Processes of Background KOSA outbreak: Lidar and Balloon-borne Measurements

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Abstract

Lidar measurements were made at Dunhuang (40°00'N, 94°30'E), China, to understand the vertical distribution of aerosols in the free troposphere over the Taklamakan desert, in summer of 2002. The vertical distributions of scattering ratio suggested that particulate matter distributed from near the ground to about 6km in the range of values of about 2-about 5, and rapidly decreased to about 1 at about 6 km.

Depolarization ratio shows that dust particles distribute in the aerosol layer, and the dust particle layer distribute to about 6km. Very clear boundary was also identified at 6km in the distribution of depolarization ratio.

Particulate materials were directly collected with balloon borne particle impactor in the free troposphere over the Taklamakan desert, and electron microscopic experiment of the particles suggested that large depolarization ratio was certainly due to irregular shape dust particles.

Vertical profiles of scattering ratio and depolarization ratio suggested that non-spherical shape dust particles floated from near surface to about 6km and showed good corresponding to the wind system suggested by Sun et al. (2001) and Sun (2002) who reported that typical surface wind is east and/or north wind in the Tarimu Basin and west wind dominated above about 5km. The trajectory of the balloon also showed that west wind appeared about 4km and the wind speed largely increased above about 5km, and possible long-range transport of dust particles entrained at an elevation > 5km is suggested.

Keywords: KOSA particle, lidar measurements, large depolarization ratio in the free troposphere, sharp upper boundary of aerosol layer

1. Introduction

Many lidar measurements frequently detected the highly concentrated particle layer with large depolarization ratio, especially in spring, in the free troposphere over Japan, and suggested effect of long-range transport of Asian dust particles (KOSA particles, KOSA literally means yellow sand in Japanese) which originated in desert areas of the Asian continent, such the Taklamakan desert and Gobi desert (Iwasaka et al., 1988; Kwon et al., 1997; Sakai et al., 2000; Murayama et al., 2001). KOSA particles become a great concern from view point of radiative effect of KOSA particles and KOSA particle contribution to geochemical cycle of atmospheric constituents in the east Asia and west Pacific regions (Arimoto et al., 1990; Tegan et al., 1997; Denterner et al., 1996; Sokolik et al., 2001; Uno et al., 2001; Carmichael et al., 2002; Sassen, 2002).

Some lidar measurements suggested that there were weak KOSA events (or background KOSA events) in the free troposphere which were hardly able to detect near the ground but made important contribute of long-range transport of dust particles (Iwasaka et al., 1988; Kwon et al., 1997; Sakai et al., 2000), and aircraft observation also showed important contribution of the weak KOSA to biogeochemical cycle of atmospheric constituents (Mori et al., 1998).

Recently aircraft-borne measurements (Matsuki et al., 2002; Troshkine et al., 2002) confirmed existence of weak Kosa events in the free troposphere over Japan, and interestingly they suggested importance of KOSA particle transport by west wind in the mid and upper troposphere even in summer. It has been believed that few KOSA particles diffuse from the Asian Continent to the Pacific ocean in summer since Pacific high pressure largely grows and extends over Japan and coast region of China continent. According to the aircraft measurements the lower troposphere is largely affected by the Pacific high but the mid-upper troposphere is not disturbed and usually west wind is frequently observed over Japan (Matsuki et al., 2002; Troshkine et al., 2002).

Therefore, it is of interest to know KOSA particle distribution in the summer troposphere over the desert area of Asian continent in order to obtain better understanding of long-range transport of KOSA particles. However, there were few observations of atmospheric aerosols in summer over the desert areas. Here we present results of the lidar measurements of atmospheric aerosols made in summer of 2002 at Dunhuang (40°00'N, 94°30'E), China which is in east side of the Taklamakan desert, and discuss feature of vertical profiles of lidar returns comparing with the aerosol number concentration-size and the aerosol chemical feature deduced from the balloon-borne measurements made simultaneously at Dunhuang, China.

2. Lidar Measurements of Aerosol

Aerosol backscattering ratio and depolarization ratio were measured with ground-based lidar at Dunhuang, China (Fig. 1).

The specifications of the lidar used here are summarized in Table 1.

The value of scattering ratio is defined by

$$\text{Aerosol scattering ratio} = [BSC_1 + BSC_2]/ BSC_1$$

$$= 1 + BSC_2/BSC_1$$

where BSC_1 and BSC_2 mean backscattering coefficient of air molecules and backscattering coefficient of aerosols measured at laser wavelength = 530nm, respectively (e.g., Kwan et al., 1997). The values of [aerosol backscattering ratio – 1], from above mentioned relations, can be recognized as the parameter showing mixing ratio of particulate matter in the atmosphere.

The depolarization ratio is defined by

$$\text{Aerosol depolarization ratio (\%)} = P_1/[P_1 + P_2]\text{x}100$$

where P_1 and P_2 are intensity of backscattering light measured at polarization plane perpendicular with polarization plane of emitting laser light and at that parallel, respectively(e.g., Kwon et al., 1997).

Measurements were made under the relatively calm weather conditions. The matching point was chosen above about 25km to deduce scattering ratio. Figure 2 shows distribution of the scattering ratio and depolarization ratio measured on 25, 26, 27, 28, and 29 August, 2002 at Dunhuang, China. The layer having large depolarization ratio distributes from near the ground to about 6 km (above sea level) corresponding well to the regions of large scattering ratio.

3. Discussion and Summary

3-1 Distribution of Aerosols in the Free Troposphere

The vertical distributions of scattering ratio shown in Fig. 2 suggested that particulate matter distributed from near the ground to about 6km in the range of about 2 – about 5, and rapidly decreased to about 1 at about 6 km. Considering that the weather condition during lidar measurements was relatively calm, it can be considered the scattering values in Fig. 2 typical ones showing background conditions (without disturbance of severe dust storm).

The particle number concentration measured with an optical particle counter, which was made corresponding to the lidar measurements, is shown in Fig. 3. The vertical profile of concentration of particles also showed large decrease at about 6 km, and shows good agreement in vertical profile of aerosol concentration.

3-2 Large Depolarization Ratio in the Free Troposphere

Depolarization ratio measured by lidar is useful parameter to discuss nonspherisity of particles, and was frequently used to detect KOSA particles since most of KOSA particles have irregular and nonspherical shape (Iwasaka et al., 1988; Kwon et al., 1997; Sakai et al., 2000; Murayama et al., 2001; Sakai et al., 2002). Therefore it is reasonable, from Fig. 3, to assume that dust particles distribute in the aerosol layer, and the dust particle layer distribute to about 6km. Very clear boundary was also identified at 6km in the distribution of depolarization ratio.

The lidar returns obtained in Japan frequently showed layered structure with 1-2km layer thickness in both profiles of scattering ratio and depolarization ratio. However the profiles at Dunhuang have relatively uniform values from near the ground to the upper boundary of the aerosol layer. This uniformity possibly suggests existence of dust particles from near the ground to about 6km heights, and is certainly corresponding to feature of vertical changes in aerosol number-size distributions deduced from the optical particle counter (Fig. 4). The functions of number size distributions shown in Fig. 4 mostly have noticeable mode peak at about 1 μm diameter. One of possible interpretation of the mode peak of 1 μm is that dust particles (usually their size in coarse size range) uniformly diffuse in the aerosol layer, and show reasonable correspondence to large depolarization ratio of the aerosol layer. .

Atmospheric particle collection was made, to understand aerosol shape and chemical elements, in the troposphere with balloon-borne particle impactor in August 29, 2002 at Dunhuang. Electron microscopic experiments of the particles showed that most of coarse mode particles (diameter larger than 1 μm) were composed of dust particles in heights of 3-5km (Fig. 5). This is direct evidence suggesting existence of dust particles in the free troposphere and shows good agreement with lidar measurements indicating large depolarization ratio.

Depolarization ratio measured here is compared with the values obtained at downwind regions, Japan (Table 2). It is very interesting that depolarization ratios of KOSA observed here and in Japan are mostly in the same values, especially for the case of weak Kosa events.

3-3 Aerosol Layer Top Found at about 6km

Sun (2002) and Sun et al. (2001), on the basis of analysis of 1960-1999 meteorological data and case study of 1986, described wind systems over the Tarimu Basin (Taklamakan desert). Area of the north, west, and south of the Taklamakan desert are surrounding by high mountains (average elevation is higher than 5000m) and an open area exists only in the east margin. According to their analysis, the near-surface wind in the Tarimu Basin is easterly or northeasterly, and it is suggested that dust particle cannot move out of this desert at an elevation $\leq$ 5000m (under the easterly wind region). Dust particles, if so, frequently float in height of near the surface ~ about 5km over the Taklamakan desert. Additionally they suggest that dust particles entrained to an elevation $\geq$ 5000m are transported long range by the westerly jet (some times over the Pacific ocean).

Lidar returns always showed very clear top of aerosol layer where scattering ratio and depolarization ratio sharply decreases at about 6 km during lidar measurements. This is very interesting feature considering the wind systems analyzed by Sun (2002) and Sun et al. (2001) and it is possible to recognize the present lidar return as typical examples of atmospheric particulate distribution controlled by wind system of Taklamakan desert; dust floating at an elevation $\leq$ about 5 km and dust transport by westerly jet at an elevation $\geq$5 km.

Wind speed and direction are summarized on the basis of analysis of balloon trajectory (launch 27 August, 2002) in Fig. 6. The wind speed was very low near the surface and gradually increased as increase in balloon elevation. Wind speed rapidly increased at about 4km and showed broad maximum (140 m/sec) in 10-13km. The wind direction was mainly easterly in 2-3km and drastically changed to westerly at about 4km. The balloon trajectory clearly confirmed the analytical results given by Sun (2002) and Sun et al. (2001).

Figure 7 shows distributions of height of isobaric surfaces of 700 hPa and 500 hPa on 27 August, 2002. It is suggested, from distribution of the height of isobaric surface, that westerly dominated over east China, Japan, and the west Pacific. Backward trajectory analysis of air masses at heights of 7km, 5km and 4km at Dunhuang also strongly suggested that the air masses are affected by strong westerly wind above 6km but not below 6km (HYSPLIT model provided by NOAA was used).

Therefore it is possible to consider that particulate matter diffused to downwind by the westerly above about 5km even in summer when low pressure activities usually low and few severe dust storms are observed. Figure 7 is the conceptual scheme showing that westerly jet transports dust particles enriched at an elevation higher than about 5km.

According to Matsuki et al. (2002 and this issue) and Trochkine et al. (2002) contribution of long-range transport of dust particle was not negligible even in summer, especially in the mid-upper troposphere over Japan, and major component was dust particles in the coarse particles with diameter > 1μm at heights > 4km. Effect of Pacific high pressure is large in summer over Japan and major component of particles is sea salt in coarse mode particles in the lower troposphere, however, as described above, contribution of long-range transport of dust by westerly is strongly suggested in the mid-upper troposphere.

3-4 Summary

From the lidar measurements at Dunhuang, China followings are suggested;

1. Layer of large depolarization ratio was frequently detected from near the ground to about 6km and it is suggested that lots of nonspherical particles (possibly dust particle) existed in the layer.
2. Vertical distribution of the layer having high scattering ratio shows good correspondence to the vertical distribution of particle depolarization ratio.
3. Vertical distribution of aerosol number density and size measured by balloon borne optical particle counter shows good agreement with vertical distributions of scattering ratio and depolarization ratio.
4. Existence of nonspherical coarse particles with diameter > 1μm suggested by electron microscopic experiments of directly collected particles also strongly confirmed large depolarization ratio of lidar returns in the free troposphere.
5. Wind system deduced from the balloon trajectory showed that there was clear boundary at about 5km; weak easterly at an elevation < about 5km and clear westerly at an

elevation > 5km, and good agreement was found comparing with the analysis of Sun (2002) and Sun et al. (2001)

6. It is suggested that particle distributions were strongly affected by wind system over the Taklamakan desert; dust floating at an elevation ≤ about 5km and dust transport by westerly jet at an elevation ≥5km.

Summarizing those it is reasonable to suggest that the atmosphere contains dust (KOSA) particles in not only the boundary layer but also the free troposphere in summer season over the Taklamakan desert, and westerly wind can transport long-range those dust (KOSA) particles which diffuse up from the region < about 5km in the free troposphere not only in spring but also summer. Many investigators suggested that there is strong seasonality in wind system transporting mineral particles and in source strength of soil particles from the boundary to the atmosphere (Merrill et al., 1989; Gao et al., 1992; Chung and Yoon, 1996). Measurements of free tropospheric aerosols over Japan suggested important contributions of particles traveling in the mid and upper troposphere in summer season (Matsuki et al., 2002; Trochkine et al., 2002).

The summary presented here is based on only the measurements made August, 2002 at Dunhuang and does not cover long enough time to conclude definitely vertical structure of dust particle distributions over the desert areas in the Asian continent. Long term monitoring at desert areas is necessary in future.

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Table 1 Main characteristics of Lidar system at Dunhuang

Transmitter	
Laser	Nd:YAG
Wavelength(nm)	1064,532
Energy/Pulse(mJ)	100,150
Pulse repetition rate	20Hz
Laser beam divergence	0.1mrad(after collimation)
Receiver	
Telescope type	Cassegrain
Diameter of Telescope(cm)	35
Detector	PMT
	HAMAMATSU R928 (for 532nm)
	HAMAMATSU R3236-01(for 1064nm)
Range resolution(m)	**30**

Table2 Comparison of Depolarization ratio with other measurement results

Depolarization ratio	Place(Latitude,Longtitude)	Reference
16%(Layer peak) 20 April,1998	Nagoya(35.15° N,136.97° E)	Murayama et al. (2001) (Total)
20%(Layer peak) 23 April,2001	Nagoya(35.15° N,136.97° E)	Sakai et al. (2002) (Aerosol particle)
10%(Layer peak) 20 April,1998	Tokyo(35.66° N,139.80° E)	Murayama et al. (2001) (Total)
25%(Layer peak) 23 April,2001	Tsukuba(36.05° N,140.12° E)	Sakai et al. (2002) (Aerosol particle)

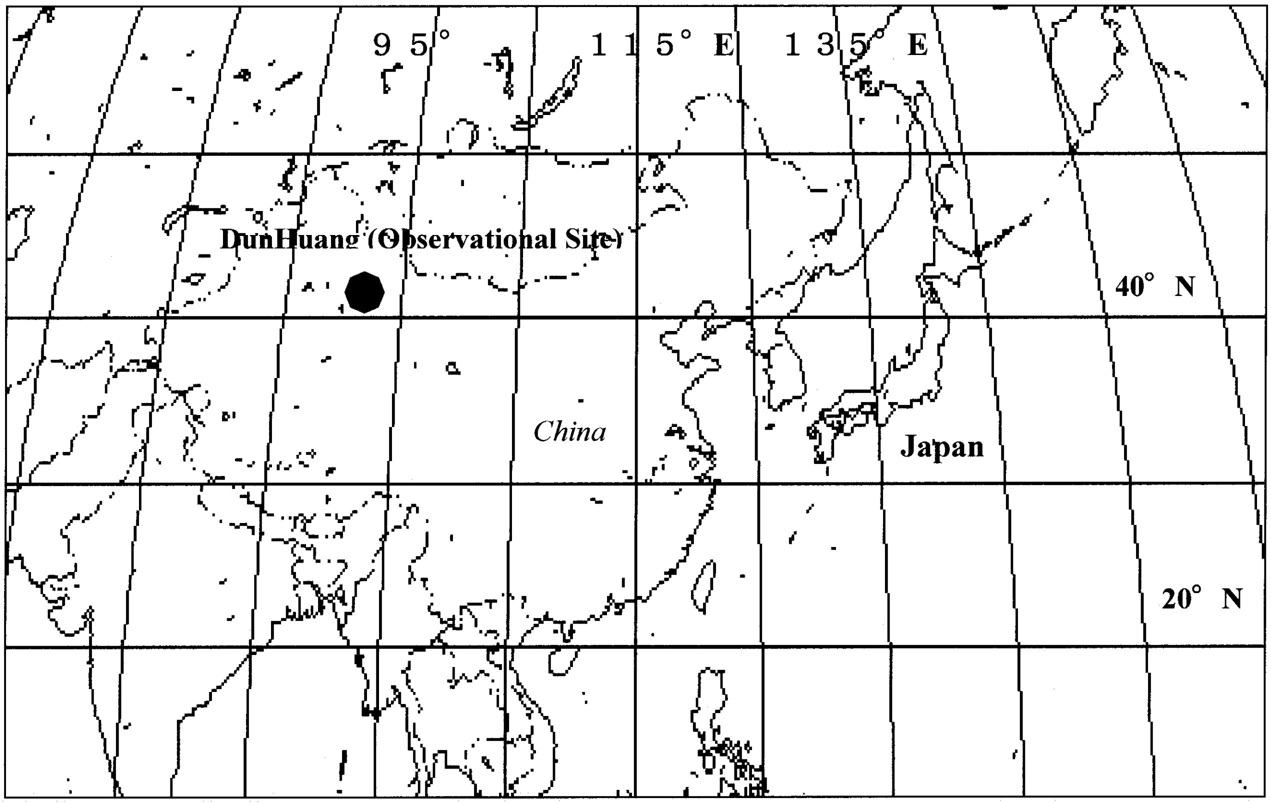

Fig.1 Lidar observation sites of Dunhuang, China (40 °00'N, 94 °30'E).

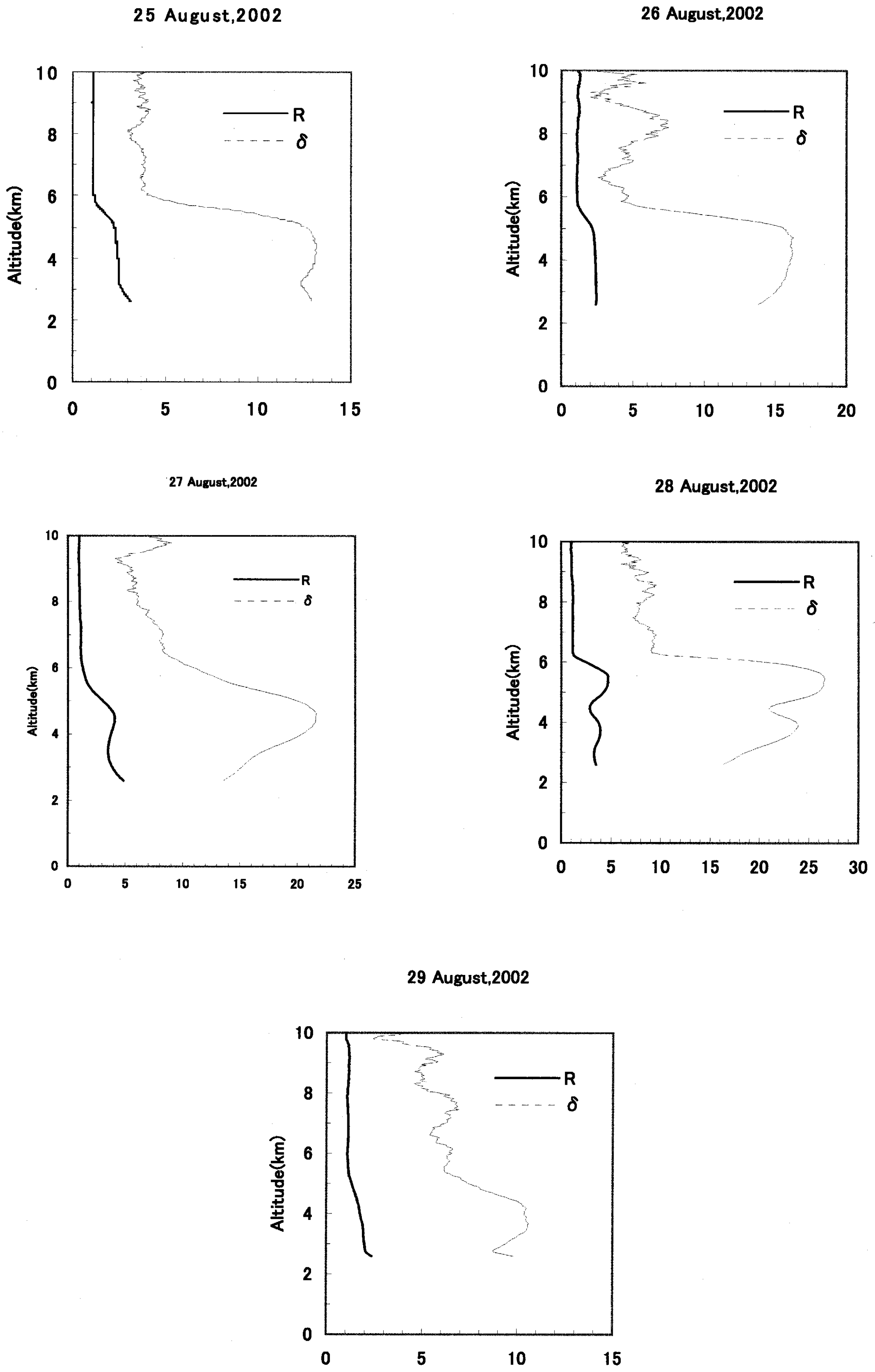

Fig.2. Vertical profiles of Backscattering ratio(R) and Depolarization ratio(δ) measured at Dunhuang, China. Clear jump was frequently detected near 5 km altitudes in profiles.

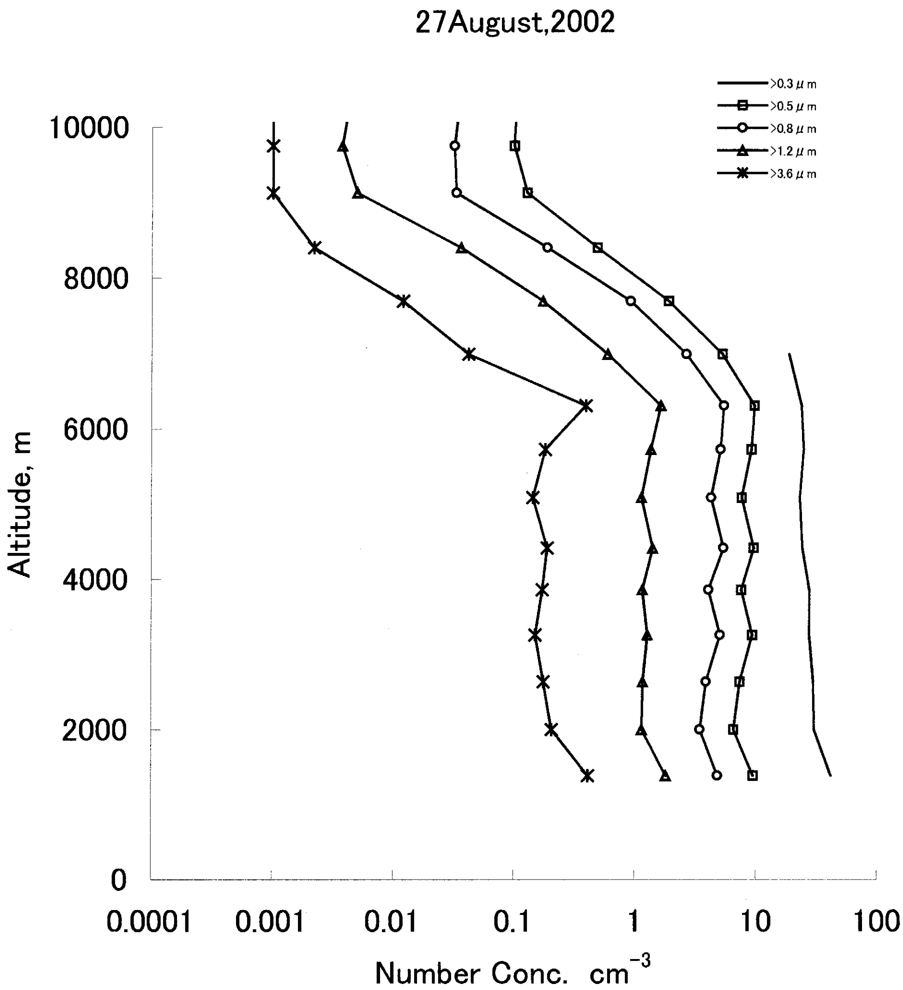

Fig.3 The particle number concentration measured with an optical particle counter made in 27 August, 2002 at Dunhuang, China.

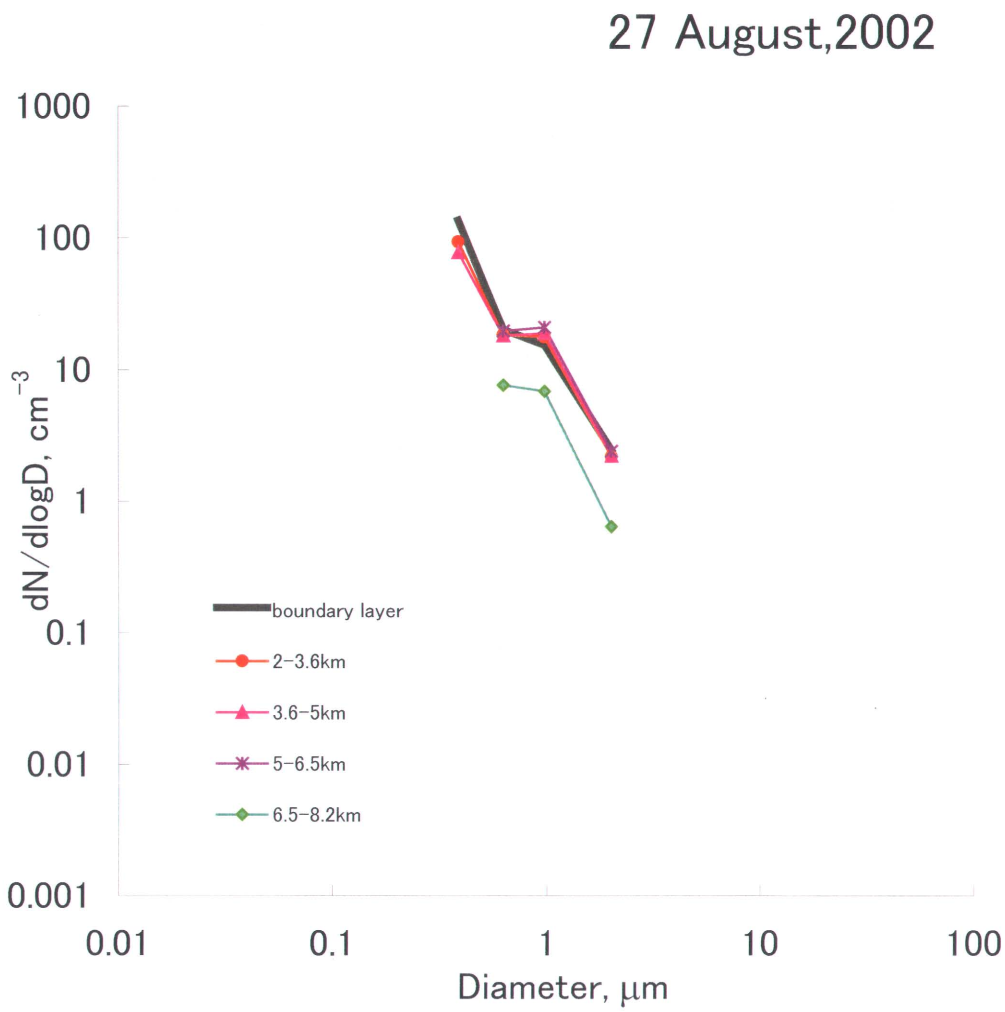

Fig.4 The feature of vertical changes in aerosol number-size distributions deduced from the optical particle counter made in 27 August, 2002 at Dunhuang, China.

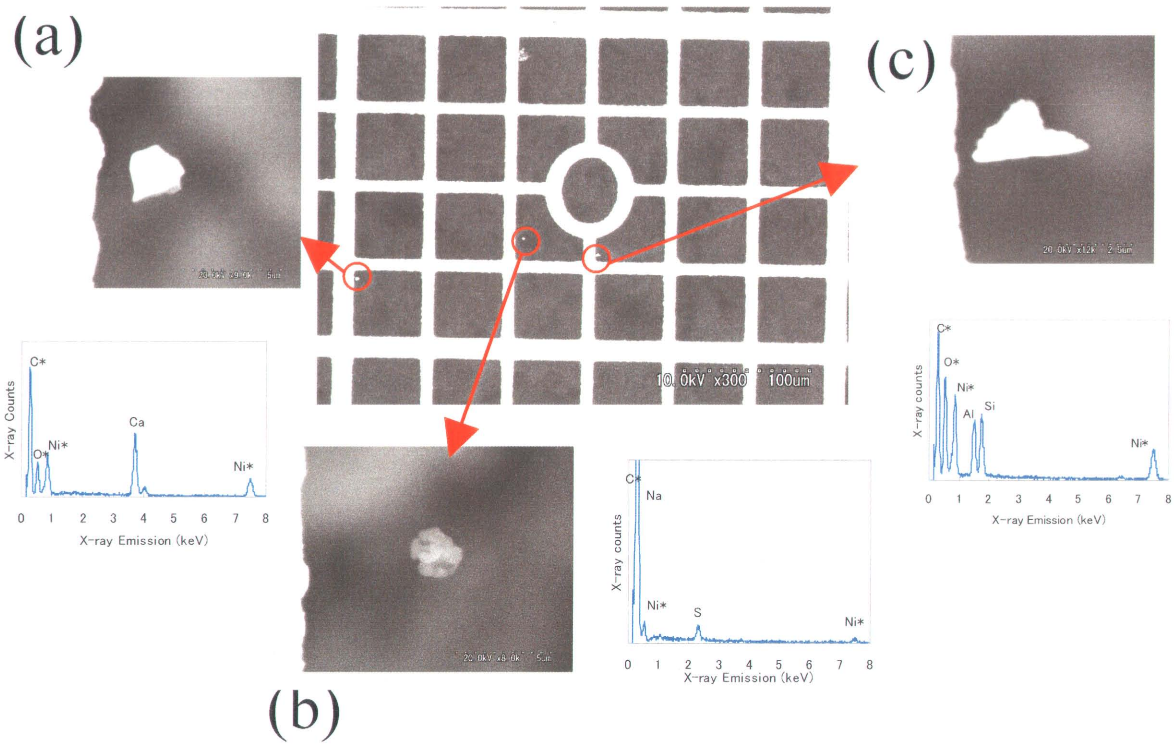

Fig.5 Electron microscopic image and X-ray spectrum of coarse particles collected in height of 3-5km in 29 August, 2002 at Dunhuang, China.

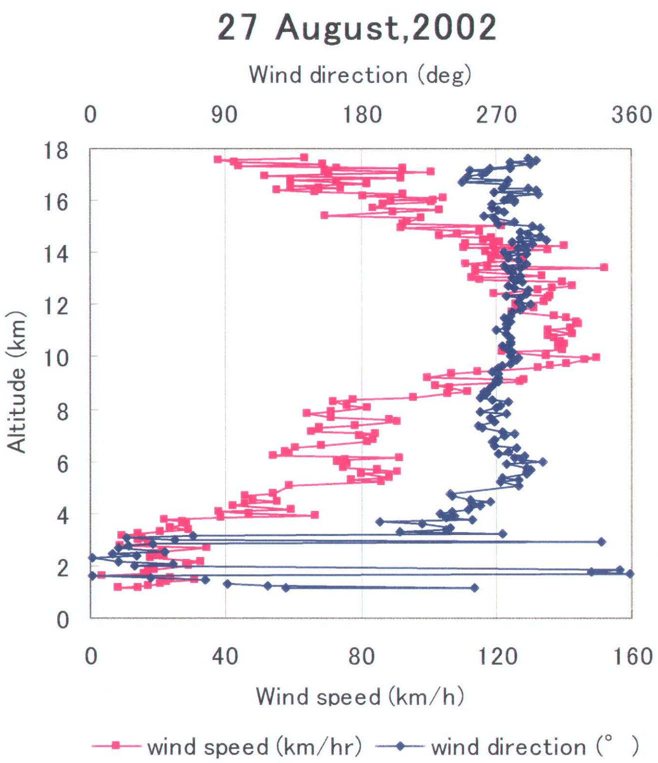

Fig.6 Wind speed and direction deduced from analysis of the balloon trajectory.

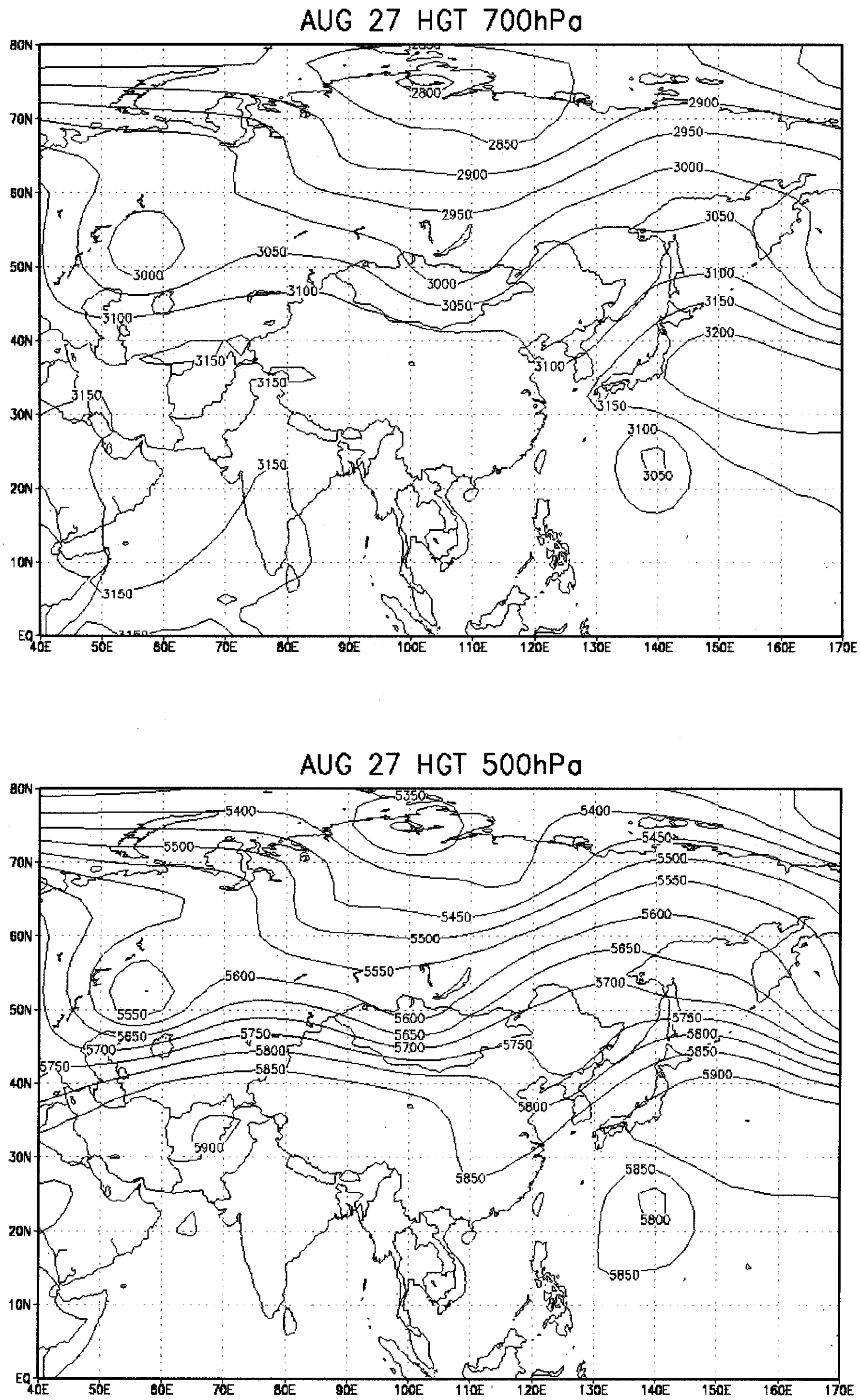

Fig. 7 Heights of 700 hPa surface and 500 hPa surface.

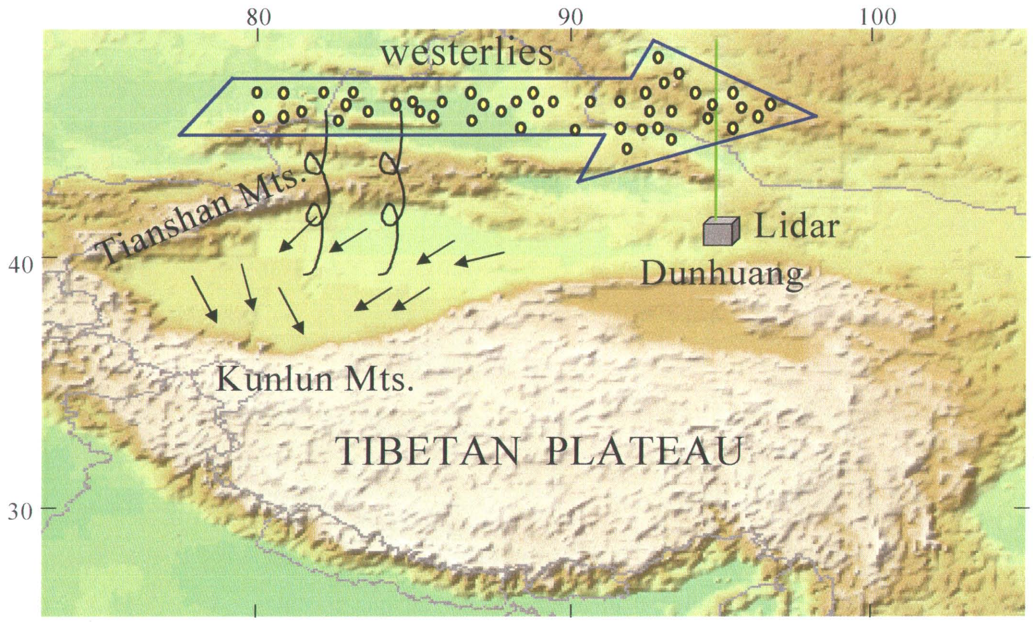

Fig.8 Schematic picture describing wind system and dust particle transports. Dominant surface wind is easterly (or northeasterly) at an elevation<5km, and westerly at an elevation>5km.

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