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On the Atmospheric Aerosol Particles in Relation to the Pressure Patterns in Winter Season, Sapporo, Japan

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Abstract

To clarify the characteristics of the source of air pollution in relation to the pressure patterns in a winter season, sampling of atmospheric aerosol particles was carried out for each wind direction on the top of Mt. Teine (1,024 m a.s.l.) (mountain site) and in the campus of Hokkaido University (urban site) in Sapporo City, Hokkaido, Japan in the winter season of 1987. In the winter monsoon pressure pattern, the concentration of anthropogenic aerosols (Carbon and SO_4^{2-}) was mainly affected by easterly winds at both sites. On the other hand, the concentration of marine aerosols (Na, K, Cl^-, etc.) in the urban site showed high values under westerly winds as compared with the mountain site. Especially, in the case of pressure distribution with Japan Sea - low pressure pattern, the concentration of soil particles (Al, Ca, etc.) was generally higher than that of marine and anthropogenic aerosols at both sites. During the sampling period, the total concentration of aerosol particles showed the highest value under easterly winds in the case of a travelling high pressure. In addition to these analyses, the aerosol particles collected on millipore filter papers using a continuous aerosol sampler were analyzed by SEM and EMAX.

Key Words: Chemical compositions of aerosol, Characteristics of the source of air pollution, Atmospheric aerosol particles, Wind direction, Winter monsoon pressure pattern, Japan Sea-low pressure pattern, Travelling high pressure pattern.

1. Introduction

Atmospheric aerosol particles produced from many sources are, in general, multicomponent particles with sizes ranging roughly from 0.01 to 10 μm in diameter (Pilinis et al., 1987). Each particle is different in shape, size and composition, which depends on the specific sources of pollution occurring from natural and anthropogenic sources. And its concentrations, especially, have some effects on

animals and human health as well as materials and plants according to the change of meteorological and topographical situations (Stern, 1976; Wark and Warner, 1976; Khemani et al., 1987). Therefore, it is deemed important survey the variation of aerosol concentrations with respect to the meteorological parameters.

Recently, long-term air samplings have been made to study the effect of meteorological parameters on the concentrations of chemical components of the particles (Sladkovic et al., 1986; Kunugi et al., 1987; Lee et al., 1987, 1988). Further, the study for the scavenging effect of precipitation and comparison of aerosol concentrations for each wind direction (Murakami et al., 1983; Lee et al., 1987) has been carried out up to date. However, no theoretical or experimental measurements of aerosol particles for each wind direction in particular have been carried out to survey the characteristics of aerosol concentrations in relation to the atmospheric pressure patterns. Hence, during short-term air sampling, our aim is to determine not only the concentration of aerosol particles for each wind direction according to pressure patterns but also the character and comparison of their concentrations between the ground surface (urban site) and mountain area (mountain site). In addition, SEM and EMAX analyses were carried out to survey the size, shape and components of aerosol particles.

2. Materials and Methods

2. 1. *Sampling collection*

Sapporo City is the largest urban area in Hokkaido with a population of about 1.58 million completed with towering buildings, a large number of motor vehicles, etc. The pollution problem in this city is caused by burning of fossil fuel for heating and, specially, street dust caused by studded tires of vehicles which come from having a considerably large snowfall in winter seasons (Kikuchi, 1984). Representative aerosol compositions occurring in this area are soil dusts, sea-salt, ammonium, nitrate, sulfate, organic and elemental carbon and so on (Ohta and Okita, 1983; Lee et al., 1987). To obtain the difference of aerosol concentrations for each wind direction in relation to pressure patterns, a sampling of aerosol particles using filter papers was performed from January 24, 1987 to March 30, 1987 on the campus of Hokkaido University (50 m a.s.l.) (urban site) situated in the center of Sapporo City. The sampling was also done at the Cloud Physics Observatory of Hokkaido University, on the top of Mt. Teine (1,024 m a.s.l.) (mountain site) separated by 10 km to the west from the city center which is located above the polluted atmospheric layer in Sapporo as shown in Figure 1 (Kikuchi, 1984). And, to investigate the physical properties (size, shape and composition) of aerosol particles, their collection was carried out by millipore filter papers, continuously, at both sites during the sampling period. The apparatus used in this study consists of an aerovane (Environmental Pollution Control Center, Model WDP-100) and a selection circuit unit assembly for each wind direction as shown in Figure 2. These are used in conjunction with filter air sampler with an electrical solenoid valve to sample air when the wind is coming from a specific direction. They are the same

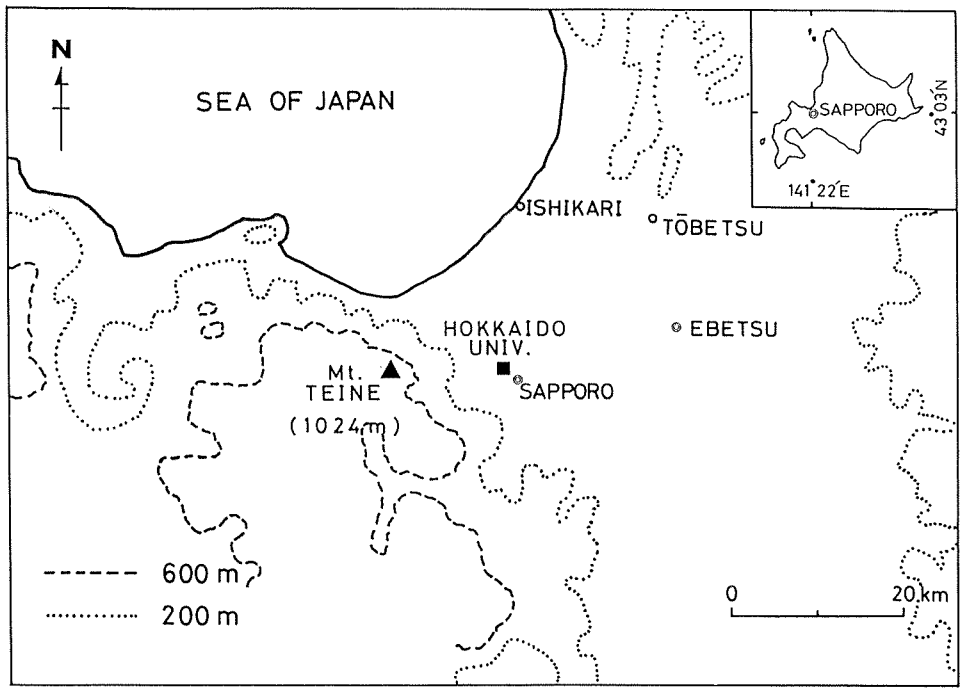

Figure 1. Locations of Sapporo and sampling sites.

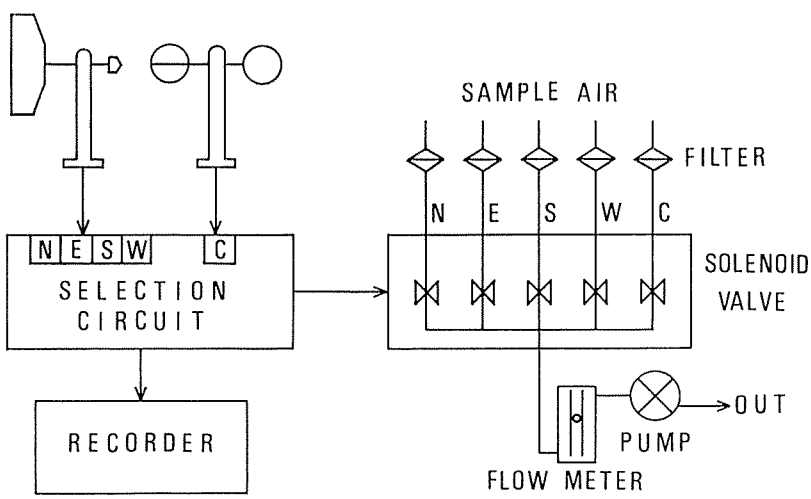

Figure 2. Sampling apparatus controlled by aerovane.

as those adopted by Lee et al. (1987, 1988). Detailed contents concerning the aerovane and the wind controlled air sampler are described in the previous paper (Lee et al., 1987). The chemical contents of aerosol particles sampled and analyzed in this study are the same as those by Lee et al. (1987); that is, organic and elemental carbon, ionic components (NH_4^+, NO_3^-, SO_4^{2-} and Cl^-) and metal elements (Al, Na, Cu, Ni, K, Zn, Ca, Mn, Mg and Cd).

Table 1. Analytical methods of individual items and instruments

Item	Analytical method	Instrument
T.C.	850°C combustion system	NC-80 Carbon analyzer
E.C.	300°C, 30 min. (burn)	(SUMIGRAPH)
NH_4^+	Indophenol method	
NO_3^-	Hydrazine reduction	UV-120-02
Cl^-	Mercury thiocyanate	Spectrophotometer
SO_4^{2-}	Barium perchlorate-thorin	(SHIMADZU SFU)
Al	HNO_3	
Ca	+	
Cd	$HClO_4$	Flameless
Cu	+	Zeeman effect
K	HF	Atomic absorption
Mg	Dry	Spectrophotometer
Mn	+	(HITACHI 170-70)
Na	HCl	
Ni	Atomic absorption	
Zn	analysis	

2. 2. *Sample preparation and analysis*

Table 1 indicates the analytical methods and instruments used to analyze aerosol samples. The determination of carbon collected on the quartz fiber filter is made in combination with an NC-analyzer and gas chromatography apparatus (Ohta and Okita, 1984). The amount of ammonium ions, nitrate, chloride and sulfate collected on the teflon filter are determined by an UV Spectrophotometer (APHA, 1977; APNC, 1975). Metal elements are analyzed by conventional atomic absorption methods using Flameless Zeeman Effect Atomic Absorption Spectrophotometer (APHA, 1977). Additionally, in order to collect aerosol particles on millipore filter papers automatically, a new continuous aerosol sampler was used (Taniguchi and Kikuchi, 1989). In the present case, a total of approximately 120 liters containing airborne particles was collected on the individual patches of the filter papers. After sampling, the filter papers were cut out and mounted on the stages of a scanning electron microscope; SEM (Hitachi, Model S-430) to determine size and shape of each aerosol particle. And the chemical components of individual particles were analyzed by an energy dispersive X-ray microanalyzer; EMAX (Horiba, Model EMAX-1800S).

2. 3. *Meteorological conditions*

The values of each meteorological parameter measured during three sampling periods at both sites were shown in Table 2. However, precipitation amounts on the Mt. Teine could not be measured, because of strong winds and icing over on top of the mountain in winter. In the last 8 days of January, a typical pressure pattern of the winter monsoon was seen which had a strong cold air mass in the

Table 2. Average values of each meteorological parameter at both sitesduring 3 sampling periods

Meteorological Parameter	Temperature (°C)		Wind speed (m/sec)		Precipitation (mm)	
Site / Date	H.U.	M.T.	H.U.	M.T.	H.U.	M.T.
24–31 Jan.	−3.9	−10.8	2.2	6.5	26	(N.M.)
19–27 Feb.	−2.6	−10.5	2.4	7.2	41	(N.M.)
23–30 Mar.	1.6	− 6.2	2.4	5.0	49	(N.M.)

H.U.=Hokkaido Univ., M.T.=Mt. Teine, (N.M.)=Not measured.

upper layer over Hokkaido. The heavy snowy weather continued for the last 9 days of February 1987 on Hokkaido arising from the Japan Sea - low pressure pattern. The low pressure developed on the Japan Sea and passed over Hokkaido. After that the low pressure stagnated at the south of the Sea of Okhotsk. During the last 6 days of March 1987 except 23rd and 24th, which showed much snow (38 mm in water), the weather on Honshu Island was distinguished by a travelling high pressure pattern. Therefore, Hokkaido was located between the high pressure area and the low pressure area which passed north of Hokkaido.

3. Results and Discussion

Figure 3 shows the surface weather map in January 26, 1987 as representative

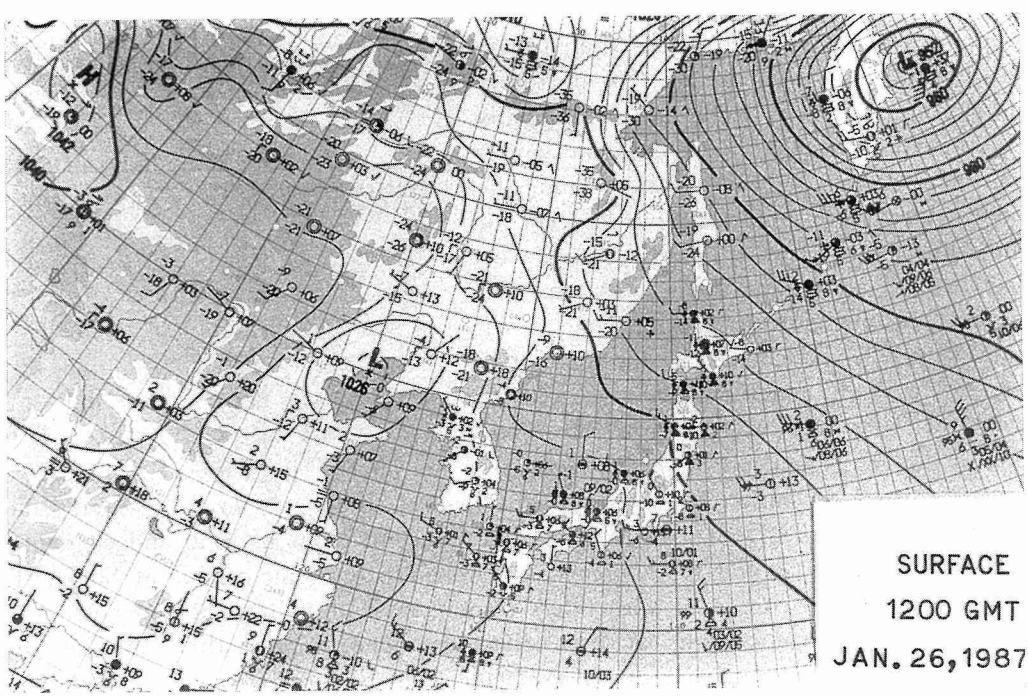

Figure 3. Surface weather map on January 26, 1987. (After J.M.A.)

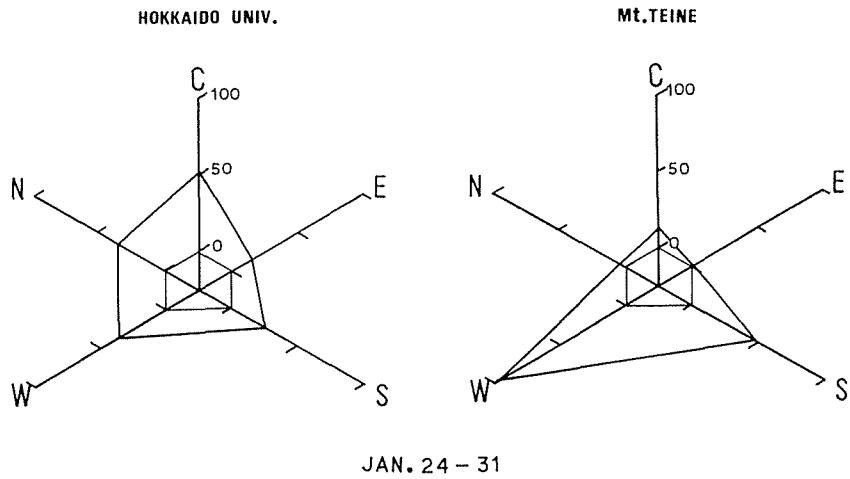

Figure 4. Cumulative time (hrs) for each wind direction at both sites in 24–31 January 1987.

of the sampling period (24–31 Jan.) which continuously showed winter monsoon pressure pattern (West-High and East-Low). Cumulative time (hrs) and concentration rate (%) of total aerosol concentration in each wind direction at both sites in 24–31 January 1987 are shown in Figure 4 and Table 3. At the mountain site, the data of cumulative time at westerly wind directions showed higher values than others and at the urban site, the time of northerly and westerly wind directions showed a slightly higher than others for the effect of the winter monsoon pattern. On the other hand, the concentration rate at easterly wind except for calm situations (C) at the mountain site indicated high values at both sites. In this winter monsoon pattern, specific wind directions (W and E) which had a long cumulative time and a high concentration rate, respectively, at both sites were selected to investigate the representative characteristics of air quality in Sapporo. Figure 5 showed the concentration ($\mu g/m^3$) of each chemical component in the westerly and easterly winds. As shown in this figure, the concentrations of total and elemental carbons (TC and EC) and SO_4^{2-} occurring from anthropogenic origins at both sites have greater values compared with other components. Further, the concentrations of anthropogenic components at the urban site were higher than that at the mountain site. The concentration of Na generally originated from marine aerosol was high for westerly winds in the urban site. It was considered that marine

Table 3. Concentration rate (%) for each wind direction of total concentration at botn sites in 24–31 January 1987

	CONCENTRATION (%)	
WIND DIRECT.	HOKKAIDO UNIV.	Mt. TEINE
N	18.1	19.2
E	24.5	25.1
S	19.4	16.0
W	24.2	8.6
C	13.8	31.1

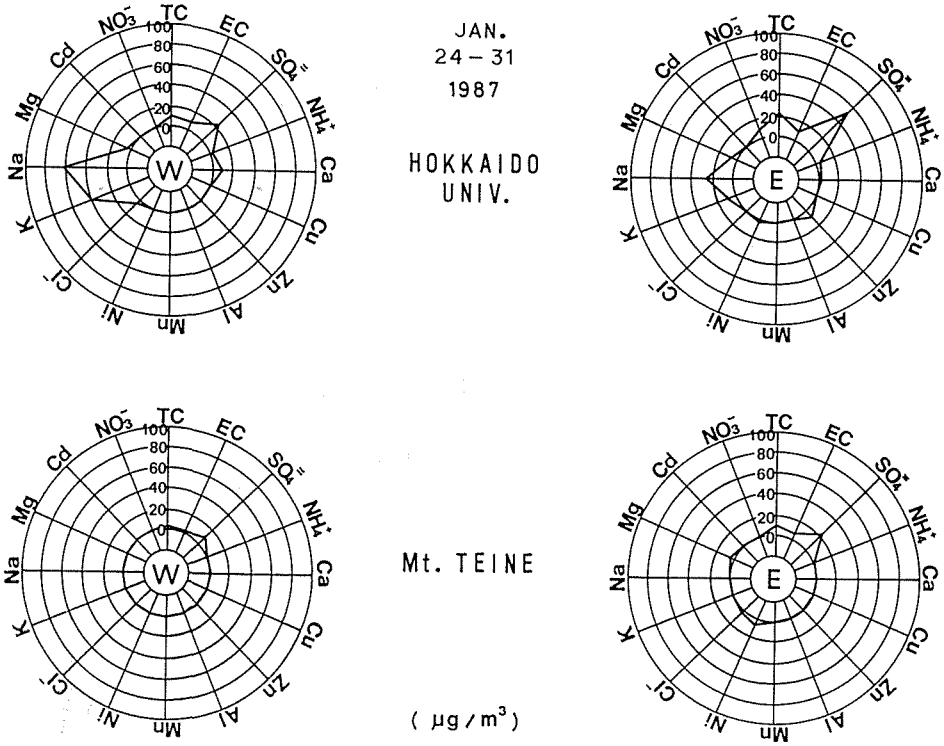

Figure 5. Concentration ($\mu g/m^3$) of each chemical component in the westerly and easterly winds at both sites (24–31 January).

aerosol particles from the Japan Sea were transported to the inland area as a result of the northwesterly winter monsoon wind. However, the above facts did not appear on the mountain site, since the large particles such as sea-salt were hard to be transported from the sea surface to the mountain site owing to their own weight and the capture by surface obstacles (Tanaka and Toba, 1969 ; Kikuchi and Yaura, 1970).

The next, Figure 6 shows the surface weather map in February 24, 1987 as a representative pattern of the 2nd sampling period (19–27 Feb.) which mainly showed the Japan Sea – low pressure pattern. During the above period, cumulative time (hrs) and concentration rate (%) of total aerosol concentration for each wind direction at both sites are shown in Figure 7 and Table 4. In this figure, southerly and westerly winds in each wind direction at both sites acquired much cumulative time as compared with others. On the other hand, concentration rate by wind direction indicated high values in calm (C) and southerly winds at the urban site and calm and easterly winds at the mountain site. These provide a basis for selecting the representative aerosol particle concentration by wind direction. Therefore, the concentrations of each chemical component in westerly and southerly winds at the urban site and the westerly and easterly winds at the mountain site were shown in Figure 8. The variation ranges of concentration in the urban site which acquired much cumulative time in southerly and westerly winds were similar

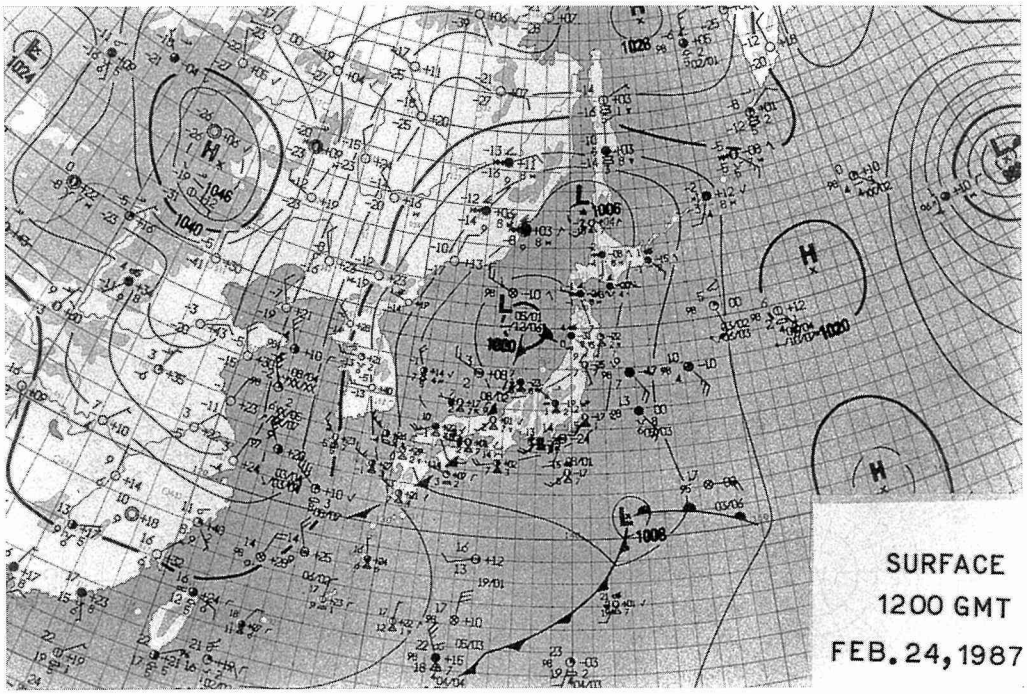

Figure 6. Same as Figure 3 but for February 24, 1987. (After J. M.A.)

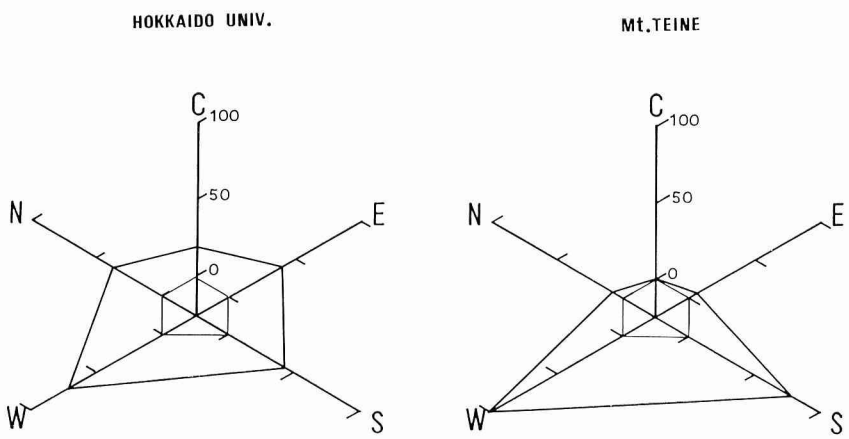

Figure 7. Same as Figure 4 but for 19–27 February 1987.

to each other. Soil particles (Al and Ca) showed a higher concentration as compared with anthropogenic aerosols (Carbon, SO_4^{2-} etc.) and marine aerosols (Na) at both sites. At the mountain site where westerly winds mainly prevailed, total aerosol concentrations were less than in the urban site. This phenomenon can be

explained by the scavenging effect of numerous snowfalls on the mountain site by the low pressure patterns (Murakami et al., 1983).

Finally, the surface weather map in March 28, 1987 which was the representative day of travelling high pressure pattern at the 3rd sampling period (23–30, March) was shown in Figure 9. The cumulative time (hrs) and concentration rate (%) of total aerosol concentration in each wind direction at both site during the above period are shown in Figure 10 and Table 5. Although the southerly winds at both sites and northerly and westerly winds at the urban site prevailed, the total aerosol concentration was high in the easterly winds at both sites. Therefore, the concentrations of each aerosol particle for the southerly and easterly winds at both sites were analyzed as shown in Figure 11. The wind direction which showed the highest value of total aerosol concentration during the whole sampling period was easterly in this travelling high pressure pattern. Especially, in the urban site, the concentrations of natural and anthropogenic aerosols showed high values as

Table 4. Same as Table 3 but for 19–27 February 1987

WIND DIRECT.	CONCENTRATION (%) HOKKAIDO UNIV.	Mt. TEINE
N	16.9	18.9
E	13.9	29.1
S	19.6	6.9
W	18.7	5.7
C	30.9	39.4

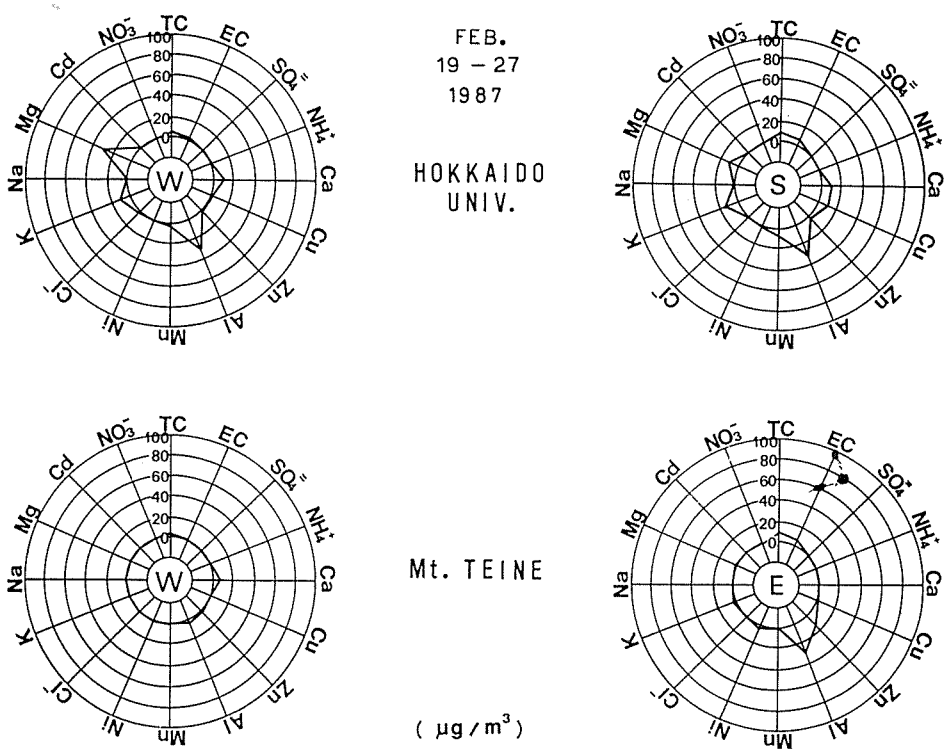

Figure 8. Same as Figure 5 but for the southerly and westerly winds at the urban site and westerly and easterly winds at the mountain site (19–27 February).

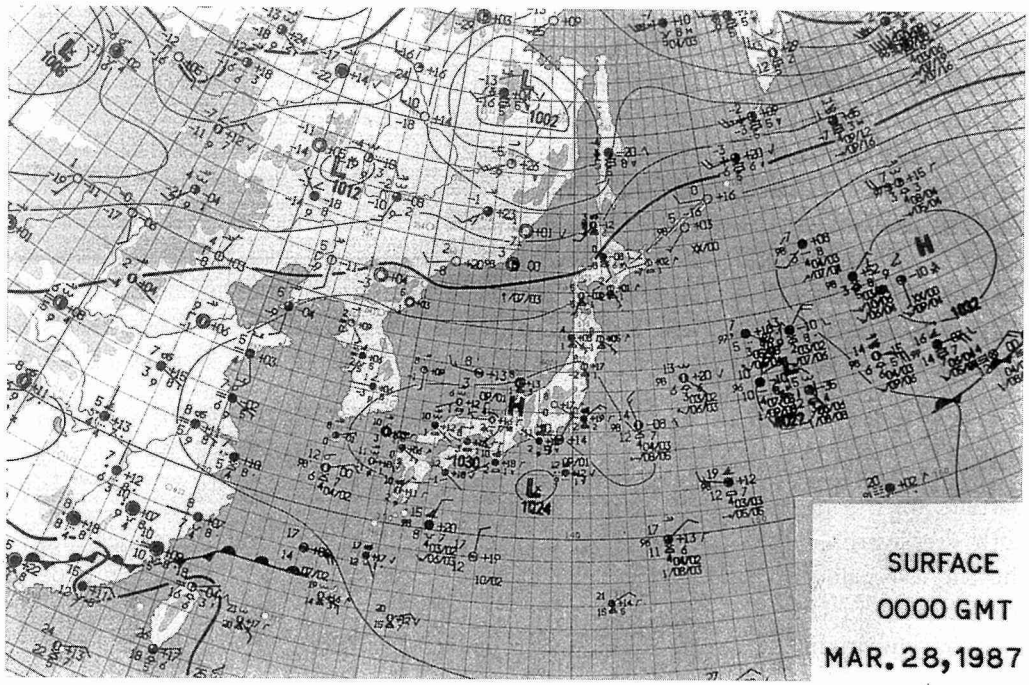

Figure 9. Same as Figure 3 but for March 28, 1987. (After J.M.A.)

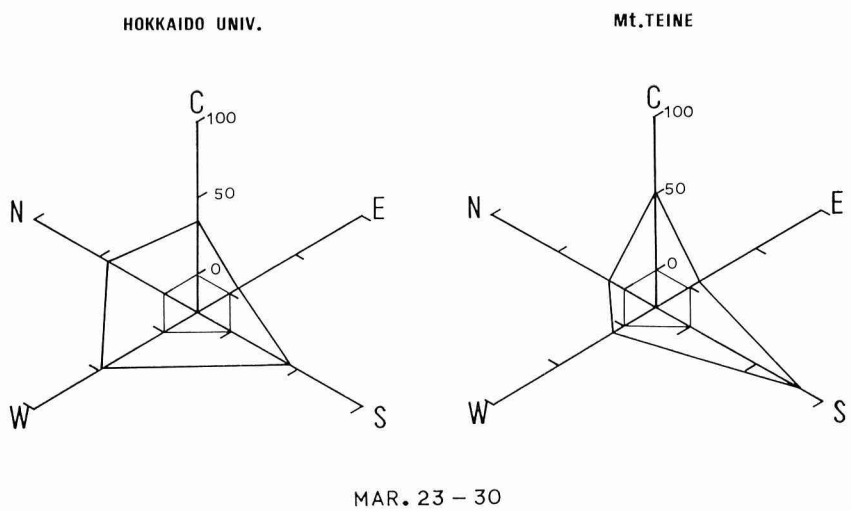

Figure 10. Same as Figure 4 but for 23–30 March 1987.

compared with the winter monsoon patterns which acquired much marine aerosols from the Japan Sea. This phenomenon also appeared in the prevailing southerly winds during the 3rd sampling period where the concentration of natural and soil particles (Al, Zn and Ca) was high. It was considered that it was affected by suspended particles from the soil and street dust, especially caused by studded tires of vehicles that greatly showed their ravages from the end of March in Sapporo. Because the end of March at Sapporo corresponded to the end period of melting of snow. However, the total aerosol concentration was low at the mountain site (1,024 m a.s.l.) in this travelling high pressure pattern, since the temperature inversion layer was formed approximately at the 400–500 m a.s.l. in Sapporo (Endoh et al., 1981).

Table 5. Same as Table 3 but for 23–30 March 1987

WIND DIRECT.	HOKKAIDO UNIV. (CONCENTRATION (%))	Mt. TEINE (CONCENTRATION (%))
N	10.1	18.1
E	38.5	26.6
S	14.6	25.0
W	12.3	21.0
C	24.5	9.3

The typical shape, size and physical components of aerosol particles collected by the continuous aerosol sampler were shown in Figure 12. These particles were displayed by a scanning electron microscope (SEM) and analyzed by an energy dispersive X-ray microanalyzer (EMAX). In this figure, horizontal bars shown at

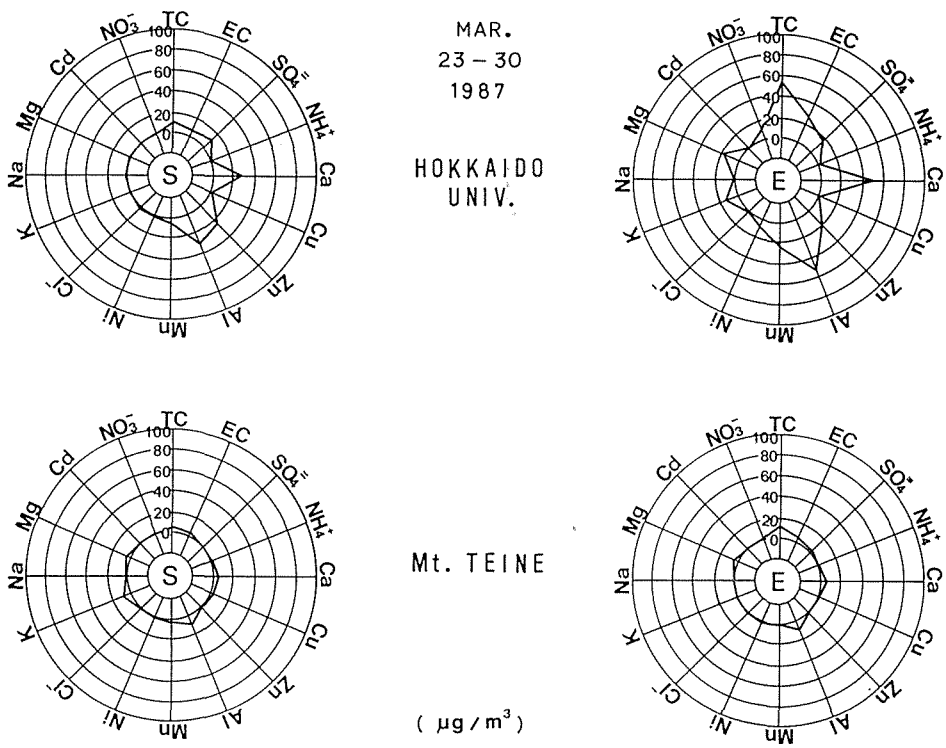

Figure 11. Same as Figure 5 but the southerly and easterly winds at both sites (23–30 March).

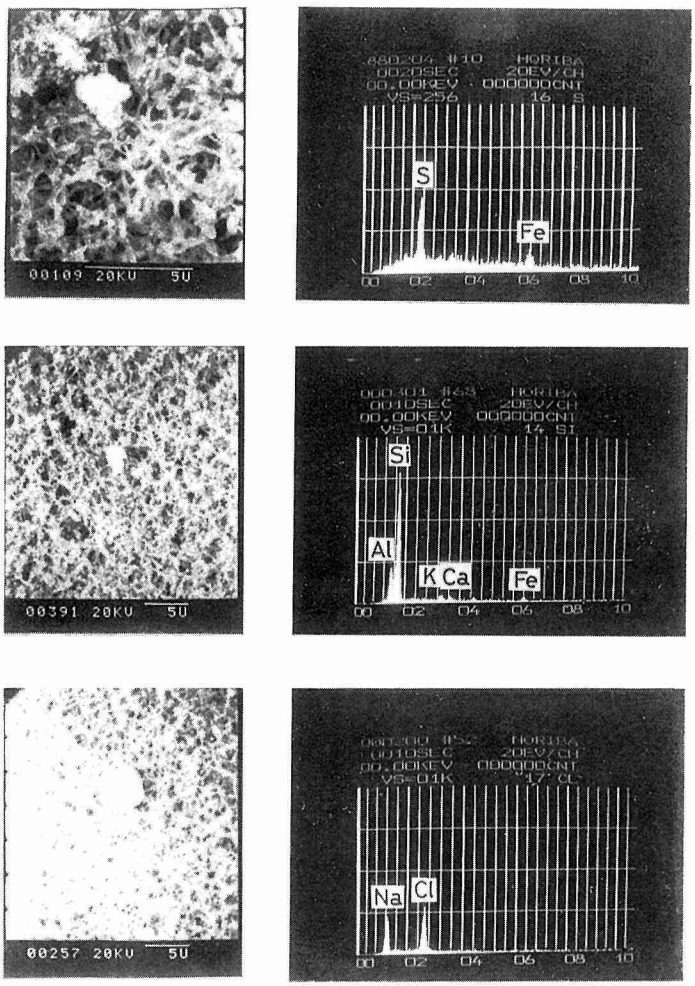

Figure 12. Typical three examples of SEM image and X-ray spectra of aerosol particles.

the bottom of each picture of SEM images indicate the size of picture in μm. And vertical predominant peaks shown in EMAX spectra indicate radiation occurring from each element. Marine aerosol particles (Na and Cl^-) mainly originated from sea-salt are larger than others, namely, anthropogenic aerosol (S) and natural soil particles (Al and Si). This fact can be explained that sea-salt particles are difficult to be transported from the sea surface to the high altitude such as mountain site owing to their own weights as compared with other aerosol particles (Tanaka and Toba, 1969; Kikuchi and Yaura, 1970). More detailed results about SEM-EMAX analyses are continuously being analyzed to find out the representative characteristics of aerosol samples collected at both sites.

4. Conclusions

Aerosol sampling in relation to the atmospheric pressure pattern was performed

for each wind direction at the urban and mountain sites from January to March, 1987. In this study, we fortunately chose the sampling periods which indicated three typical types of pressure patterns in the winter seasons : (1) winter monsoon pattern (24–31, January), (2) Japan Sea – low pressure pattern (19–27, February), and (3) travelling high pressure pattern (23–30, March). At the first, the concentration of marine aerosols (Na and Cl^-) such as sea-salt particles for westerly winds as a result of the winter monsoon pattern and large their own weights was high in the urban site as compared with the mountain site. On the other hand, TC and SO_4^{2-} concentrations were higher for easterly winds than others. Secondly, at the low pressure pattern passing over the Japan Sea, the scavenging of heavy snowfalls depending on the turbulence was effective at both sites. Finally, at the travelling high pressure pattern, the difference of vertical aerosol concentration at both sites was appeared clearly as a result of atmospheric stability effect. And the air quality in Sapporo during this period was predominantly affected by suspended particles (Al, Zn and Ca) from the soil and street dust especially caused by studded tires of vehicles. In addition to, determination of typical shape, size and components of aerosol particles using the SEM-EMAX analyzer proved that the size of marine aerosols were larger as compared with others.

Acknowledgments

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