Chemical Characteristics of Snowpack due to Differences in Snowfall Type in Japan Alps

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Abstract

We conducted a snow survey in February 2006 and January 2007 in Japan Alps. Approximately 0.60 m and 1.05 m snowfalls were deposited at the study site in February 2006 and January 2007, respectively. It was observed that the occurrence of snowfall was due to the low pressure formation in the vicinity of Japan and it also being the winter monsoon period. As a result of the analyzed snowpack, including new snow at a high resolution every 0.03 m, a plurality of high-electric conductivity layers were observed at different depths. From the measurement of the major ion concentrations, it was observed that the high-electric conductivity layers had different chemical characteristics. High concentrations of NO_3^- and SO_4^{2-} deposits were observed in the snowpack layer that was formed due to the low-pressure system that passed in the vicinity of Japan. On the other hand, the layer that formed during the winter monsoon pattern, large amounts of sea salts were deposited in the snowpack in January 2007. However, layers with a high sea-salt concentration were not observed in February 2006. We analyzed the movement of the air mass that flowed into the study area. Air mass passed through the city at the time of the passage of the low-pressure system. In addition, the air mass that crossed the Sea of Japan entered the study area during the winter monsoon pattern. However, the movement of the air mass was different during the winter monsoon pattern in February 2006 and January 2007.

1. Introduction

The chemical components accumulated with snowfall during the winter season are stored in the snowpack. The accumulated chemical components are separated by the process when the snow particle metamorphoses into the surface of the snow particle and begins to flow out with the snowmelt water (Suzuki, 1996; Suzuki, 2000). The snowmelt water flow in the early snowmelt period begins to dissolve the chemical components at the surface of the snow particle. Therefore, many chemical components are included in the snowmelt water that begins to flow out in this period. The acidification occurs temporarily in the river as the snowmelt water flows out (Kuramoto and Suzuki, 2006).

A study on the weather conditions and winter precipitation was performed. Suzuki (1983, 1984) collected the winter precipitation and snowpack of one winter season in Sapporo, Hokkaido prefecture. The origin of the chemical components was examined in the sample. SO_4^{2-} was influenced by the use of fossil fuels in Sapporo, whereas Na^+ and Cl^- were sea salt. Suzuki and Endo (1994a, 1994b) collected winter precipitation samples everyday in Tohkamachi, Niigata prefecture. The chemical characteristics of the samples and the weather conditions were investigated. Large amounts of sea salt were deposited during the winter monsoon pattern and large amounts of acid-containing materials were deposited when a low-pressure system passed the south coast of Japan.

There is no outbreak source near the mountainous regions. The pollutants from the neighborhood are not deposited in these regions. In addition, the weather condition changes with time. Therefore, sampling at short intervals of time is necessary to examine a detailed change. However, if the area does not pass through the snowmelt process, it is thought that the chemicals originating from the precipitation is stored and accumulated intermittently. The chemical components preserved in the snowpack of the mountainous region can be obtained through various atmospheric information. However, it is difficult to clarify the exact time scale of the deposited snow in each layer where there is little availability of meteorological observation data in the mountainous region. Therefore, the presumption of the deposition period has been done so far by using various techniques. For example, a method to estimate the deposition period was reported with the sea salt components or $\delta^{18}O$ in the snowpack at Mt. Tateyama, which is a heavy snowfall mountainous region located in the Sea of Japan side (Kido *et al.,* 1997, Toyama *et al.,* 2005).

Nishita *et al.* (2007) studied the transportation process of aerosols during summer in Mt. Norikura. The air mass flowed from the Pacific and the Asian Continent and it became clear aerosol was different by an air mass. However, the author did not discuss the difference in the chemical property resulting from differences in the air mass composition. In the Sea of Japan side, considerable winter precipitation was observed; that is, mainly two patterns such as the winter monsoon pattern and low pressure pattern that passed over the Sea of Japan. On the other hand, winter precipitation occurs due to the passage of the low-pressure system along the south coast of Japan in the Pacific side. The Japan Alps area is the backbone of Japan where precipitation is observed under both conditions during the entire winter season. The different course of water bringing these precipitations is thought to be the different sources of ion species included in the snowpack. In the Sea of Japan coastal area, many ion species are included in the precipitation, and it is reported that the pH of the winter precipitation is low (Satow, 1993; Suzuki and Endo, 1994b). Toyama *et al.,* (2007) studied the origin of nss-SO_4^{2-} in the snowpack on the basis of $\delta^{34}S$ and the S/N ratio at the Mt. Nishi-Hodaka, Japan Alps. The assumption that the ion species included in the snowpack depend on the different snowfall types for estimating the deposition period. In this study, we conducted a multiple snow survey at the eastern slope of Mt. Norikura in the Japan Alps between the winter season of 2006 and 2007. The purpose of this study is to clarify the chemical characteristics of the snowpack by different snowfall types.

2. Methods

Mt. Norikura (3026 m a.s.l.) is located in the southernmost part of the northern Japan Alps. The sampling site (1590 m a.s.l.) is located at the eastern slope of Mt. Norikura (Fig. 1). It is at the foot of the mountain and is formed by lava.

The meteorological observation devices were set up at the sampling site; the air temperature and snow depth were measured automatically. Moreover, the precipitation was measured with a tipping-bucket rain gauge set up at Norikura station (1440 m a.s.l.), Institute of Mountain Science, Shinshu University, that was located approximately 2 km northeast from the sampling site. The annual mean air temperature that we observed in sampling site was 6.3℃, the annual precipitation was 2525.5 mm, and the winter season precipitation observed from December to March was 564.5 mm in Norikura station in 2006. The study site is approximately 5 km from the top of Mt. Norikura. The prevailing wind of winter blows from the northwest in Japan Alps. In the sampling site, northwest wind is observed in the winter season. Therefore, it is thought that a local influence can be disregarded. We considered the study area to represent the eastern slope of Mt. Norikura.

A heavy snowfall was observed to occur in the study area in February 2006 and January 2007. The snow samples were collected before and after the snowfall. The snow pits were dug up to the ground level for the sample collection. Afterwards, the samples were collected from the snow surface layer to the ground level at intervals of 0.03 m. A cube-type snow sampler made of stainless steel and having a height of 0.03 m was used for the sample collection. The sample was inserted into a sample bag (Nasco: Whirl-pak) and sealed to be transported to the laboratory. Samples were preserved without melting in a deep refrigerator until their analysis. They were allowed to

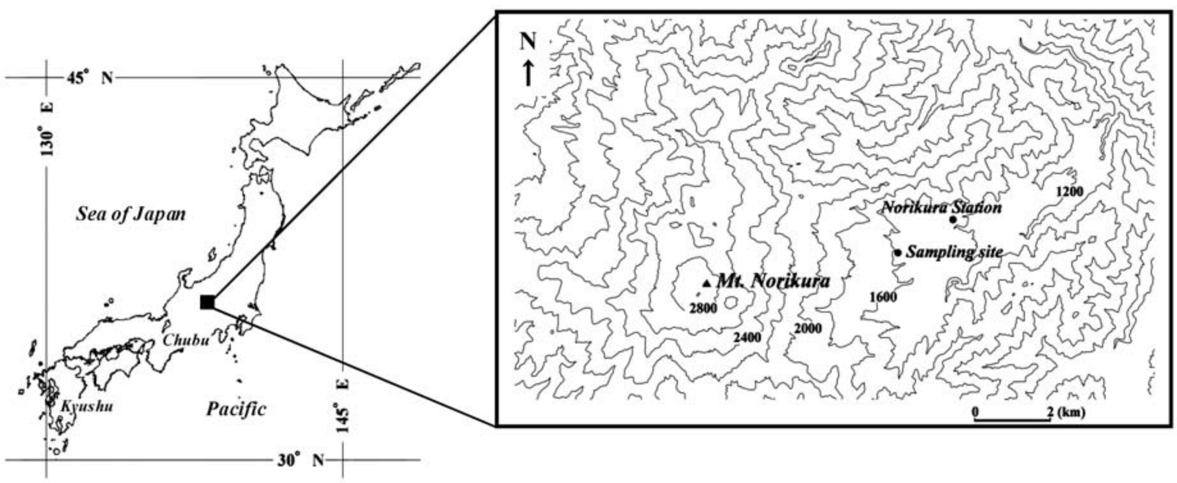

Fig. 1. Location map of Mt. Norikura (left) and a detailed map of the study site (right).

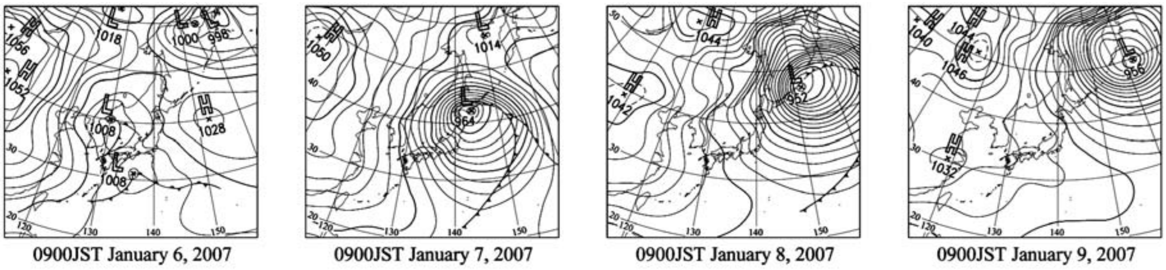

Fig. 2. Change of weather chart from January 6 to 9, 2007 (Source: Japan Meteorological Agency, 2007).

melt at room temperature before the analysis. The pH, electric conductivity, and major ions (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}) were measured with the pH meter, conductivity meter, and ion chromatograph (Dionex: DX-500), respectively. All the analytical work was performed in a clean room.

3. Results and Discussion

An increase in snowfall of approximately 1.05 m was observed at the study site on January 6 to 8, 2007. Figure 2 shows the ground weather chart in the vicinity of Japan from January 6 to 9, 2007. The low-pressure system passed along the Sea of Japan and the south coast of Japan on January 6, 2007. Afterwards, it intensified while moving northwards and a strong winter monsoon pattern developed in the vicinity of Japan. From January 7 to 8, 2007, the vicinity of Japan was covered by the strong winter monsoon. Figure 3 shows the changes in the precipitation, air temperature, and snow depth from January 5 to 9, 2007. The air temperature during daytime had increased on January 6, 2007. However, the air temperature decreased during the day on January 7 and 8, 2007, because the vicinity of Japan was under the influence of the strong winter monsoon pattern. The precipitation observed the study site on January 6, 2007 was 25.5 mm. The precipitation observed on January 7 and 8, 2007, was 26.0 mm and 6.5 mm, respectively. The snow depth began to increase from January 6, 2007, and it reached up to 1.35 m on January 8, 2007, at 8 : 00 (JST).

Figure 4 shows the vertical profiles of the pH and electric conductivity in the snowpack sampled on

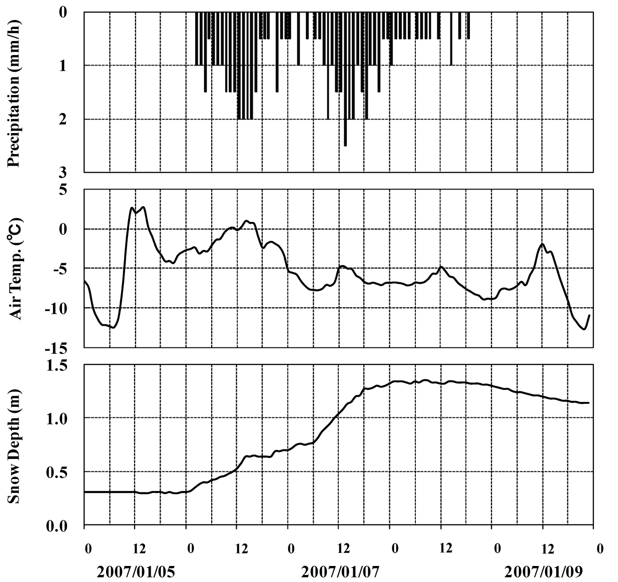

Fig. 3. Variations in precipitation, air temperature, and snow depth from January 5 to 9, 2007.

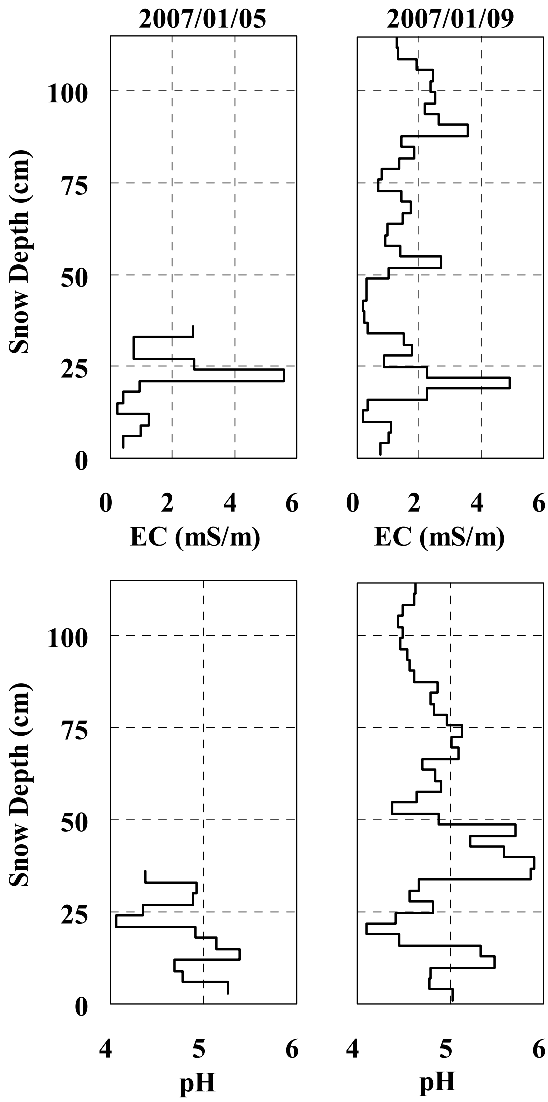

Fig. 4. Vertical profiles representing electric conductivity and pH in snowpack samples obtained on January 5 and January 9, 2007.

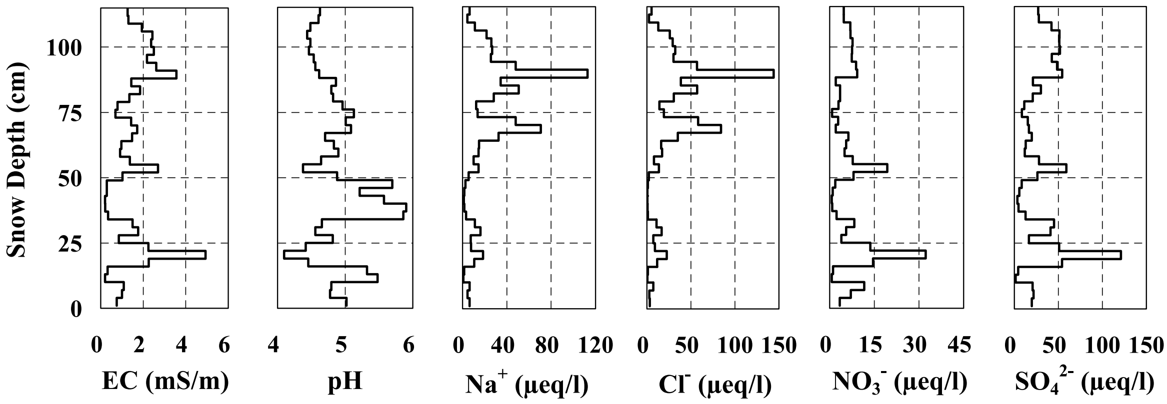

Fig. 5. Vertical profiles representing electric conductivity, pH, and major ion concentrations in snowpack samples.

January 5 and January 9, 2007. The snow depths at the sampling time on January 5 and January 9, 2007 were 0.36 m and 1.15 m, respectively. The profiles of the pH and electric conductivity of the snowpack resembled those in the layer lower than approximately 0.35 m. From this, we understand that the new snow layer was greater by approximately 0.35 m on January 9, 2007.

Figure 5 shows the vertical profiles of the pH, electric conductivity, and concentrations of major ions in the snowpack sampled on January 9, 2007. In the new snow layers, we observed high-electric conductivities in some layers at approximately 0.55 m; however, the pH was low in the same layer. In this layer, the concentrations of NO_3^- and SO_4^{2-} were high. Therefore, the pH was decreased and the electric conductivity was increased. The neighboring layer of 0.55 m can estimate the snowfall on January 6 2007 from the precipitation and a change in snow depth point of view. Therefore, we analyzed pattern of the trajectory in order to examine the course of the movement of air masses by the data obtained from CGER-METEX (NIES-CGER). The precipitation reached the highest at 12 : 00 (JST) on January 6, 2007, in the vicinity of the study area. We analyzed this by employing an isentropic method and show the pattern of trajectory for the past four days. We used the analysis results obtained from the pattern of trajectory and showed the course of movement of the air mass that drifted into the study area at 12 : 00 (JST) on January 6, 2007 (Fig. 6a). The plots in Fig. 6a are shown at intervals of 12 h. We understand from the pattern of trajectory that the air mass that began to flow from the Asian continent on January 2, 2007, passed the south coast of the Kyushu and Chubu regions and then arrived in the study area. From this, it is thought that the chemicals that occurred in an area westward of the Chubu region were brought with an air mass into the study area when the low-pressure system passed along the south coast of Japan.

On the other hand, a high-electric conductivity was observed in the layers of the snow depth of

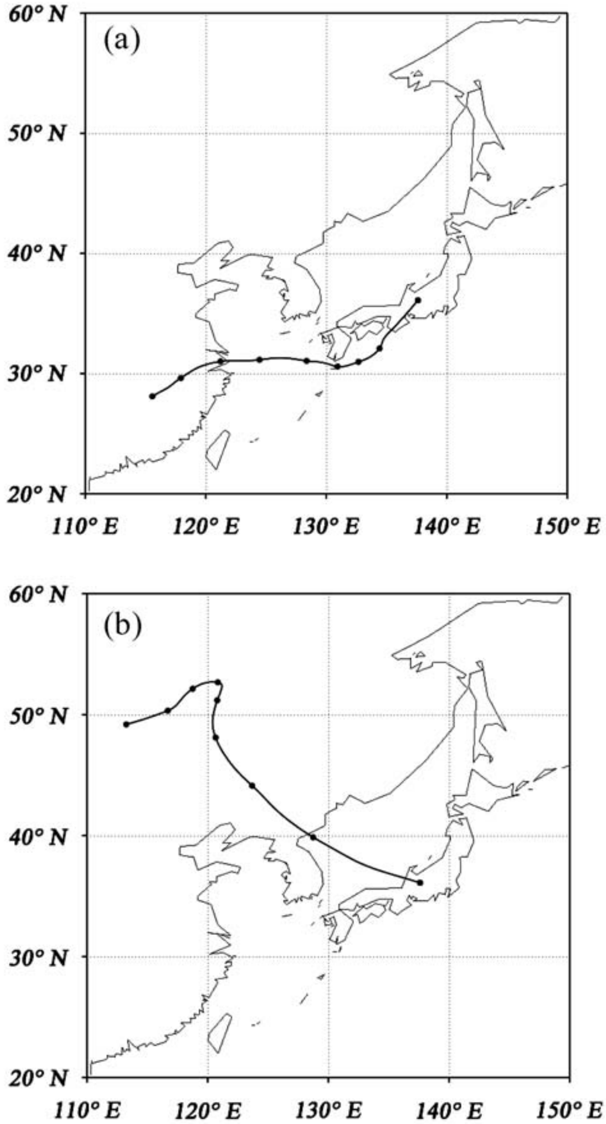

Fig. 6. Air mass back-trajectory generated using the CGER-METEX model for winter precipitation observed at sampling site. ● denotes every 12 h. (a) Low-pressure system that passed in vicinity of Japan ending on January 6, 2007, at 12 : 00 (JST), (b) Winter monsoon pattern ending on January 8, 2007, at 4 : 00 (JST).

approximately 0.70 m and 0.90 m. In these layers, the decrease in the pH and the remarkable increase in the NO_3^- and SO_4^{2-} concentrations were not observed. However, the Na^+ and Cl^- concentrations increased remarkably. We can estimate that it is the snow that was deposited on January 7 to 8, 2007, when the vicinity of Japan was under the strong winter monsoon pattern; these layers occur due to the precipitation and the change in the snow depth. We used the pattern of trajectory analysis results and obtained the course of the movement of the air mass at the time of the snowfall at 4 : 00 (JST) on January 8, 2007 (Fig. 6b). When an air mass passes the Sea of Japan, the sea salt substances, included in the atmosphere by the northwest periodic wind, are carried to the study area. It is thought that the layers of high Na^+ and Cl^- concentrations originated from sea salts. On the other hand, a remarkable increase in NO_3^- is not observed.

In the study area, heavy snow was observed in February 2006. Figure 7 shows the change in the precipitation, air temperature, and snow depth from February 2 to 8, 2006. Precipitation was observed on February 3 and from February 6 to 8, 2006. The air temperature decreased in this period. Therefore, it was thought that the study area received snowfall. The precipitation observed at the study site during the latter half of the period from February 6 to 8, 2007, was 23.5 mm. The snow depth begins to increase from February 6, 2006, when precipitation was observed, and it reaches 1.69 m on February 8, 2006, at 17: 00 (JST). Figure 8 shows the ground weather chart in the vicinity of Japan from January 6 to 8, 2006. The low-pressure system passed along the south coast of Japan. This low-pressure system intensifies while going northwards and the winter monsoon pattern develops in the vicinity of Japan.

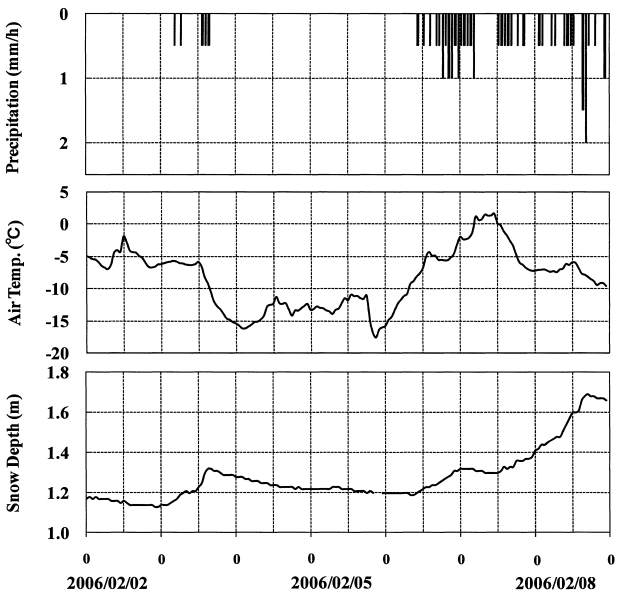

Fig. 7. Variations in precipitation, air temperature, and snow depth from February 2 to 8, 2006.

Figure 9 shows the vertical profiles representing the pH and electric conductivity in the snowpack sampled on February 2 and February 8, 2006. The snow depths at the sampling time on February 2 and February 8, 2006, were 1.05 m and 1.47 m respectively. The profiles of the pH and electric conductivity of the snowpack resembled in the layer lower than approximately 0.90 m on February 2 and February 8, 2006. From this, we understand that the new snow layer had a thickness of approximately 0.90 m on February 8, 2006.

Figure 10 shows the vertical profiles of the pH, electric conductivity, and concentrations of major ions in the snowpack sampled on February 8, 2006. In the new snow layer, we observed high-electric conductivities in some layers at depths of approximately 0.95 m and 1.15 m. Similar to the layer observed at a depth of approximately 0.55 m on January 2007, the pH was lowered and the NO_3^- and SO_4^{2-} concentrations were high in these layers. The neighboring layer of 1.15 m can estimate the snowfall on February 6, 2006 from the precipitation and a change in snow depth point of view. We analyzed the pattern of trajectory to examine the course of the movement of air masses. On February 6, 2006, it was at 10: 00 (JST) when the precipitation began to fall in the vicinity of the study area. We analyzed this by employing an isentropic method and showed the pattern of trajectory for the past three days (Fig. 11a). We learnt from the pattern of trajectory that the air mass that began to flow from the Asian continent on February 4,

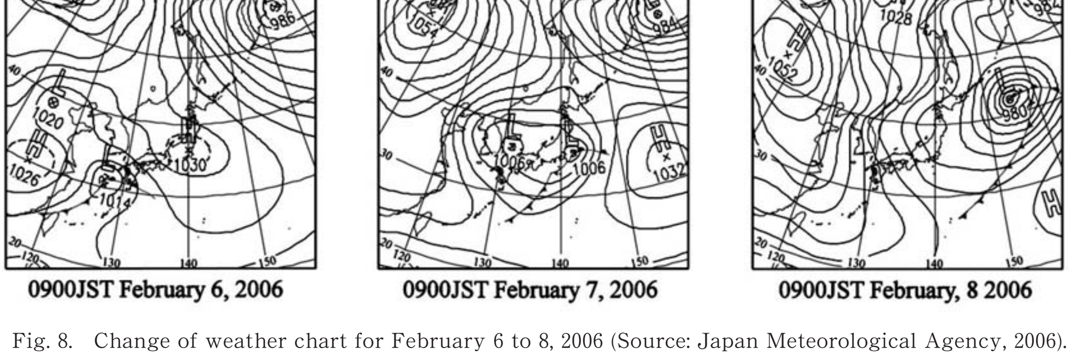

Fig. 8. Change of weather chart for February 6 to 8, 2006 (Source: Japan Meteorological Agency, 2006).

2006, passed the Yellow Sea and the West Japan region, and then, it entered the study area. From this, it is thought that the concentrations of ion species that occurred in the West Japan region were brought with an air mass to the study area when the low-pressure system passed along the south coast of Japan.

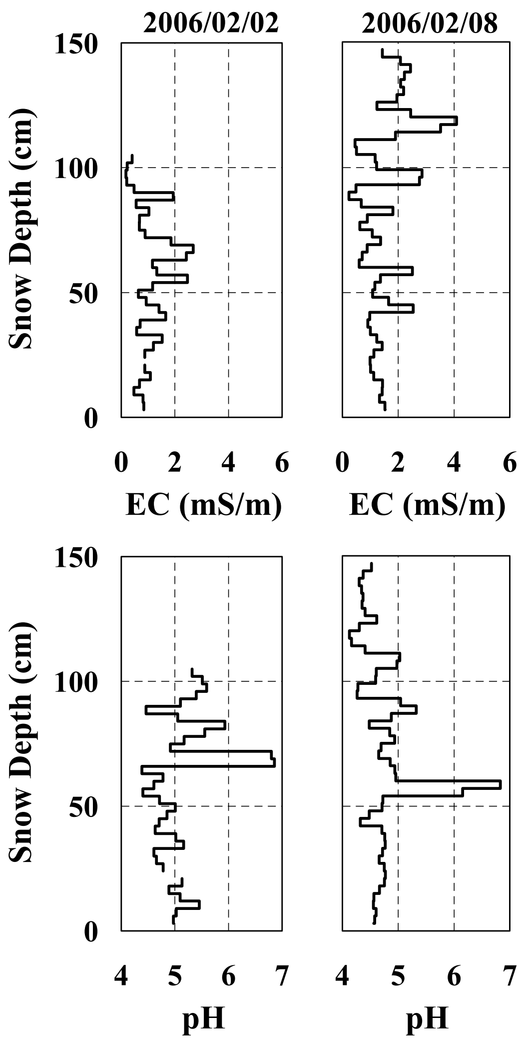

Fig. 9. Vertical profiles representing electric conductivity and pH in snowpack samples obtained on February 2 and February 8, 2006.

On the other hand, remarkably high-concentration layers of Na^+ and Cl^-, as observed on January 2007, were not observed. We used the pattern of trajectory analysis results and obtained the course of the movement of air masses when the vicinity of Japan was under the winter monsoon pattern at 9: 00 (JST) on February 8, 2006 (Fig. 11b). It is understood that the air mass that flowed into the study area at 9: 00 (JST) on February 8, 2006, came from the west as compared to that observed on January 2007. It is thought that the air mass was caused due to the weak development of the low-pressure system in February 2006 as compared with January 2007. Therefore, there are little sea salt components taken in the atmosphere by the northwest periodic wind. It is thought that the layer did not form high concentrations of sea salt components such as Na^+ and Cl^- in the study area.

4. Conclusion

A heavy snowfall was observed in eastern slope of Mt. Norikura in February 2006 and January 2007. We conducted the snow survey before and after the snowfall. The low-pressure system observed in February 2006 and January 2007 developed in the vicinity of Japan. Approximately 0.60 m and 1.05 m of snowfall was deposited in sampling site, respectively. The chemical characteristic differed with the depth in the new snow layer. At the time of this snowfall event, there was an influence on the course of two different air masses in the study area. When the low-pressure system passed the vicinity of Japan, the air mass flowed through the West Japan region into the study area. For the snow layer that accumulated in this period, large amounts of NO_3^- and SO_4^{2-} were deposited that was considered as the outbreak source in the West Japan region. On the other hand, there was an air mass crossing the Sea of Japan from the Asian Continent when the vicinity of Japan was under the strong winter monsoon pattern. In January 2007, a large amount of sea salt substances were deposited in the layers, where they accumulated. However, high

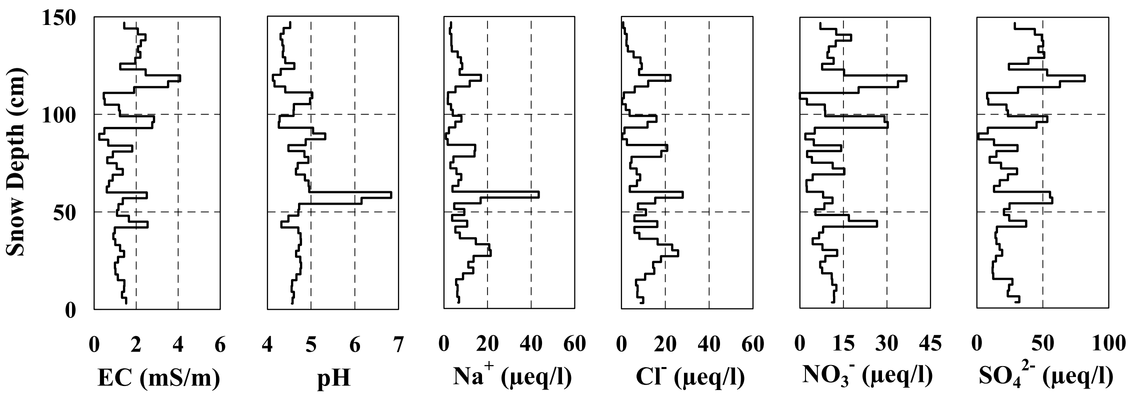

Fig. 10. Vertical profiles representing electric conductivity, pH, and major ion concentrations in snowpack samples.

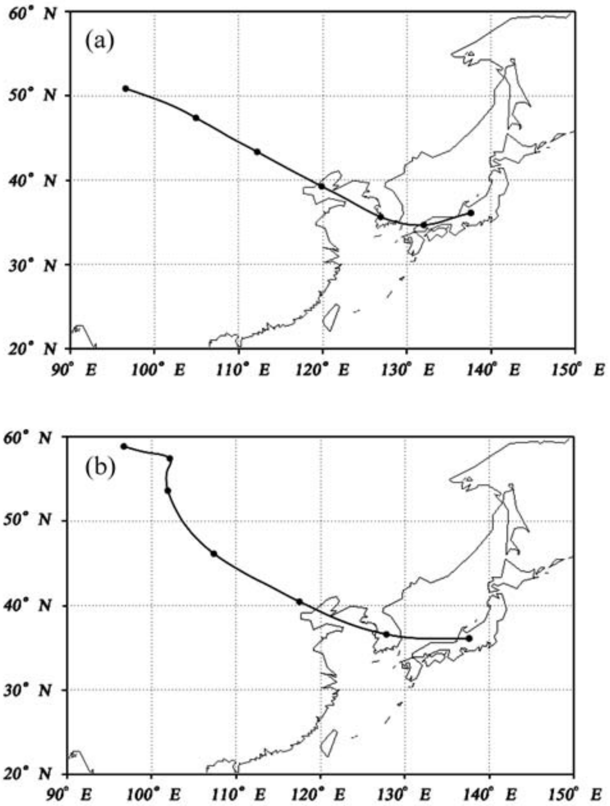

Fig. 11. Air mass back-trajectory generated using the CGER-METEX model for winter precipitation observed at sampling site. ● denotes every 12 h. (a) Low-pressure system that passed the vicinity of Japan ending on February 6, 2007, at 10 : 00 (JST), (b) Winter monsoon pattern ending on February 8, 2007, at 9 : 00 (JST).

sea salt concentration layers were not observed in February 2006. The low-pressure system intensified in January 2007. As a result, it is thought that the reason is because many sea salt components were carried by a strong northwest periodic wind. The snowfall observed in the Japan Alps area was a characteristic of different chemical components brought in the case of a strong winter monsoon pattern and low pressure pattern in the vicinity of Japan.

Acknowledgements

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