A Case Study of Local Wind-Blown Dust

Observed in Tsukuba, Japan

By

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Abstract

Wind-blown mineral particles were observed in the daytime on 5 February 1991 in Tsukuba, Japan. The time change in the number-size distribution of aerosol particles with radii between 0.15 and 5 μm were measured with an optical counter. Aerosol particles were collected on electron microscope grids with impactors to obtain the composition of individual particles by electron microscopy.

A meteorological investigation indicated that the local dust episode was generated in the daytime during a strong vertical mixing of air. The number-size distribution measured during the dust episode revealed concentrations of many coarse particles with radii of more than 1 μm . However, an electron microscopic examination indicated the presence of another mode of mineral particles in the radius range of less than 0.5 μm , together with the dominant mode of coarse mineral particles.

The lifting of mineral particles by a dust whirl is an important process in the generation of atmospheric mineral particles under strong horizontal wind velocities, as are saltation sandblasting and bombardment processes.

1. INTRODUCTION

Atmospheric mineral particles are a primary component of aerosols in the Earth's atmosphere and play an important role in atmospheric radiation (e.g., Arao and Ishizaka, 1986) and cloud physical processes (Isono et al., 1959). The global emission rate was estimated to be approximately 2000 Tg y^{-1} , which is 25% of the aerosol emission rate for natural sources (Jaenicke, 1993).

The concentration and size distribution of aerosols in the desert atmosphere have been measured (Schütz and Jaenicke, 1974; d'Almeida and Schütz, 1983; Gomes et al., 1990; Zaizen et al., 1995; Ren et al., 1995). However, little is known about the number-size distribution and composition of wind-blown dust particles from non-desert and -loess

areas or about the meteorological conditions during a wind-blown dust episode.

Wind-blown dust particles are generated in dry seasons (mainly from late winter to early spring) in the Kanto Plain in Japan. The aim of this paper is to clarify the time changes in the number concentration and size distribution of aerosols and the meteorological conditions during the generation of atmospheric mineral particles in Tsukuba, in the Kanto Plain. In addition, this paper will describe the features of mineral particles, including those in the submicrometer size range.

2. METHODS

Observations were conducted on 5 February 1991 at the Meteorological Research Institute (MRI) in Tsukuba (36° 3' 6" N, 140° 7' 43" E). The MRI is located in a small town surrounded by rice fields in

which the surface soil can be seen from winter to early spring.

The number-size distribution of aerosol particles with radii between 0.15 and 5 μm was measured every hour with an optical counter (Dansangyo Co. Ltd., Model PM-730) that has a 15-channel size discriminator. This counter uses a halogen lamp and detects light scattering with an angle of 60°. The counting interval was 20 sec for each measurement. The measurements were carried out at 1.5 m above the ground. The counter was calibrated with polystyrene latex particles before the observation. The number-size distribution was evaluated assuming that the particles have the same optical properties as polystyrene latex spheres (refractive index = 1.592).

Individual aerosol particles were collected on carbon-coated nitrocellulose (collodion) films with impactors of 1 mm and 0.5 mm diameter jets on the roof of an MRI building (30 m above ground). Air flow-rates of 1.3 and 1.0 l min^{-1} were used for collections with 1 and 0.5 mm jet impactors, respectively. The collection efficiencies of the particles were evaluated using the experimental results reported by Ranz and Wong (1952) on the assumption of particles with densities of 2.6 g cm^{-3} (Ishizaka, 1972). The 1 mm jet impactor has a collection efficiency of 10% at 0.25 μm radius, 50% at 0.37 μm radius, and 100% at $\geq 0.55 \mu\text{m}$ radius, while the 0.5 mm jet impactor has an efficiency of 10% at 0.08 μm , 50% at 0.12 μm and 100% at $\geq 0.21 \mu\text{m}$ radius.

The mineral particle size was evaluated using the average of the long and short widths.

Particles collected on carbon film were coated with Pt/Pd alloy at a shadowing angle of $\arctan 0.5$ (26.6°) and were examined with an electron microscope (Hitachi, H-600) to assess the size and morphology. The elemental composition of the collected particles was investigated with an energy-dispersive X-ray (EDX) analyzer (Kevex, delta 5) equipped with the microscope. The electron beam was irradiated at the central part of a particle at an accelerating voltage of 50 kV. The X-ray spectrum was obtained through a Kevex UTW (ultra thin window) detector with a counting interval of 50 to 100 sec. The sizes of particles other than minerals were calculated using the shadow length and apparent diameter, as described by Okada (1983).

Wind data measured at a meteorological tower (213 m height) at the MRI and wind aloft data measured by a rawin sonde at the Tateno Aerological Observatory (TAO) were used to evaluate the vertical distribution of the wind. The TAO is located about 0.5 km north of the MRI.

3. RESULTS

3.1 Brief Description of the Meteorological Conditions

Time changes in the pressure altitude and temperature over Tateno at a pressure of 500 hPa from 1 to 10 February 1991 are shown in Fig. 1. The

Figure 1. Time changes in the pressure altitude and temperature over Tateno at a pressure of 500 hPa from 1 to 10 February 1991. The data was measured at the Tateno Aerological Observatory (TAO) at 0900 and 2100 LST every day.

altitude and temperature exhibited minimum values at 2100 LST on 4 February and had retained the low values at 0900 LST on 5 February, indicating an invasion of a cold air mass over Tsukuba. The surface pressure and wind patterns in central Japan at 0900 LST on 5 February (Fig. 2) were a typical

type recognized during winter monsoons and are modified by mountain ranges in central Japan (Kawamura, 1966). Snowfall is observed in most of the windward areas of the mountain range. Snowfall also occurs in some limited areas in the leeward portion of the mountain range. Vertical profiles of

Figure 2. Surface weather map in central Japan at 0900 LST on 5 February 1991. Mountain areas with altitudes higher than 1000 m are shaded. T indicates the location of Tsukuba in the Kanto Plain.

Figure 3. Vertical profiles of air temperature and dew point temperature from 0830 to 0844 LST on 5 February over Tsukuba, measured at the Tateno Aerological Observatory (31 m altitude).

the air temperature and dew point temperature over Tateno from 0830 to 0844 LST on 5 February are shown in Fig. 3. As seen in Fig. 3, the temperature profile reveals the presence of a ground inversion layer below about 200 m altitude. The lapse rates of the temperature above the inversion are smaller than the adiabatic lapse rate and the values of $T-T_d$ are 10 to 16 °C.

3.2 Aerosol Size Distribution

Figures 4a and b show the time changes in the number concentrations of aerosols with 0.15 to 0.5 μm and 1 to 5 μm radii, respectively. The wind velocity measured on the MRI tower at 10 m height above the ground is shown in Fig. 4c. The concentration of fine particles with 0.15 to 0.5 μm radii changed greatly from 10 to 170 cm^{-3} , with a maximum value in the morning. The concentration decreased rapidly after 0900 LST in relation to the occurrence of strong winds and it was approximately 10 cm^{-3} from 1300 to 2000 LST. Strong winds of $>4 \text{ ms}^{-1}$ were measured at 10 m height from 1000 to 1800 LST. In contrast, the concentration of coarse particles with 1 to 5 μm radii began to increase after 1000 LST. A maximum concentration of 3 cm^{-3} was measured at 1300 LST, when the wind velocity exceeded 8 ms^{-1} . The concentration subsequently decreased with decreasing wind velocity.

Figure 5a shows the number-size distributions of aerosol particles measured at 0800 LST and 1300 LST. The distribution at 1300 LST has a high concentration of coarse particles (radii larger than 1 μm) compared with that at 0800 LST, and has a depression at about 0.5 μm radius. The volume-size distributions (Fig. 4b) exhibited a dominant mode at 3 μm radius. The features of the volume-size distribution were nearly consistent with those obtained

Figure 4. Time changes in number concentrations of aerosols of (a) 0.15 to 0.5 μm and (b) 1-5 μm radius, and (c) in wind velocity measured on the MRI tower at 10 m height above the ground.

in previous research in the desert atmosphere (e.g., d'Almeida and Schütz, 1983).

3.2 Features and Elemental Composition of Individual Particles

We collected three samples from 1300 to 1400 LST, as shown in Table 1. The meteorological conditions during the collections did not change significantly. Figure 6 depicts an electron micrograph of coarse particles collected on a carbon film from 1259 to 1309 LST with the impactor of 1-mm diameter jet (Sample TB). As described previously, the coarse particle concentration was at maximum during the collection. The collected particles shown in Fig. 6 were composed of electron-opaque materials with irregular shapes. The X-ray spectra from

Figure 5. (a) Number-size distributions and (b) volume-size distributions of aerosol particles measured at 0800 LST and 1300 LST.

coarse particles A and B are also shown in Fig. 6. These spectra exhibit dominant peaks of Al, Si, Fe, and O, along with a small peak of Ti. They were identified as minerals, based on the X-ray spectra. Figure 7 shows an electron micrograph of fine particles (radii less than $1 \mu\text{m}$) collected from 1350 to 1353 LST with the 0.5-mm impactor (Sample TS). The X-ray spectra are also shown in Fig. 7. Although particles other than mineral particles (for example, Particle D) were present in the submicrometer size range, the submicrometer mineral particles (for example, Particle C) were dominant in the electron micrograph. Note that Particle D was determined to be a sulfate particle on the basis of the X-ray spectrum and morphological appearance. Table 2 shows the numbers of total particles and mineral particles in the combined data of Samples TB, T, and TS. The results were obtained by EDX analyses of the particles. All the particles with radii $>0.7 \mu\text{m}$ were minerals. In contrast, mineral particles were present in number percentages of 71 to 88% in the radius range of 0.1–0.7 μm .

4. DISCUSSION

The time change in the aerosol number concentrations exhibited different features within the radius range. The fine particles with 0.15 to 0.5 μm radii decreased rapidly from 170 to 30 cm^{-3} between 0900 and 1100 LST, synchronized with the occurrence of strong winds.

Figure 8 shows the vertical distributions of wind velocity measured at the TAO. The wind velocity increased linearly with altitude from 0230 to 0243 LST on 5 February. In contrast, the vertical wind profile measured at 0830 to 0844 LST, just before the appearance of a strong wind near the ground, indicated the presence of a jet-type wind shear below 3 km in altitude. The wind shears below 1 km in altitude were larger than the critical value

Table 1. Sampling period and meteorological condition on 5 February 1991, together with the collection film and impactors used.

Sample ID	Collection film	Impactor nozzle	Sampling period (LST)	Meteorological condition*				
				T ($^{\circ}\text{C}$)	Td ($^{\circ}\text{C}$)	RH (%)	WD	WV (ms^{-1})
TB	carbon	1 mm	12:59–13:09	8.3	–11.5	23	WNW	11.2
						(13 LST)		
T	carbon	1 mm	13:28–13:48					
TS	carbon	0.5 mm	13:50–13:53	8.3	–11.1	24	WNW	10.4
						(14 LST)		

*: The data were obtained at the Tateno Aerological Observatory (WMO code: 47646).

Figure 6. Electron micrograph of coarse particles collected on a carbon film from 1259 LST to 1309 LST, with the impactor of 1-mm diameter jet (Sample TB). The EDX spectra of particles A (radius $r=2.5\ \mu\text{m}$) and B ($r=1.8\ \mu\text{m}$) are also shown.

Figure 7. Electron micrograph of fine particles (radii less than $1\ \mu\text{m}$) collected from 1350 LST to 1353 LST with the 0.5-mm impactor (Sample TS). The EDX spectra of particles C (radius $r=0.13\ \mu\text{m}$) and D ($r=0.56\ \mu\text{m}$) are also shown. Particle C is a sulfur-rich particle.

Table 2. Numbers of total particles and mineral particles examined. The results were obtained from the EDX analysis of the combined Samples TB, T and TS (see Table 1). The percentage of mineral particles in the total particles is shown in parenthesis.

	Radius range (μm)				
	0.1-0.35	0.35-0.5	0.5-0.7	0.7-1.0	1.0-3.0
Total particles	76	31	26	17	18
Mineral particles	60 (79 %)	22 (71 %)	23 (88 %)	17 (100 %)	18 (100 %)

Figure 8. Vertical distributions of wind velocity measured at the TAO from 0230 to 0243 LST and 0830 to 0844 LST on 5 February.

reported by Gamo and Yokoyama (1974), suggesting the occurrence of forced convection. A similar low-level jet was observed over Beijing during a dust-storm episode (Zhou et al., 1981).

Time changes in the temperatures and wind velocities measured on the MRI tower at 213 and 50 m heights from the ground are shown in Fig. 9. Note that the wind direction at both heights was mainly between W and NW from 0300 to 1830 LST. The diurnal temperature variation at 213 m height is similar in shape to that at the 50 m height (Fig. 9a). However, the range of variation is substantial at the lower atmosphere. The temperature at 50 m height was lower than that at 213 m height from 0000 to 0850 LST, mainly due to radiative cooling of the ground. The temperature at 50 m height increased rapidly after about 0900 LST, and it was larger than that at 213 m height by 2200 LST, indicating thermodynamically unstable conditions in the daytime. The wind velocities at heights of 50 and 213 m (Fig. 9b) tended to increase with increases in the thermodynamic instability. The Richardson number Ri was evaluated by using the wind and temperature measurements at 213 and 50 m heights on the MRI tower. The values of Ri were less than 1 (from 0.2 and -0.04) from 0900 to 1800 LST. These results suggest the occurrence of a dominant mixing of air that produced a strong wind near the surface.

A vertical distribution of the aerosol concentration usually exhibits a decrease with altitude. The decrease in the concentration of fine particles shown in Fig. 4a is considered to be mainly due to the supply of clean air from the upper layer caused by the vertical mixing of air. In addition, strong horizontal winds may suppress the growth of sulfate

Figure 9. (a) Time changes in temperature and (b) wind velocity measured on 5 February on the MRI tower at 213 m and 50 m heights above the ground.

particles to particles of $> 0.1 \mu\text{m}$ radius by gas-to-particle conversion since the air velocity is too great to permit growth during the stay over the Kanto Plain (e.g., Okada et al., 1986).

A comparison of the fraction of mineral particles (Table 2) with the number-size distribution of the total particles measured at 1300 LST (Fig. 5a) indicates that the number concentration of mineral particles tends to increase with decreasing radius. However, there was a depression of the concentration at about $0.5 \mu\text{m}$ radius. This indicates that the size distribution was composed of two particle modes (fine and coarse particle modes). One possible mechanism for generating atmospheric mineral particles, including those in the fine mode, by strong horizontal winds would be sandblasting (Gillette and Porch, 1978; Gomes et al., 1990) and bombardment processes (Shao et al., 1993) driven by the saltation of larger sand grains. A dust whirl with a spatial scale of about 10 m was observed during the aerosol collections (Fig. 10). The lifting of mineral particles by the dust whirl would also be an impor-

Figure 10. Picture of a dust whirl with a spatial scale of about 10 m taken at 1344 LST on 5 February from the roof of the MRI building (30 m above the ground).

tant process in generating atmospheric mineral particles.

The number-size distributions of aerosols obtained in this study was compared with those measured during dust-storm episodes in the desert atmosphere of China (Fig. 11). The result reported by Ren et al. (1995) was obtained at Pingchuan (39° 21'N, 100°09'E) in April 1991. The distribution measured in the suburbs of Zhangye (39°52'N, 100°23'E) (Zaizen et al., 1995) was also compared. Since mineral particles were present in high number fractions (97 to 98%) of aerosol particles in the radius range of 0.1 to 6 μm in these areas (Okada and Kai, 1995), these size distributions can be regarded as those for mineral particles. The number concentrations at Pingchuan increased with decreasing radius and exhibited high concentrations of 10^3 cm^{-3} in $dN/d\log r$ in the radius range of 0.15 to 0.3 μm . Ren et al. (1995) reported that the size distribution at Pingchuan has three modes in the radius range of 0.15 to 5 μm . However, the modes are not clear as those for Tsukuba, and the concentrations are more than one order of magnitude higher than those measured at Tsukuba. The distribution measured at Zhangye also exhibits high concentrations of aerosols below 1 μm radius.

Fine mineral particles can be formed abundantly from the surface minerals in arid regions through weathering processes (e.g., Pye, 1987). An abundance of these fine particles on the surface would produce high number concentrations of atmospheric fine mineral particles. The generation of fine particles would mask the concentration depression between the fine and coarse particle modes in the size distribution for desert aerosols. As mentioned previously, dust whirls also play an important role in lifting mineral particles. A well-developed dust

Figure 11. Number-size distributions of aerosols obtained in this study and measured during dust-storm episodes in the desert atmosphere of China (Ren et al., 1995; Zaizen et al., 1995). The distribution reported by Ren et al. (1995) was obtained at Pingchuan (39°21'N, 100°09'E) in April 1991. The distribution by Zaizen et al. (1995) was measured in the suburbs of Zhangye (39°52'N, 100°23'E) at 0900 BST (Beijing Standard Time) on 5 May 1991.

whirl (also called a dust devil) is formed in the desert atmosphere during sunny, hot, and calm weather, which creates superadiabatic conditions near the surface, and it follows a spiral course on windless days (Ives, 1947). The lifting of mineral particles by dust devils would become significant on calm days in the desert atmosphere.

5. CONCLUSIONS

Wind-blown soil particles were observed during strong winds in the daytime on 5 February 1991 in Tsukuba, Japan. The time change in the number-size distribution of aerosol particles with radii between 0.15 and 5 μm was measured using an optical counter. In addition, aerosol particles were collected on electron microscope grids using impactors to examine the compositions of individual particles.

Meteorological conditions indicated that local dust was generated during the occurrence of a strong vertical mixing of air. The number-size distribution measured during the local dust episode revealed high number concentrations of coarse particles with radii of more than 1 μm . Moreover, the electron microscopic examination indicated the presence of submicrometer soil particles with radii of less than 0.5 μm .

In addition to sandblasting and bombardment driven by saltation of larger sand grains under strong wind velocities, the lifting of mineral particles by dust whirls would also be an important process in generating atmospheric mineral particles.

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つくばで観測された地域的な風塵の事例解析

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つくばにおいて、1991年2月5日の日中に発生した風塵を観測した。半径0.15から5 μm のエアロゾル個数粒径分布の時間変化をオプティカルカウンターにより測定した。また、電子顕微鏡によって粒子組成を分析するため、エアロゾル粒子を電子顕微鏡グリッド上に採集した。

風塵の発生は大気の激しい鉛直混合が起っている気象状態において認められた。その発生時におけるエアロゾル粒径分布は、半径1 μm 以上の粗大粒子の濃度が高かった。しかし、電子顕微鏡分析から、粗大鉱物粒子のモードだけでなく、半径0.5 μm より小さい半径領域にも鉱物粒子のモードがあることが分かった。

水平風速の増大による砂粒子の saltation による sandblasting と bombardment 過程に加えて、塵旋風による鉱物粒子の巻き上げも風塵の発生にとって重要であることが示唆された。