Temporal variation in acidity and ion concentration of snowmelt water in light and heavy snow years

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Abstract This paper describes the temporal variation in chemical components of snowfall and snowmelt in a temperate snowy area. We conducted snowfall and snowmelt water sampling and their water quality analysis in light and heavy snow years at the Tohkamachi experiment station, Japan. We compared the behaviour of acidity and ion concentration of snowmelt water in response to annual snow conditions. Our results show that the mean acidity of snowfall is slightly higher than that of snowmelt. More acidic melt water flows out of the snowpack into the ground when snowmelt is generated on the surface and meltwater reaches the bottom of the snowpack. Comparisons between the two years revealed that although the snowpack has higher capacity for storing chemical components with increase of snowdepth, the stored chemical components gradually flow out of the snowpack with melt water caused by the heat flux from soil.

Key words snowmelt; temperate snow area; annual snow condition; pH; electric conductivity; yellow sand

INTRODUCTION

Snowfall contains sulfur oxides and nitrogen oxides due to human activity or mineral dust generated by wind action on arid and semi-arid areas, present in the troposphere (Nishikawa *et al.*, 2000; Ooki & Uematsu, 2005). The chemical components, which are included in the snowfall, are stored in the snowpack during the winter season. The accumulated chemical components infiltrate through the snowpack with repeated water melting and freeze. Intensive chemical components may flow out of the snow bottom due to the lower freezing point and higher melting point of water contaminated by chemical components, relative to pure water (Colbeck, 1981; Gro & John, 2008). It has been suggested that this may lead to temporal acidification of river environments in cold climate regions (Johannessen & Henriksen, 1978; Jeffries *et al.*, 1979; Aga *et al.*, 2001).

The Japan Sea side of the main Japanese island is famous as a heavy snow area and belongs to the warm temperate zone. Generally, a cold dry winter monsoon blows from the Asian continent to Japan during winter. Heat and vapour are transported from the relatively warm sea surface to the lower atmospheric layer as it crosses the Japan Sea. This causes a decrease in the stability of the lower temperature layer, the occurrence of cumulo-nimbus, and brings heavy snowfall to the Japan Sea side during the intensification of typical winter synoptic patterns, which are characterized by high pressure over Siberia (Siberia high) and low pressure over the Pacific (Pacific low). Cold-air advection from the north is another factor that leads to heavy snow. High snowpack has the potential of storing chemical components. A high rate of melt is driven by the temperate climate during the snowmelt season (Asaoka *et al.*, 2002, 2007). Moreover, Asian dust occurs from arid regions in eastern Asia, such as the Taklamakan and Gobi deserts, in spring time, and the spring monsoon transports mineral dust over the North Pacific Ocean and Japanese mainland (Yabuki *et al.*, 2005).

Winter precipitation and snow depth in temperate snowy areas, such as the Japan Sea side of the Japanese main island, have greater variation than in the cold snow regions. In this study, we conducted snowfall and snowmelt water sampling and their water quality analysis in a light snow year and a heavy snow year in the temperate snowy area. We also compared the acidity and ion concentration of snowmelt water between these two years. There are few observed data in the temperate snowy area. Better understanding the characteristics of snowmelt acidity and chemical components is important for soil and river environment management.

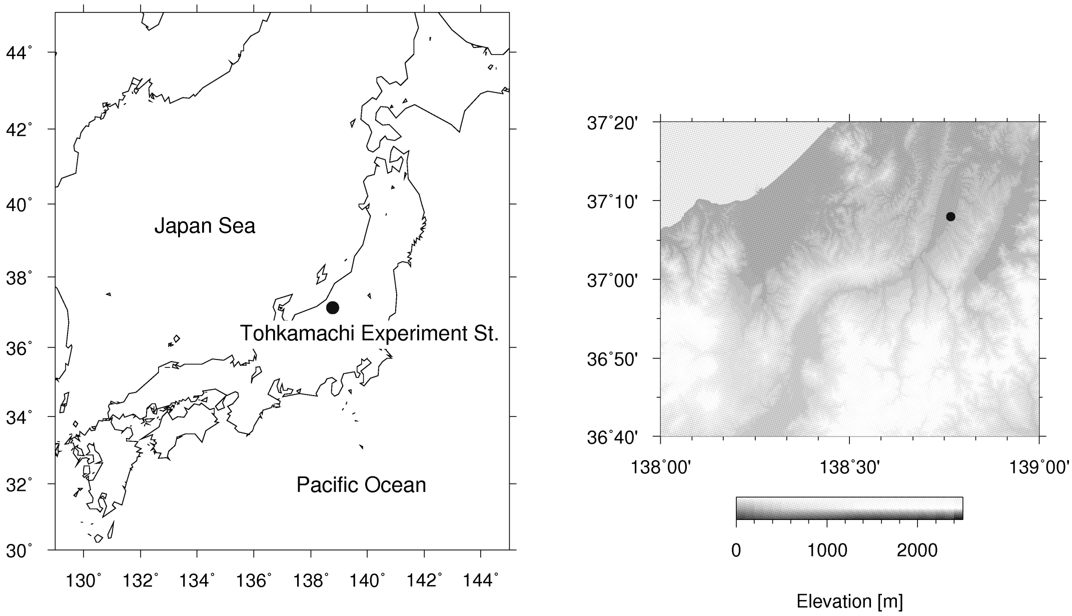

Fig. 1 Location of Tohkamachi Experimental Station, FFPRI.

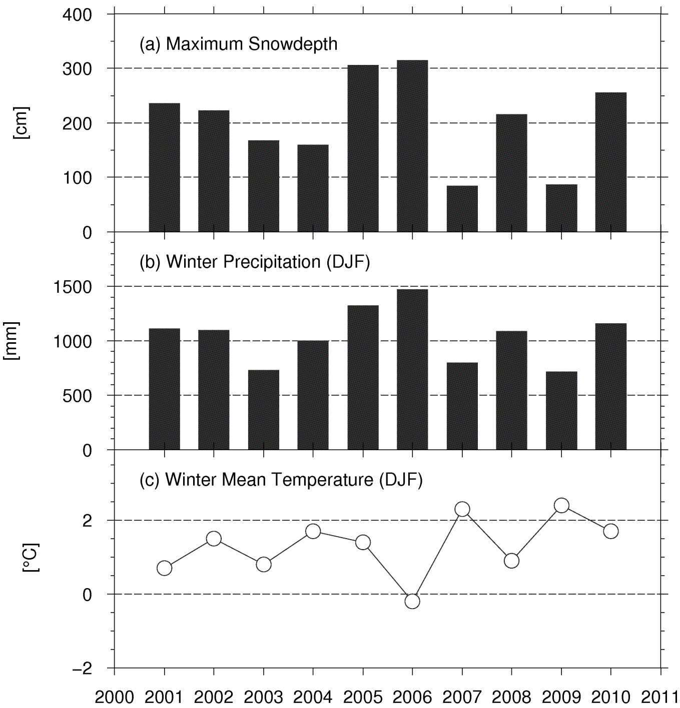

Fig. 2 Records of maximum snowdepth, winter precipitation and mean temperature from December to February, 2000–2011.

STUDY SITE AND METHODOLOGY

Snowmelt and precipitation sampling were carried out in a light snow year, December 2008 to March 2009, and a heavy snow year, December 2009 to March 2010, at the Tohkamachi Experimental Station, Forestry and Forest Products Research Institute (37°08′N, 138°46′E; 2000 m a.m.s.l., Fig. 1). Meteorological data such as temperature, precipitation, snow depth, etc. have been observed for more than 90 years at this site (Takeuchi *et al*., 2008). Moreover, discharge

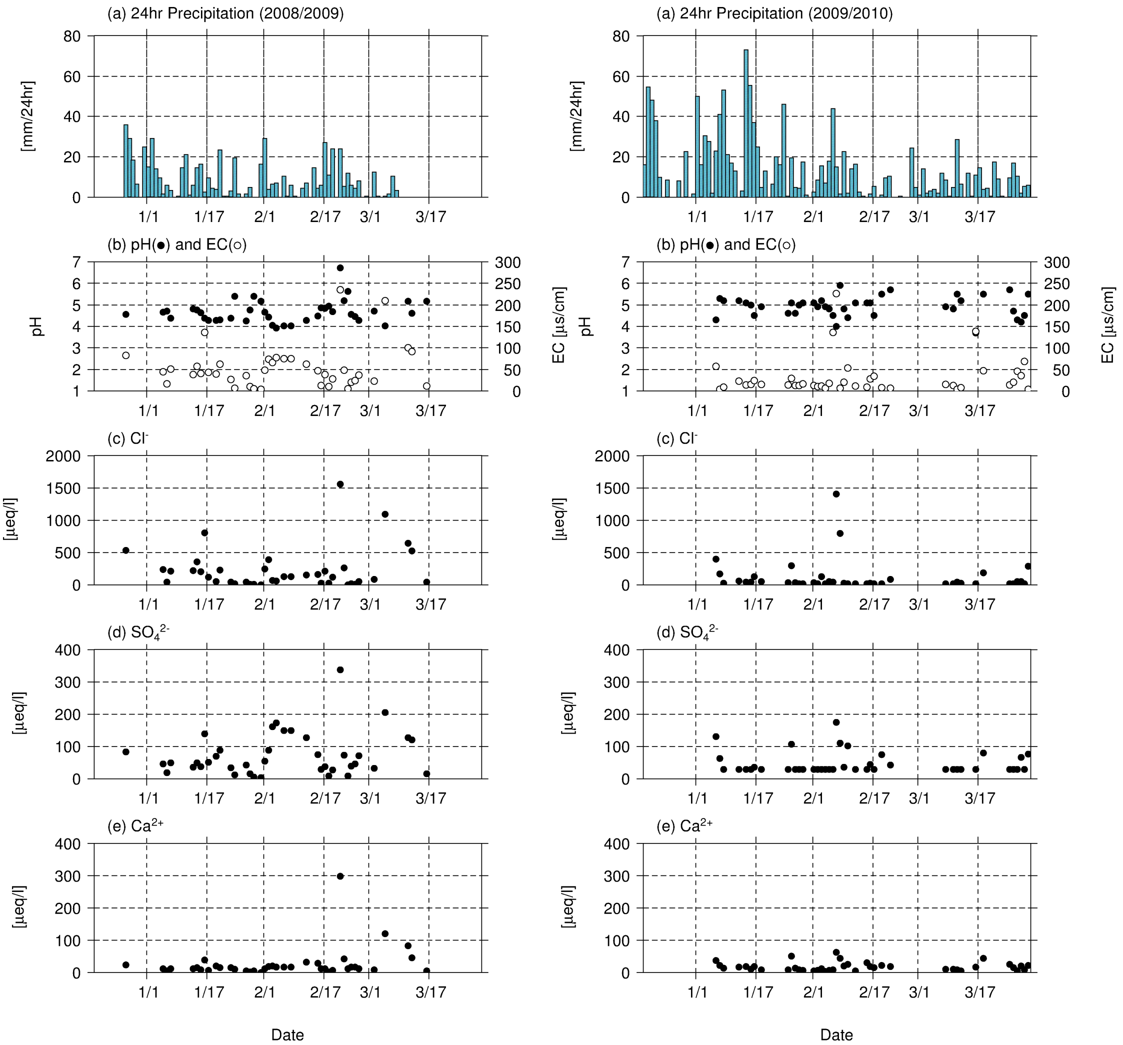

Fig. 3 Temporal variations in precipitation and its pH, EC, Cl^-, SO_4^{2-} and Ca^{2+}.

from the base of the snow and snow weight have been measured with a snow-lysimeter and metal wafer, respectively, for more than seven years (Takeuchi *et al.*, 2007). The study area is located on the Japan Sea side near the central mountains of the main island of Japan and belongs to a temperate climate zone. There are heavy snowfalls, and the annual maximum snow depth at Tohkamachi Experimental Station is more than 2 m on average. However, the monthly air temperature is higher than 0°C except in January, and rainfall sometimes occurs even in winter (Takeuchi *et al.*, 2009). It is reported that there is a distinct negative correlation between mean air temperature and total precipitation from December to February (Takeuchi *et al.*, 2008). In this study, we choose "a light snow year" and "a heavy snow year", December 2008–March 2009, and December 2009–March 2010, respectively. Annual maximum snow depth, mean air temperature, and precipitation during winter (December–February) for 2001 to 2010 at the Tohkamachi Experimental Station are shown in Fig. 2. The highest and lowest maximum snow depth over the 2001–2010 period were recorded in 2006 (314 cm) and in 2007 (84 cm), respectively, and its variability is very large, in spite of being a heavy snow area. The maximum snow depths in 2009 and 2010, when we conducted snowfall and snowmelt sampling, were 86 cm and 254 cm.

The snowfall samples, which were accumulated over about 24 hours on the plate, were collected at around 09:00 JST nearly every day. The plate was put on the snow surface for the next sampling after sampling the snowfall and removing the residue. With regard to snowmelt water sampling, we collected the discharge water out of the snow-lysimeter at around 17:00 JST nearly

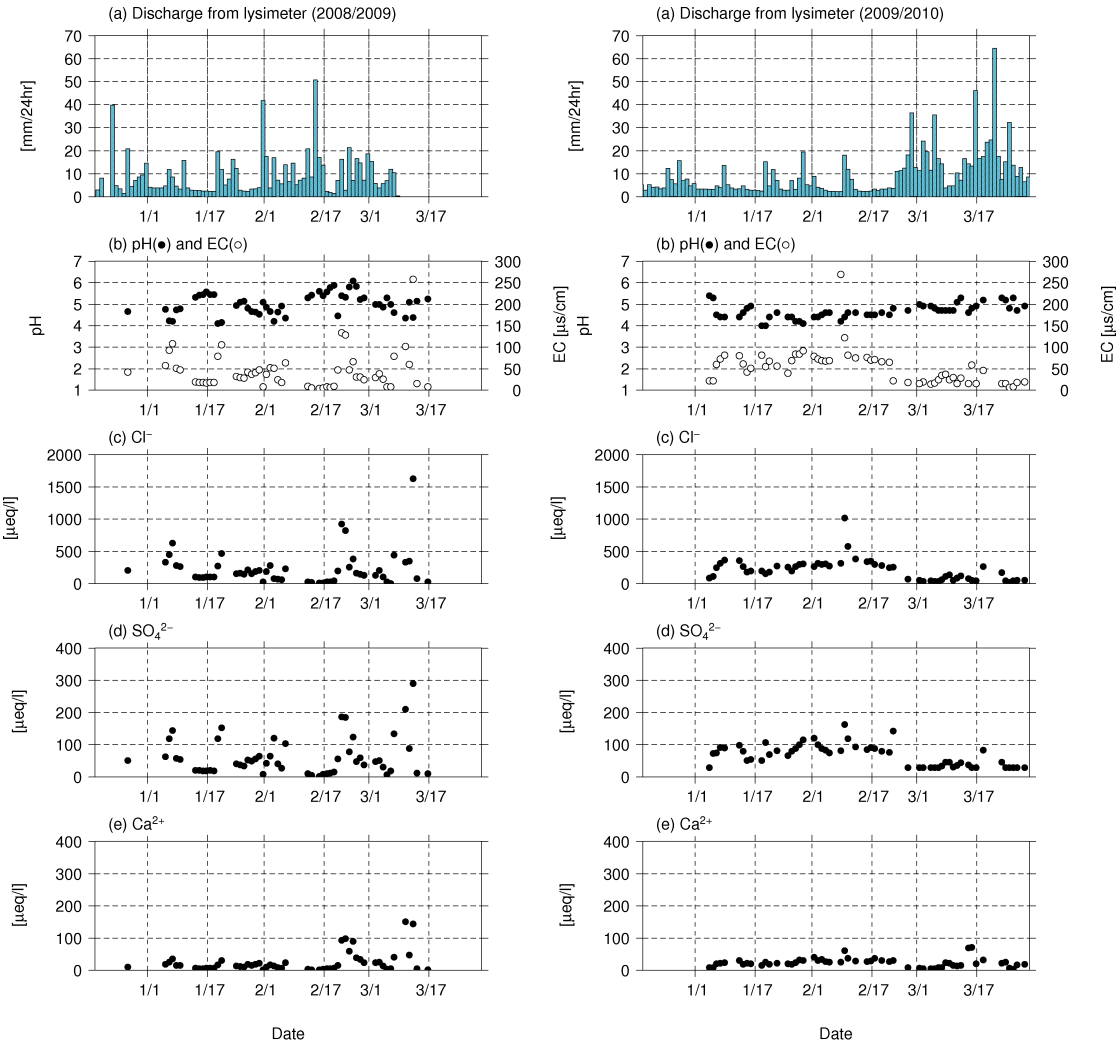

Fig. 4 Temporal variations in discharge from snow lysimeter and its pH, EC, Cl^-, SO_4^{2-} and Ca^{2+}.

every day. After filtering, for both types of sample, electric conductivity (EC) and pH were measured by the glass electrode method (DKK-TOA, CM-30R and HM-30R) and the respective concentration of the major dissolved components (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}) were measured by ion chromatography (DIONEX, ICS-1500).

RESULTS AND DISCUSSION

The temporal variations in precipitation and its chemical components (pH, EC, Cl^-, SO_4^{2-}, Ca^{2+}) in the light snow year (2009) and heavy snow year (2010) are shown in Fig. 3. Mean pH in snowfall in 2009 and 2010 is approximately 4.6 (SD: 0.4) and most of snowfall samples have a negative correlation between pH and EC. It is confirmed that pH and EC become lower and higher, respectively, with increasing SO_4^{2-}. However, high pH and EC snowfall were observed on 21 February 2009 with an increase in Ca^{2+} (Asaoka & Takeuchi, 2011). It is known that Ca^{2+} originates not only from the sea salt but also from soil particles such as yellow sand (Isawaka *et al.*, 1998). According to measured chemical components, snowfall nssCa^{2+} (non-sea salt Ca^{2+}) is 242.5 μeq/L and equivalent to approximately 80% of total Ca^{2+} (298.2 μeq/L). Calcium carbonate, which is one of the major components of Asian dust, has the ability to reduce high acidity. For this reason, high pH was observed in spite of high EC and SO_4^{2-}, and the slight increase of pH might be similarly caused by an increase of Ca^{2+} on 18 March 2010.

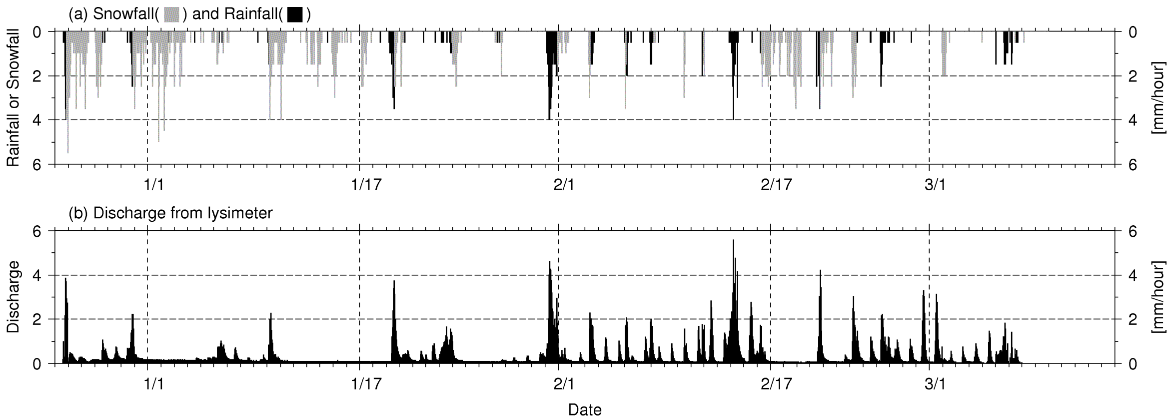

Fig. 5 Separated snowfall and rainfall and observed discharge during 2009 winter.

Temporal variations in discharge from the snow base by a snow-lysimeter and its chemical components (pH, EC, Cl^-, SO_4^{2-}, Ca^{2+}) in the light snow year (2009) and heavy snow year (2010) are shown in Fig. 4. The mean pH are 5.0 (2009) and 4.5 (2010), which are slightly higher than for mean snowfall. The temporal changes in EC and pH have the same tendency as those of the snowfall. Moreover, the pH and EC become lower and higher, respectively, at the time of abrupt snowmelt after the stable discharge, because the stable discharge is caused by the continuous heat flux from the soil, whereas the abrupt snowmelt is due to heat exchange between the snow surface and the atmosphere. If snowmelt water occurs on the snow surface and melt water reaches the snow bottom with abundant chemical components, then the pH increases. Nevertheless, if the surface melt water does not reach and freeze within the layer of snowpack because of high snowdepth, then the stored chemical components flow gradually out of the snowpack with the melt at the bottom due to heat flux from the ground. Therefore, the fluctuation of EC and pH in the light snow year is higher than in the heavy snow year. We separated snowfall and rainfall from observed precipitation by a discrimination method for precipitation using air temperature and humidity data (Yamazaki, 2001). It is noted that the precipitation was rainfall on 31 January and 14 February 2009, and rainfall flowed into the soil through the snowpack (Fig. 5). Therefore, the pH was stable and did not decline, in spite of the abrupt high discharge from the snow-lysimeter.

CONCLUDING REMARKS

We conducted snowfall and snowmelt water sampling and their water quality analysis in the temperate heavy snow area in both light and heavy snow years. There is little such field data in the temperate snowy area. In the main, the pH in snowfall and snowmelt becomes low with an increase in EC. However, it is suspected that snowfall which contains the yellow sand has higher pH in spite of its high EC due to the buffering action by calcium carbonate. More-acidic snowmelt water flows out of snowpack into the ground when meltwater occurs at the surface and reaches the snow bottom. Comparisons between the light and heavy snow years revealed that stored chemical components flow out of snowpack gradually with melt water caused by the heat flux from the soil below, although the snowpack has a high capacity for storing chemical components with the increase of snowdepth.

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