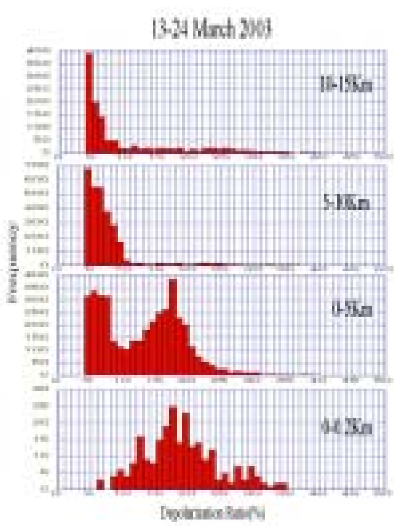


Figure 5: Histograms showing the change in the depolarization ratio for different altitudes from 13 - 24 March 2003.

Figure 6 summarizes the dust layer as revealed by the depolarization results obtained using the lidar. On the vertical axis is the altitude, while on the horizontal axis is the depolarization ratio, or the degree to which the particles are not spherical. The surface of the Taklamakan Desert is the primary source of the soil dust in the atmospheric boundary layer. The soil dust constitutes most of the dust layer from the ground to a height of between 2 km and 4 km. At the top of the dust layer, there is a clearly defined boundary. As well, the free atmosphere from 5 km to 10 km is relatively clear. The aerosols in the free atmosphere with low values of depolarization fall into the atmospheric boundary layer, thereby causing the observed double depolarization peaks in Figure 5. Finally, there was a zone with a high depolarization ratio at an altitude of 10 km to 15 km, which corresponds to cirrus clouds passing over the Pamir Plateau and the Tianshan Mountains.

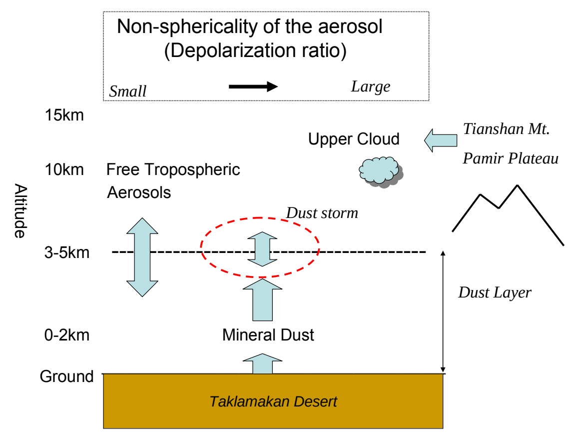


Figure 6: An empirical model of the dust layer over the Taklamakan Desert.

5. Conclusion

As part of the Japan-China Joint Studies on Aeolian Dust and its Impact on Climate (ADEC), we developed a new lidar that was used in studying the vertical structure of the dust layer over the Taklamakan Desert. Since 2001, the lidar has successfully operated at the Aksu Water-Balance Station of the Xinjiang Institute of Ecology and Geography. Our lidar can measure the vertical structure of the Asian dust over the source regions. Finally, we presented an empirical model of the dust layer over the Taklamakan Desert (Fig.6).

6. Acknowledgement

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