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Relationship between Ice Nuclei and Snowfalls Obseved in the Arctic Regions

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Abstract

The observations of number concentrations and chemical compositions of ice nuclei, and snowfalls at Inuvik, N.W.T., Canada and Kiruna, Northern Sweden in the Arctic regions were carried out in the winter of 1995/1996 and 1996/1997. Results showed that the number concentrations of ice nuclei related to the precipitation events. Chemical components of ice nuclei corresponded to the soil and man made particles. The presence of sea salt particles depended on the difference of the trajectory of air masses.

1. Introduction

To understand in more detail the mechanisms of snowfalls, the advection of water vapor which form precipitating clouds, and the difference of nucleus which form the low temperature type snow crystals (Kikuchi, 1969, 1970), the relationship between ice nuclei and snowfalls in the Arctic regions was investigated.

Many surface observations of aerosol particles within the Arctic regions have continued (Shaw, 1983 ; Pacyna and Ottar, 1985 ; Heidam, 1985 ; Heintzenberg and Covert, 1987 ; Bodhaine, 1989) beyond the international sampling network of Rahn (1981), including some by a Swedish ice breaker (Lannefors et al., 1983). The majority of these observations were based on analyses of bulk samples of aerosol particles or gases which were sampled for several days. Heidam (1984) collected aerosol samples throughout the year at five locations in Greenland and analyzed them by PIXE to determine the elemental composition of the Arctic aerosols. Comparison of nearby meteorological soundings with short duration aerosol collection or measurement was shown by Leaitch et al. (1984) to provide an objective analysis of transport of lower latitude aerosol to the Arctic surface.

Most of these papers, however, didn't consider the ice nuclei. Kikuchi et al., (1990) and Sakurai et al., (1987) collected the snow crystals and aerosol particles on filter papers in the Arctic Canada and analyzed them using a SEM and EDX system. They also considered the relationship between the center nucleus of snow crystal and airborne aerosol particles.

In this paper, the concentration and chemical components of ice nuclei were examined from the point of view of the aerosol transportation and the effect of the ice nuclei in the Arctic regions.

2. Locations and measurements

Observations of snow crystals and the collection of aerosol particles were carried out at Inuvik (68°22′N, 133°42′W), N.W.T., Canada from December 12, 1995 to January 15, 1996 and at Kiruna (67°51′N, 20°25′E), Northern Sweden from December 25, 1996 to January 14, 1997.

Aerosol particles were collected on membrane filters using a suction pump twice a day (00 and 12 LMT) at Inuvik, and (03 and 15 LMT) at Kiruna. The sampling volume of the air was 75 liter which took 30 minutes to measure. After the observation was completed, the filter papers on which the aerosol particles had been collected were sealed to keep them from absorbing moisture and they were bought back to the laboratory.

These filters were exposed in a static diffusion chamber at a temperature of -25° C at 2% supersaturation with respect to water. Calculated ice nucleus concentrations (IN) were corrected by blank counts of filter papers through which the air was not sucked. This method provided the possibility to measure the relative variations of the IN with time, but not the absolute IN concentrations in the air.

For the preparation of a specimen to determine the center nucleus of snow crystals, the snow crystals were replicated by a simple vapor method. Collected particles in the replica of snow crystals which were considered as ice nuclei were examined using a scanning electron microscope (SEM) and an energy dispersive X-ray microanalyzer (EDX) system to obtain the elemental composition.

Further, aerosol particles were nucleated in a cold chamber at −25°C and small ice crystals were replicated. The aerosol particles included in those crystals were examined using a SEM and EDX system as center nuclei in the natural snow crystals. The precipitating snow particles were sampled to measure the electric conductivity and pH.

3. Results and consideration

3.1 Results of Inuvik

a) Meteorological conditions

Radiosonde observations were made twice daily (00, 12 UTC) at the Inuvik Upper Air Station. Figure 1 shows a time-height cross section of the air temperature and relative humidity from the surface up to 400 hPa level from 05

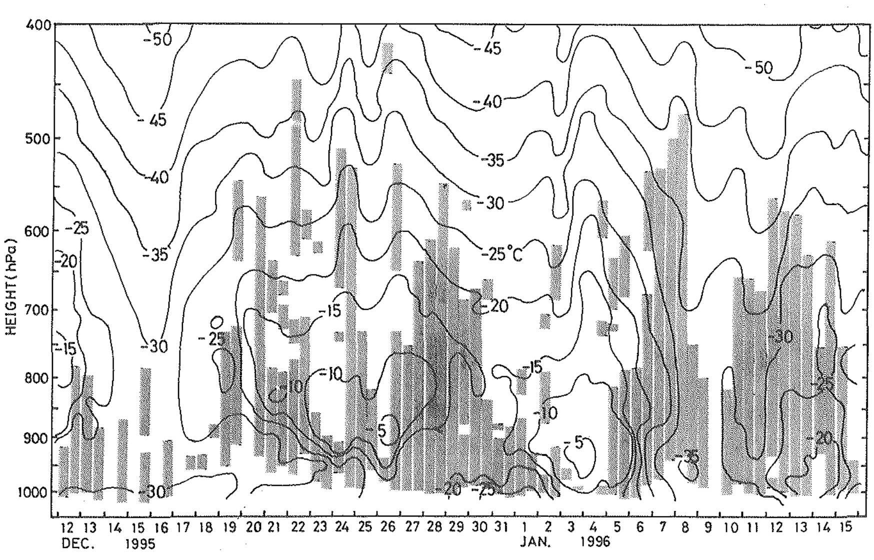

Fig. 1. Time-height cross section of the air temperature and relative humidity from December 12, 1995 to January 15, 1996, at Inuvik, N.W.T., Canada. Isotherms are drawn at an interval of 5°C and isopleths above 80% of relative humidity are shaded by dark screen.

Table 1. Characteristics of snowfalls.

characteristics	Pacific Origin (Dec. 20～30, 1995)	Storm Track (Jan. 6～15, 1996)
temperature	warm	cold
wind velocity		strong
liquid water content	high	low
shapes of snow crystals	rimed dendrite, graupel, needle, *supercooled drops*	combination of bullets, column, *crossed plates*
precipitation duration	short	long
precipitation amount	heavy	light

LMT December 12, 1995 to 17 LMT January 15, 1996 at Inuvik. Isotherms are drawn at an interval 5°C each and isopleths above 80% of relative humidity are shaded with a dark screen. As seen in the figure, there are thick cloud layers extending to 500 hPa. Snowfall periods were divided into warm and cold periods, respectively. The warm period was from December 20 to 29, 1995. This period corresponded to the Pacific Origin disturbance. Contrarily, the cold period was from January 6 to 15, 1996. This period corresponded to the Storm Track disturbance (Asuma, 1997). The characteristics of snowfall in each period are summarized in Table 1.

b) Concentrations of ice nuclei

The time change in the number concentrations of ice nuclei at Inuvik is shown in Fig. 2 along with air temperature at the ground surface and electric conductivity of snowfalls. Open and closed circles show the number concentration of ice nuclei at midday and midnight, respectively. A dotted line shows the average value. Focusing on the fluctuation in the concentration of ice nuclei in detail, there are minimal concentrations during snowfall periods. This seems to correspond to the occurrence of supercooled drizzle in January 27. The electric conductivity decreased in the latter half of snowfall periods. It also seems to correspond to the decrease in the number concentration of ice nuclei.

c) Aerosols nucleated as ice nuclei

Analyses of the center nuclei of snow crystals were carried out using a SEM

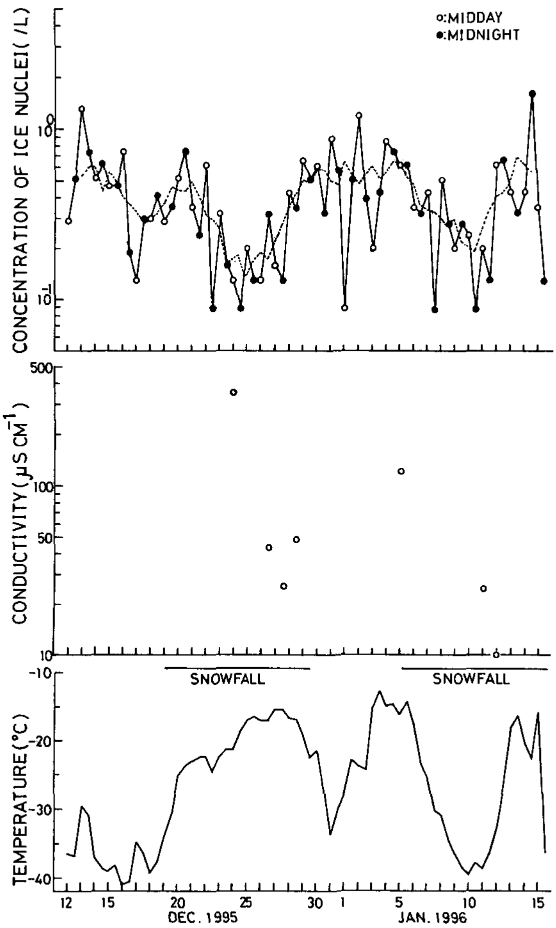

Fig. 2. Time changes in the number concentrations of ice nuclei (upper), electric conductivity of snowfall (middle), and air temperature (lower panel) at Inuvik.

and EDX system. Photographs of column type crystals observed in January 11, 1996 taken by the SEM and EDX are shown in Fig. 3. A small nucleus which resembles the center nucleus of this crystal was recognized around the right part of this crystal. As shown in this figure, the chemical compositions of the nucleus was comprised of the components Na, Cl and K. Therefore, the nucleus was considered a sea salt particle. Another sample of the nucleus taken on the same day showed Na, Cl and S as shown in Fig. 4. The nucleus, therefore, can be considered to be a mixed nucleus, containing sea salt and man made compo-

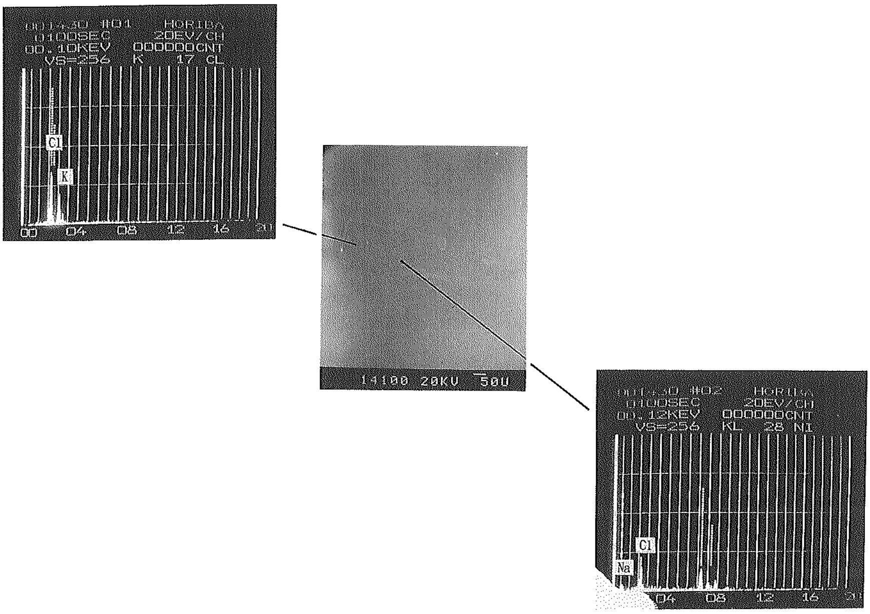

Fig. 3. Photographs of a column type crystal observed in January 11, 1996 taken SEM and EDX system.

nents. The results are summarized in Table 2. As shown in the Table 2, which described the center nucleus during the warm period, components of soil origin dominated. In the higher temperature conditions during the cold period, the components of man made origin dominated. In the lower temperature conditions during cold period, components of marine origin dominated. Aerosols nucleated on the filter paper showed the same tendency as the center nucleus.

d) *Trajectory analysis of air mass*

Back trajectory analyses were carried out using 700 hPa level charts at 12 hour intervals. It can be seen that the air masses arrived at Inuvik observation site on December 26 and 28 were from the Gulf of Alaska as shown in Fig. 5. In contrast, the air masses on January 5 and 11 were from the Arctic Ocean as shown in Fig. 6. It is considered therefore that the difference between the chemical compositions of the center nucleus of snow crystals and aerosols nucleated on filter papers during the warm and cold periods corresponds to the difference between the trajectories of the air masses.

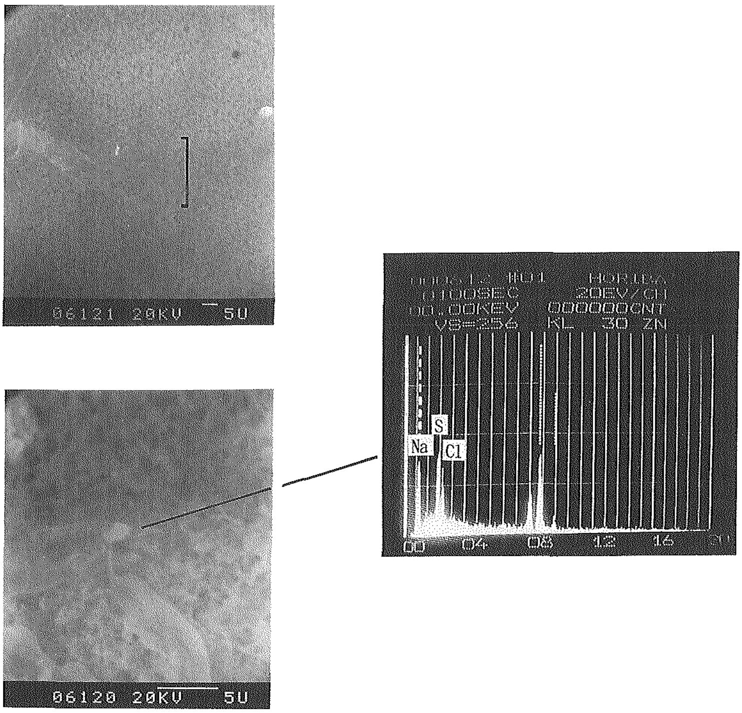

Fig. 4. Photographs of aerosol particle on the filter paper observed in January 11, 1996 taken SEM and EDX system.

Table 2. Elemental compositions of center nucleus of snow crystals and aerosol particles nucleated on membrane filter papers.

	snow crystals		aerosols nucleated
	shapes	elements of center nucleus	elements
Dec. 26, 1995	needle	Cl, Si, S, K	Ca, Si
Dec. 28, 1995	broad branch	Si, Fe, K, Ca	Si, K, Cl
Jan. 5, 1996	dendrite	S	
Jan. 11, 1996	column	K, Cl, Na, Si	S, Cl, Na

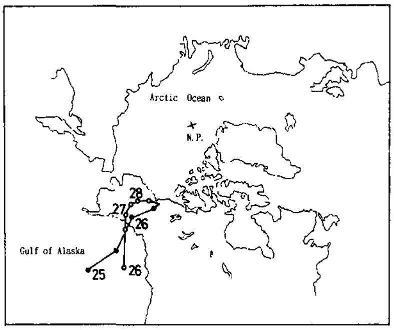

Fig. 5. Back trajectory analysis at 12 hour intervals from December 25 to 26, and from December 26 to 28, 1995.

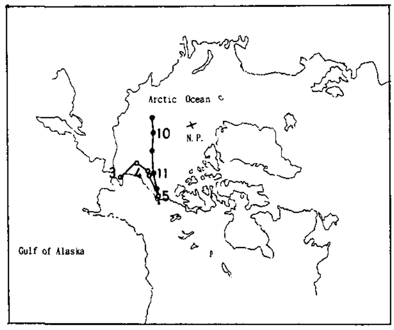

Fig. 6. Same as Fig. 5 but for from January 3 to 5, and from January 10 to 11, 1996.

3.2 Result of Kiruna

a) Meteorological conditions

Figure 7 shows air pressure read from the surface charts, air temperature, and the amount of snowfall in centimeters during the observation period. The air temperature at the ground surface was between 0 and $-30°$ C. The snowfall events were divided into four episodes (I～IV) as shown in Fig. 7. The locations of the centers of low pressure and fronts are shown for each snowfall episode in Fig. 8. Low pressures moved to the east in episode I, to the southeast in the episodes II and III, and to the northeast in the episode IV as shown in Fig. 8.

b) Concentrations of ice nuclei

The time change in the number concentrations of ice nuclei at Kiruna is shown in Fig. 9. The events of snowfalls are shown in the asterisk. Open and closed circles show the number concentration of ice nuclei at midday and midnight, respectively. Focusing on the fluctuation of the concentration of ice nuclei in detail, it seems that the concentrations are increasing during snowfall days. Further, it seems that there is a short cycle of the concentrations. Figure 10 shows the relationship between the number concentration of ice nuclei and the wind direction at 850 hPa level. There is, however, no clear relationship between the two.

c) Aerosols nucleated as ice nuclei

Analyses of the center nucleus of snow crystals were done by a SEM and

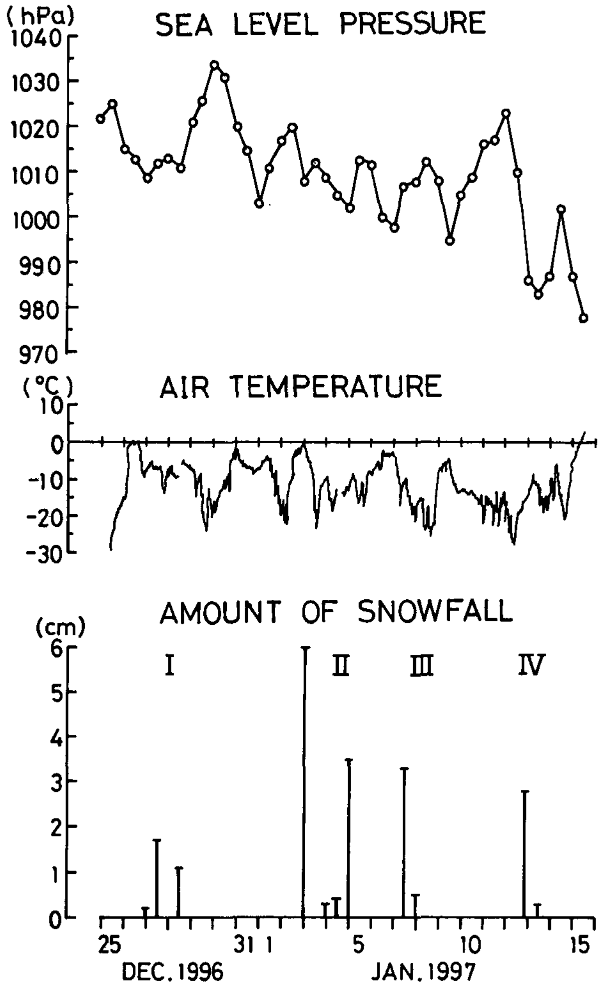

Fig. 7. Time changes of the sea level pressure (upper), air temperature (middle), and amount of snowfall (lower panel) at Kiruna, Sweden.

EDX system. The SEM and EDX photographs of a dendritic crystal observed in January 4, 1997 are shown in Fig. 11. A small nucleus in the lower right panel which resembles the center nucleus of this crystal was recognized around the center part of this crystal. Another nucleus near the center nucleus is shown in the lower left panel. As shown in Fig. 11, the chemical components of the nucleus are considered to be a mixed nucleus having components of Si, Ca, Cl, Al, and S. The frequency of the elements present in the ice nuclei is shown in

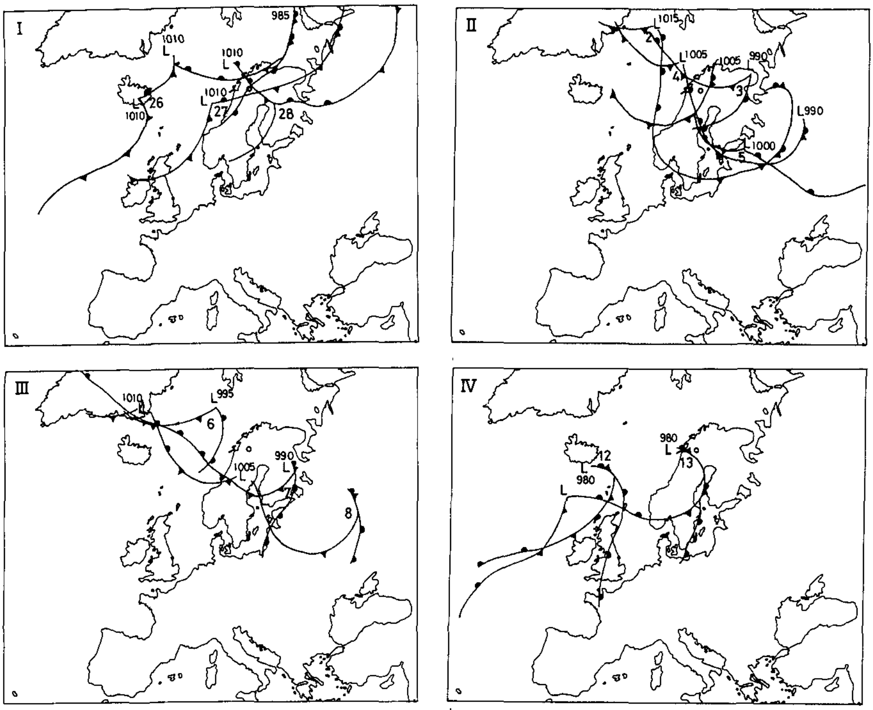

Fig. 8. Synoptic weather charts in the episode I (December 26 to 28, 1996), II (January 2 to 5, 1997), III (January 6 to 8, 1997), and IV (January 12 to 13, 1997).

Fig. 12. In the figure, the number of elements comprising the nuclei is expressed in percentage to the nuclei analyzed by the EDX system. As understood in this figure, the chemical components of ice nuclei were Si, S, Cl, K, Ca, and Na on January 4 and 5 (snowfall episodes II), Si, S, and Cl on January 7 (snowfall episode III), and Si, S, and Cl on January 12 (snowfall episode IV), respectively. It was considered therefore that the ice nuclei consisted of mixed nuclei containing soil, man made and partially sea salt particle components.

The chemical components of aerosol nucleated on the membrane filter sampled on January 5 were Al, Si, K, and Fe as shown in Fig. 13. The results of four days are represented in Table 3. As shown in this table, the elements of the aerosols can be considered to be mainly soil.

d) Trajectory analysis of air mass

Back trajectory analyses were carried out using 850 hPa level charts at one day intervals. It can be seen that the air mass arrived at the Kiruna observa-

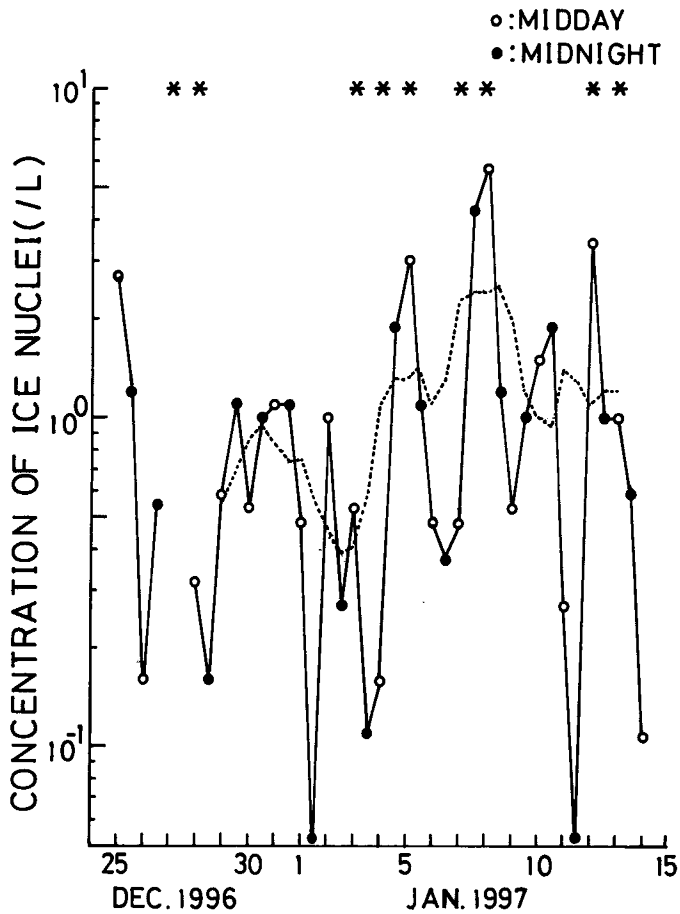

Fig. 9. Time change in the number concentrations of ice nuclei at Kiruna.

tion site in episode IV from the Atlantic Ocean and in episodes II and III from the Arctic Ocean as shown in Fig. 14.

4. Concluding remarks

The observation results obtained at Inuvik, N.W.T., Canada are summarized as follows.

During the warm period of snowfalls, soil particles tended to nucleate and acted as an ice nucleus. During the cold period of snowfalls, however, sea salt particles tended to act as an ice nucleus. This tendency corresponded to the

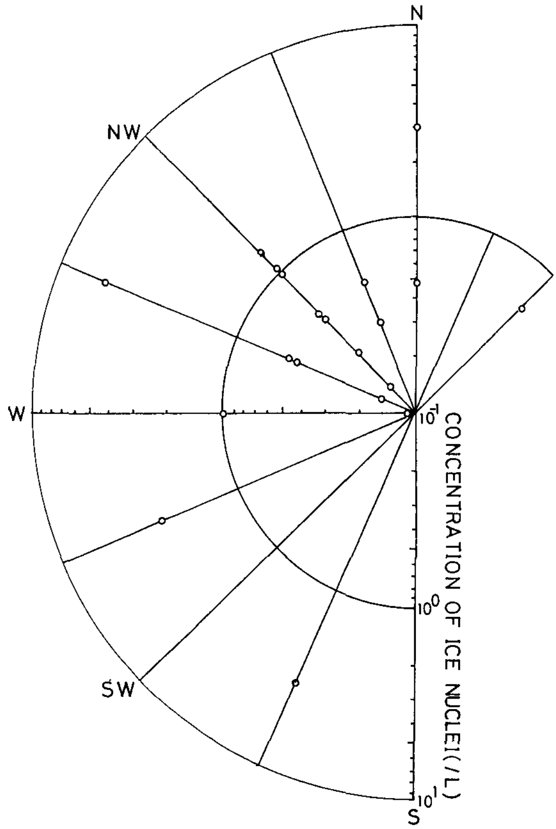

Fig. 10. Relationship between the number concentrations of ice nuclei and wind direction at 850 hPa level.

results obtained by the previous work of Kikuchi et al., (1990). From the time change in number concentration of ice nuclei, the number concentrations tended to decrease during snowfalls. This seems to correspond to the events of the supercooled drizzle during the warm period and to the snowfalls of the polycrystalline snow crystals which have a sea salt particle acting as the center nucleus during the cold period. It is considered from the back trajectory analysis that the trajectory of water vapor is similar to that of airborne aerosols.

The results obtained at Kiruna, northern Sweden are as follows.

The number concentrations of ice nuclei did not depend on the wind direction. Analyses of the chemical compositions of the center nuclei of snow crystals show a dominance of soil and man made components. The presence of sea salt particles depended on the difference of the trajectory of air masses.

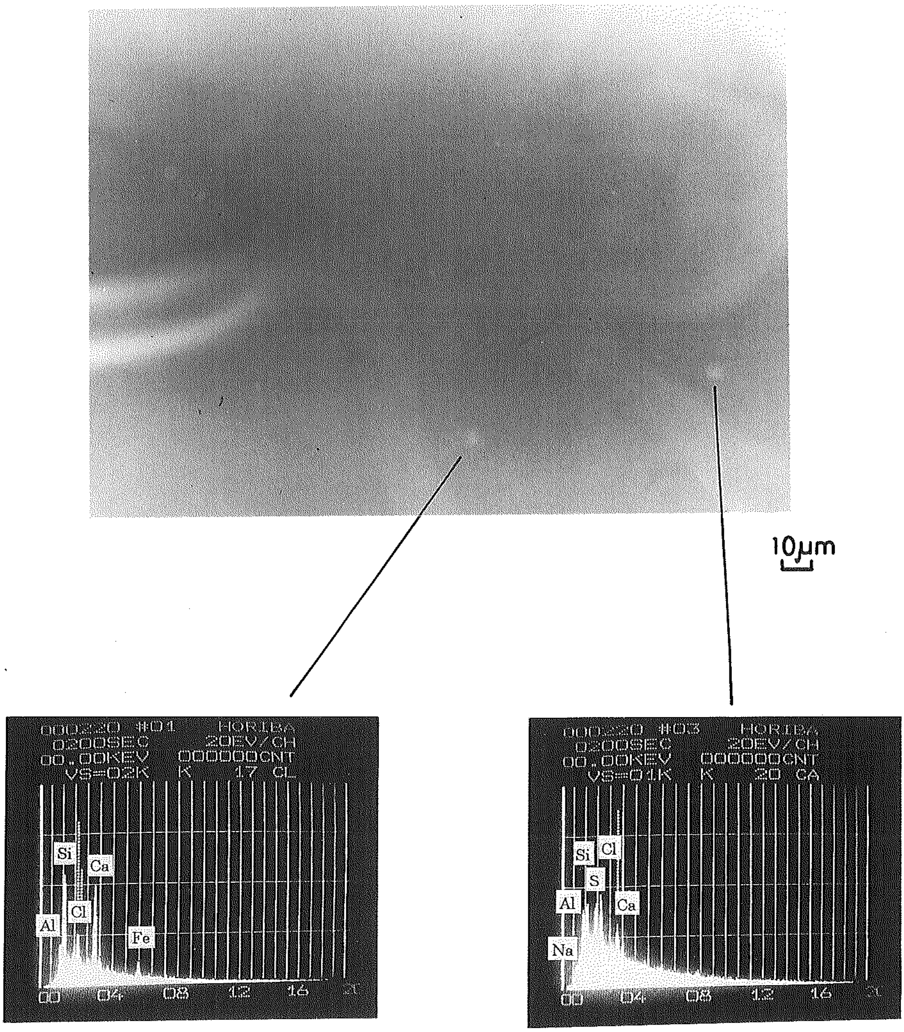

Fig. 11. Photographs of a dendritic crystal observed in January 4, 1997 taken SEM and EDX system.

Most of the aerosol particles nucleated on the filter papers were dominated by soil particles. This seems to support the lack of relationship between the wind direction and the number concentration of ice nuclei.

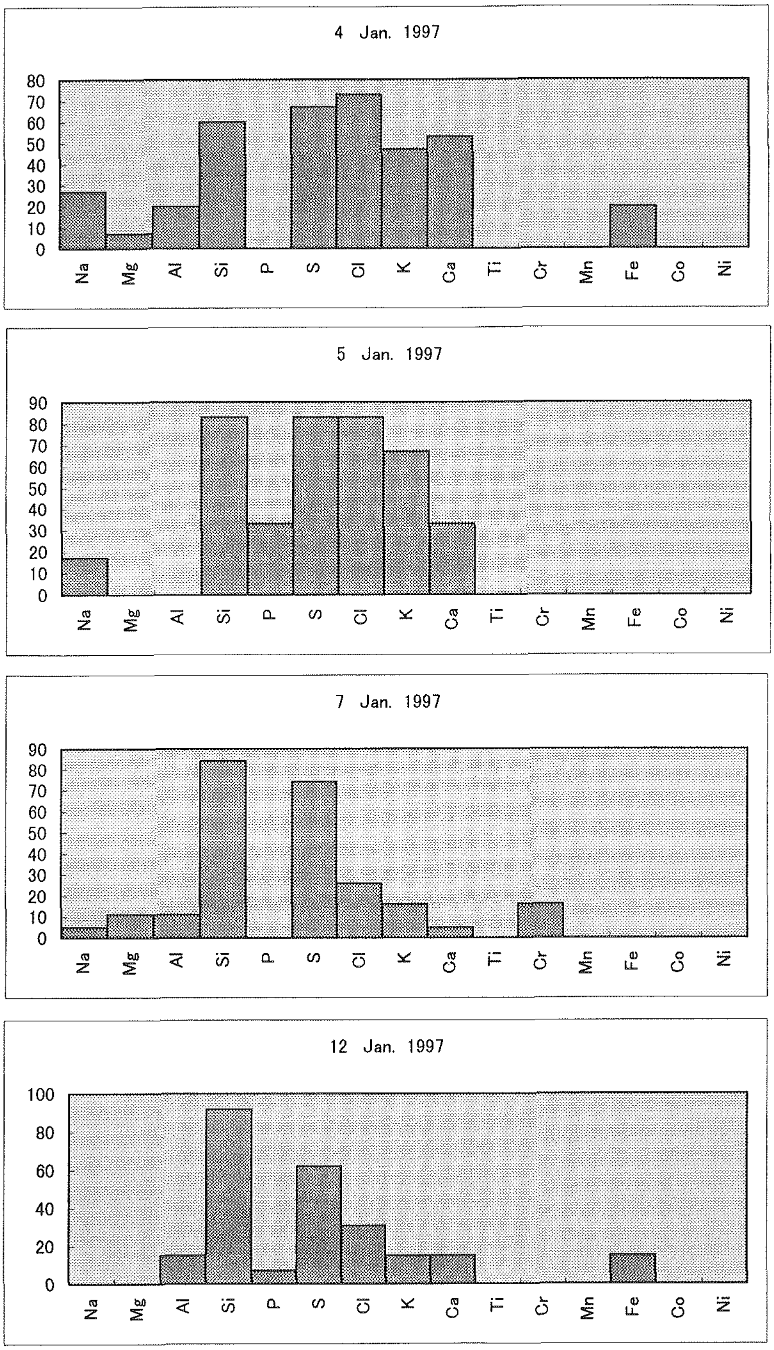

Fig. 12. Frequency distributions of the elements presented in ice nuclei.

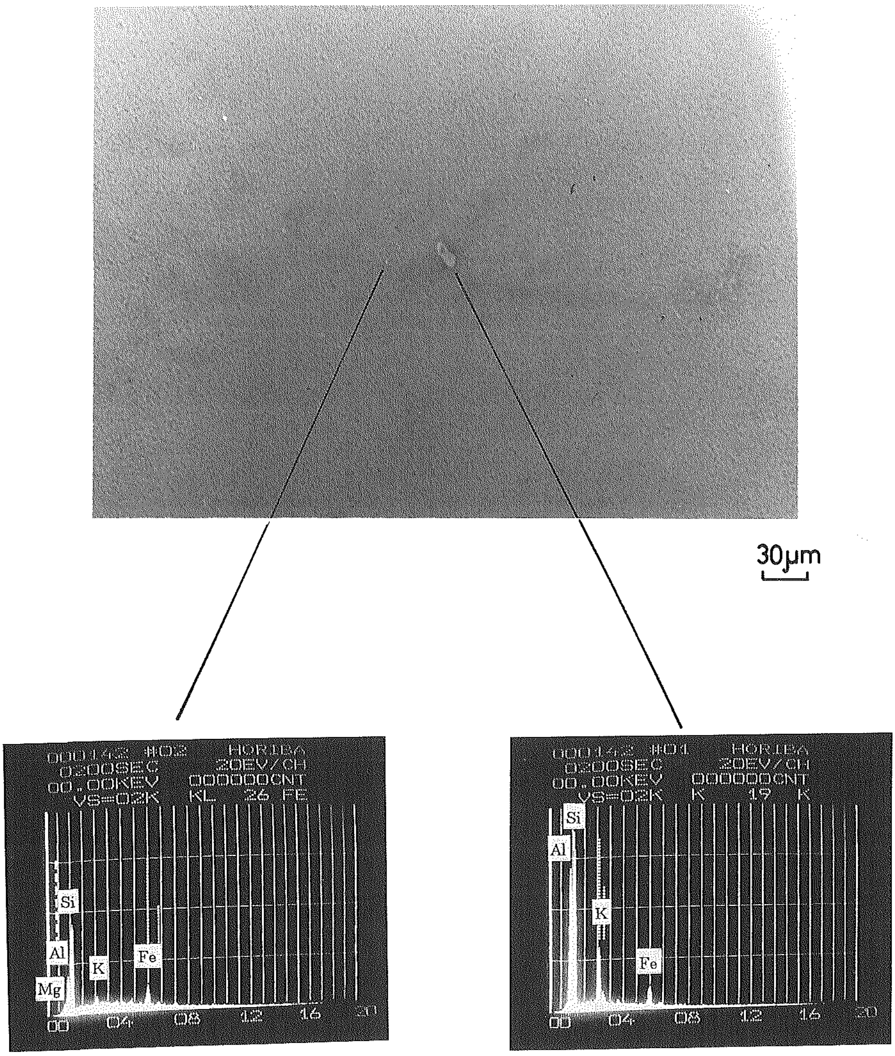

Fig. 13. Phorographs of aerosol particle on the filter paper observed in January 5, 1997 taken SEM and EDX system.

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Table 3. Elemental compositions of aerosol particles nucleated on membrane filter papers.

	Elements
Jan. 4, 1997	Si, K, Fe
Jan. 5, 1997	Si, Al, Mg, K, Fe
Jan. 7, 1997	Ca, Mg, Al, Si, S, Cl
Jan. 13, 1997	Si, Al, K, S, Fe

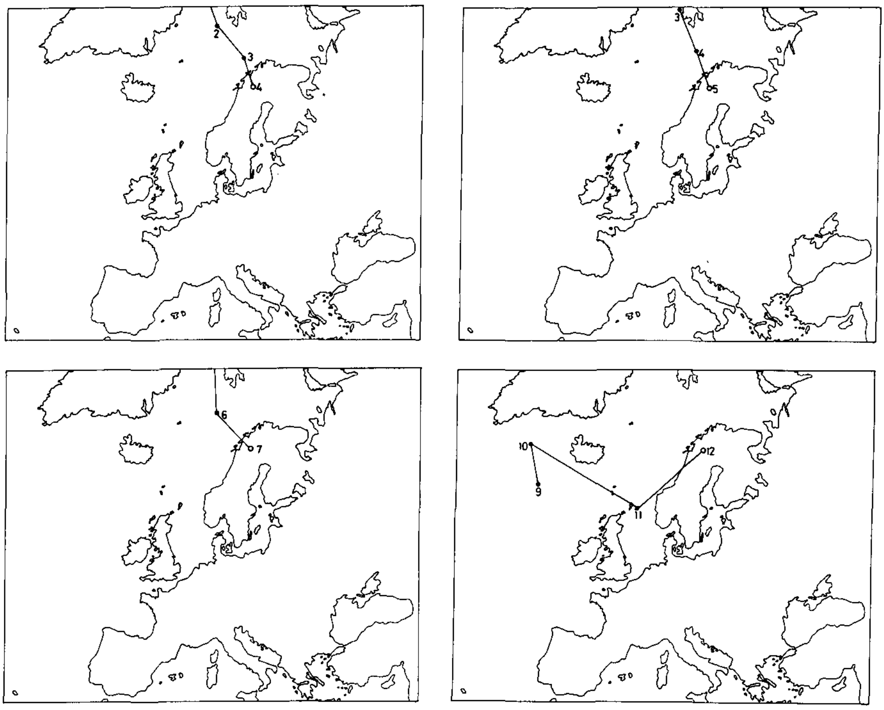

Fig. 14. Back trajectory analysis at one day interval from January 2 to 5, 6 to 8, and 12 to 13, 1997.

the supply of facilities.

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References

Asuma, Y., 1997. Structures of disturbances and water circulation in the Arctic regions. Symposium abstract. Autumn meeting of the Meteorological Society of Japan at Sapporo, 1-6. (in Japanese).

Badhaine, B.A., 1989. Barrow surface aerosol; 1976-1986. Atmos. Environ., **23**, 2357-2369.

Heidam, N.Z., 1984. The components of the Arctic aerosol. Atmos. Environ., **18**, 329-343.

Heidam, N.Z., 1985. Crustal enrichments in the Arctic aerosol. Atmos. Environ., **19**, 2083-2097.

Heintzenberg, J. and D.S. Covert, 1987. Chemically resolved submicrometric size distribution and external mixing of the Arctic haze aerosol. Tellus, **39B**, 374-382.

Kikuchi, K., 1969. Unknown and peculiar shapes of snow crystals observed at Syowa Station, Antarctica. J. Fac. Sci., Hokkaido Univ., Ser. VII (Geophysics), **3**, 99-116.

Kikuchi, K., 1970. Peculiar shapes of solid precipitation observed at Syowa Station, Antarctica. J. Meteor. Soc. Japan, **48**, 343-349.

Kikuchi, K., T. Taniguchi and H. Tsujimura, 1990. Relation between the center nucleus of snow crystals and aerosol particles in Arctic Canada. J. Fac. Sci., Hokkaido Univ., Ser. VII (Geophysics), 8, 415-435.

Lannefors, H., J. Heintzenberg and H.-C. Hansson, 1983. A comprehensive study of physical and chemical parameters of the Arctic summer aerosol; results from the Swedish expedition Ymer-80. Tellus, **35B**, 40-54.

Leaitch, W.R., R.M. Hoff, S. Melnichuk and A.W. Hogan, 1984. Some physical and chemical properties of the Arctic winter aerosol in northeastern Canada. J. Climate and Appl. Meteor., **23**, 916-928.

Pacyna, J.M. and B. Ottar, 1985. Transport and chemical composition of the summer aerosol in the Norwegian Arctic. Atmos. Environ., **19**, 2109-2120.

Rahn, K.A., 1981. The Arctic air-sampling network in 1980. Atmos. Environ. **15**, 1349-1352.

Sakurai, K., M. Kajikawa and K. Kikuchi, 1987. On ice nuclei of peculiar shapes of snow crystals observed at Yellowknife, N.W.T., Canada. Studies on the Snow Crystals of Low Temperature Types and Arctic Aerosols (edited by K. Kikuchi), Hokkaido University, 260-283.

Shaw, G.E., 1983. On the aerosol size distribution spectrum in Alaskan air mass system: Arctic haze and nonhaze episodes. J. Atmos. Sci., **40**, 1313-1320.