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# Seasonal variations of pH and electrical conductivity in a snow-firn pack on Glacier No. 1, eastern Tianshan, China

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#### Abstract

Analyses of pH and electrical conductivity (EC) in surface snow and snow-firn pack samples collected successively in a weekly basis during September 2002 to September 2004 on the east branch of Glacier No. 1, eastern Tianshan, China is presented. pH and EC in surface snow show obvious seasonal variations. pH and EC values are high in spring and early summer, and they are low in late summer; moreover, pH value indicates more and less alkalinity in spring and winter, respectively. In addition, both pH and EC peaks strongly coincide with the corresponding period of greatest NE and ENE wind velocity. After deposition, pH and EC in snow-firn pack display diverse features and seasonal trends, which correlate with snow compaction, dry deposition, precipitation and temperature, and so on. Furthermore, both pH and EC peaks occur above dust layers, and are adjacent to dust layers in some snow-firn packs. This implies that dust layers may have an influence on the elution process of soluble ions. In addition, linear correlation analyses among major chemical species (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, NH<sup>4</sup><sub>4</sub>, Cl<sup>-</sup>, SO<sup>2-</sup><sub>4</sub>, NO<sup>-</sup><sub>3</sub>, pH and EC) in surface snow indicate that Ca<sup>2+</sup> is the key ion determining pH and EC in the study area. © 2006 Elsevier B.V. All rights reserved.

Keywords: Glacier No. 1; pH; EC; Seasonal variation; Elution process; Snow-firn pack

# 1. Introduction

Glaciers potentially contain a wealth of information on the history of air pollution (Herron, 1982; Wolff and Peel, 1985). Ice cores retrieved from Greenland and Antarctica contain atmospheric chemistry records from a single season to hundreds of thousands of years, providing insight on atmospheric impurities records (Millar, 1982; De Angelis et al., 1987; Jouzel et al., 1990; Mayewski et al., 1993, 1994, 1996; Kimitaka et al., 1996). pH and electrical conductivity measurements of polar ice cores are widely used for this purpose to rebuild the history of air pollution (Hammer, 1980; Barrie et al., 1985; Taylor et al., 1993; Wolff et al., 1995; Hempel et al., 2000). Similar works were carried out on the Tibetan plateau (Yao et al., 1993; Sheng et al., 1995, 1996), Tianshan Mountains (Hou et al., 1999; Li et al.,

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2003) and other regions (Goto-Azuma Kumiko et al., 1993, 1995, 2002). However, there are few studies on the variations of pH and EC in successive snow-firm pack during the post-depositional process.

In order to better understand the effects of deposition and meltwater-related post-depositional processes on chemical signals recorded in glacial snow and ice, a research program for glacier processes investigation (PGPI) was launched by the Tianshan Glaciological Station (TGS), Chinese Academy of Sciences (CAS) in July 2002. An observational and experimental site (henceforth the PGPI site) was carefully located in a percolation zone on the east branch of Glacier No. 1 at the headwaters of the Urumqi River, Xinjiang Uygur Autonomous Region of the Northwest China at an altitude of 4130 m above sea level (masl). Aerosol, surface snow and snow pit samples were collected on a weekly basis at the PGPI site using established techniques to prevent contamination. Most of the samples were analyzed for pH, EC, major ions and insoluble microparticles, while oxygen isotopic ratios ( $\delta^{18}$ O), trace metals, and carbonaceous particles (organic and black carbon, OC and BC, respectively) were analyzed for selected samples. A suite of samples was also archived (frozen) for future analyses. This study focused on both the seasonal variations of pH and EC in surface snow and elution processes in snow-firm packs, and the factors determining pH and EC.

## 2. Methodology

#### 2.1. Sampling site

The Glacier No. 1  $(43^{\circ}06' \text{ N}, 86^{\circ}49' \text{ E})$  is located at the headwaters of the Urumqi River in the eastern

Tianshan Mountains of central Asia that are surrounded by vast deserts: the Gobi desert to the east, the Taklimakan desert in the Tarim basin to the south, the Peski Muyunkum and Peski Sary-Ishikotrau deserts to the west, and the Gurbantunggut desert in the Junggar basin to the north (Li et al., 2003) (Fig. 1). The mountain environment in this region includes a forest zone (1500– 2900 m), alpine meadows above 2900 m, bare rock, glacial deposits and permafrost situated above 3000 m (Luo, 1983). With a typical continental climate, the westerly jet prevails across these high mountains. Near the surface, the local valley winds prevail from March through September (Williams et al., 1992; Zhang et al., 1994).

The Glacier is a northwest-facing valley glacier composed of east branch (1.12 km<sup>2</sup>) and west branch  $(0.61 \text{ km}^2)$  with an average elevation of 4330 m and a total area of about 1.73 km<sup>2</sup>. The annual equilibrium line altitude (ELA) has averaged approximately 4055 masl from 1959 to 2003, and the mean annual precipitation is around 645.8 mm  $a^{-1}$  on the east branch (Wang and Zhang, 1985; Yang et al., 1988, 1992). The PGPI site is situated at 4130 masl, with no direct wintertime exposure to sunshine due to the shadowing effect of the mountain ridges. The mean annual air temperature and precipitation at the site were -9.1 °C and 700 mm water equivalent (w.e.) during the experimental period. Maximum precipitation occurs in the summer, which accompanies the maximum snow melt. The floor of snow-firn pack at this site is composed of superimposed ice that is typically formed in the glacial percolation zone or superimposed-ice zone. The ice is characterized by clear, impermeable, opaque ice with spherical bubbles which have a diameter of 1 to 5 mm



Fig. 1. Map showing the study area. On the top right corner is the location of the study area in China; on the top left corner is the study zone, where the left dot as the arrow points to is the sampling site on Glacier No. 1 and the right dot is the site of Daxigou Meteorological Station.

diameter. Field observations indicate that the snow depth of the percolation zone typically ranges from about 1.5 m in the late summer to about 3 m in the late spring. During winter, it remains stable due to snow compaction, snow drifting and sublimation. In the early summer, as air temperatures rise to  $\sim 0$  °C, the upper part of the snow layer begins to melt, leading to rapid thinning. The melt originates primarily from the accumulation received in the previous autumn. In the late summer to early autumn, melting dominates and affects the entire annual layer and even the previous year's accumulation. The meltwater infiltrates the underlying firn layers, reaching the firn that overlies the impermeable ice formed in the previous year. The meltwater fills the pores of the firn and is refrozen to form superimposed ice, while some of meltwater pools on the ice surface and eventually drains off (Li et al., 2006).

# 2.2. Sample collecting and analysis

Samples were collected weekly and every effort was made to collect fresh, well-preserved surface snow (i.e. snow not affected by post-depositional processes such as sublimation or melting) to facilitate our investigation of the seasonality in the chemical composition of both precipitation and dry deposition. The fresh and surface snow samples were retrieved from the topmost 3 to 5 cm snow during different seasons, and the snow-firn samples were successively recovered at 10 cm intervals through the entire pit depth. After sampling, the pit was refilled with snow and firn to prepare for the following sampling, which involved digging the same pit and refacing the sampling surface by at least 0.5 m, and then the same strata were re-sampled. About 100 surface snow samples and 1018 snow-firn samples from 104 successive snow-firn packs were collected on a weekly interval from September 2002 to September 2004 (Tianshan Glaciological Station, 2006). The detailed sampling methods (i.e. fresh snow, surface snow, and snow-firn pack samples) have been described by Li et al. (2006).

Strict procedures were followed during sampling and transportation processes to eliminate contamination, including using disposable polyethylene gloves, oronasal masks, and pre-cleaned polyethylene sample containers. Snow and ice samples were transferred into the polyethylene plastic bottles in a frozen state. The bottles were then tightly sealed to avoid evaporation or diffusion. Bottled samples in a frozen state were transported to the TGS laboratory, Chinese Academy of Sciences, in insulation boxes, and kept in a cold room at -20 °C. Blanks were measured to make sure that cumulative contamination was below the baselines of each measured chemical species. Highly correlated ionic concentration profiles between the neighboring sampled snow-firn pack in most seasons have proven that no contamination was introduced into samples during sample preparation and measurements.

After the samples were retrieved, they were immediately analyzed for pH and EC by a pH Meter (PHJS-4A) (0 to 14 measurement range with uncertainty less than 1‰) and a Conductivity Meter (DDSJ-308A) (0 to 999  $\mu$ S/cm measurement range with an uncertainty of less than 1‰), respectively, prior to that the snow and ice samples were melted gradually up to 20 °C at room temperature. For each measurement, the electrode was calibrated with pH 6.86 and pH 9.18 reference buffer; the electrode was rinsed with deionized water after each sample and the temperature-compensated pH determination was made on a fresh, quiescent sample after 5 min. Major ions (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, NH<sub>4</sub><sup>+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, and  $NO_3^{-}$ ) were analyzed by ion chromatography (Dionex DX-320). The concentrations and size distributions of insoluble microparticles were analyzed by an AccuSizer 780A (0.5 to 400 µm measurement range with an uncertainty less than 5%). These methods have been described by Zhao and Li (2004) and Zhu et al. (2006).

## 3. Results and discussions

## 3.1. Seasonal variations in surface snow

The seasonal variabilities of chemical species in surface snow can reflect seasonal inputs of impurities from the atmosphere (Li et al., 2006). Chemical species are removed from the atmosphere through dry and wet deposition (Heather et al., 2004). For both types of deposition, precipitation and wind are the main control factors on Glacier No. 1 (Wang et al., 2006). Surface snow samples were examined to investigate the seasonality of pH and EC in dry deposition.

Fig. 2 demonstrates that the temporal trends of pH and EC show obvious seasonal variations. pH and EC values are high in spring (April and May) and early summer (June), low in late summer (August and September). Both pH and EC from late summer (September), 2003 to early summer (June), 2004 increase gradually up to the maximum of one year, then decrease rapidly until the late summer, 2004 again, afterwards they increase once more. As Table 1 shows in detail, the variation ranges of pH and EC in spring and summer, respectively, are wide, while both of



Fig. 2. Temporal variations of pH and EC in surface snow, compared with contemporaneous wind speed versus time from September 14, 2002 to September 28, 2004. The smoothed curves are generated from negative exponential smoother with sampling proportion 0.1 and polynomial degree 1.

them are narrow in fall. The average values of pH and EC from spring to winter decrease gradually and reach the minimum in winter. The pH value of surface snow in spring displays more alkalinity while it shows less alkalinity in winter, and EC reaches the maximum and minimum in spring and winter, respectively. The annual average values of pH and EC are 6.66 and 12.74  $\mu$ S/cm respectively, pH value reaches the maximum 8.05 and 7.67 on May 29, 2003 (spring) and April 24, 2004 (spring) respectively, EC reaches the maximum 44.9  $\mu$ S/cm and 95.5  $\mu$ S/cm on May 16, 2003 (spring) and June 11, 2004 (early summer) respectively. Although pH and EC, as Fig. 2 shows, present similar seasonal variation trends, some discrepancies still exist.

Seasonal variability in the chemical composition of the surface snow is closely associated with climatic and environmental characteristics in the region. Cold frontal

Table	e 1

The ranges, a	verage values	and annual	average	values o	of pH ar	nd EC in
surface snow	during Septe	mber 2002	to Septer	mber 20	004	

		Spring	Summe	er	Fall	Winter
pН	Ranges	6.14-	5.79-		6.08-	5.91-
		8.05	7.61		7.02	6.88
	Average values	6.99	6.62		6.56	6.45
	Annual average			6.66		
	values					
EC (µS/cm)	Ranges	4.43-	2.14 -		2.94-	2.85 -
		63.1	95.5		17.77	20.30
	Average values	22.73	13.93		7.41	6.87
	Annual average			12.74		
	values					

systems frequently sweep across the region during spring (April and May) producing large dust storms (Gao at al., 1992; Li et al., 1994; Wake et al., 1994). This stormy period is followed by the summer precipitation maximum (May through September) that accounts for approximately 90% of the annual precipitation. During the rest of the year, the climate regimes are cold and dry (Li et al., 2006). Both the spring dust storms and summer precipitation can bring terrestrial impurities to the glacier surface, as reflected by pH and EC values, of which the high values during spring and early summer strongly coincide with period of greatest NE and ENE wind velocity (Fig. 2). This suggests that high peaks of pH and EC result from the input of localto-regional dust aerosols derived by strong winds. And part of dust aerosols derived from surrounding arid and semiarid regions (Berner and Berner, 1987; Wake et al., 1992; Williams et al., 1992; Sequeira, 1993; Zhang et al., 2002) is another contribution for pH and EC of surface snow in spring and early summer. Furthermore, the amplitudes of pH and EC peaks during July to August likely result primarily from wet deposition and long range transport to the glacier, which can be supported by what the amplitudes of ionic concentration peaks are different, especially during the precipitation events on August 2004, the highest ionic concentrations coincide with the largest precipitation events (Li et al., 2006). Whereas during winter, the sampling site is mainly influenced by the free troposphere, and the atmospheric aerosol transforms from primary to secondary style in the region, and results in low values of pH and EC in surface snow (Sun et al., 1998).



Fig. 3. The profiles of pH and EC in successive snow-firn pack. T1, T2,..., and T20 in the top of stratigraphy profiles are the serial numbers of snow-firn packs. The three real lines are the elution curves of the EC peaks (represented by P1, P2 and P3). The thick and thin arrows indicate the EC peaks in a different location of snow-firn packs, thin arrows indicate peaks of  $10-20 \,\mu$ S/cm and thick arrows indicate peaks of  $>20 \,\mu$ S/cm, the inclined thin arrows present the dates of P1, P2 and P3 merging into superimposed ice respectively. The rectangular boxes show the corresponding relationship between dust layers and peaks of pH and EC.

#### 3.2. The elution processes in snow-firn pack

Temperature can be used as a predictor for the elution process in many cases. Quantifying the linkage between the elution process and in-situ air temperature has the potential to provide a useful tool for evaluating the effect of elution, and thus for assessing ice core quality over a wide range of locations (Li et al., 2006).

Fig. 3 shows the elution processes of pH and EC from October 2003 to September 2004. Li et al. (2006) and Wang et al. (2006) found that the elution sequence of chemical species in snow-firn pack is  $SO_4^{2-}>Ca^{2+}>Na^+>NO_3^->Cl^->K^+>Mg^{2+}>NH_4^+$ . The Mg<sup>2+</sup> peaks coincide with dust layers, and are well consistent with those of large particles (>10 µm measure range in diameter), which are also consistent with dust layers. Therefore in this study, both Mg<sup>2+</sup> and large particle peaks were used as a reference to trace the elution processes of pH and EC.

As Fig. 3 shows, most peak values of pH and EC usually occur in the top parts of snow-firn pack. During melting season, both pH an EC peaks move downward rapidly; while during other seasons that of pH and EC move downward slowly until merging into superimposed ice. In this study, we trace three apparent high peaks of EC (Fig. 3, P1, P2 and P3) in the top, middle and bottom of snow-firn pack (T1) in the early fall (Oct. 4, 2003), respectively, to study the elution processes of pH and EC. Originally, the distances of P1, P2 and P3 are 170 cm, 100 cm and 50 cm from the bottom of the snow pit T1 respectively. During the period from early fall (Oct. 4, 2003) to early summer (May 28, 2004), that

is snow-firn pack T1-T9, P1, P2 and P3 are obvious and present a stable fluctuation trend. Most of EC peaks except for P1, P2 and P3 are below 10 µS/cm during October 4, 2003 to January 25, 2004 (W1), P1, P2 and P3 moved downward to heights of 135 cm. 75 cm and 35, respectively from the bottom of the snow pit T4. this movement was mainly related to snow compaction. The air temperature is below zero (AT<sub>1</sub>=-11.9 °C), and few precipitation events occur during this period (W1) (Fig. 4), this means that little melt occurs, pH and EC values to some extent can represent their primary levels in the atmosphere. From March 20 to April 24 (W2), the pH and EC peaks (>20  $\mu$ S/cm) are located above P1, P2 and P3, suddenly appear at the surface of snowfirn pack (T5-T7) as the thick arrows point (Fig. 3). This resulted from limited precipitation, low temperature and weak evaporation, which enabled post-depositional processes such as sublimation and dry deposition to become more dominant (Zhao et al., 2006). During this period, the air temperature is above zero sometimes  $(AT_2 = -5.95 \text{ °C})$ , and several small precipitation events occur (Fig. 4). This indicates that little melt occurs, which partially contribute to high values of pH and EC in the surface of snow pit. From May 28 to June 30 (W3), as temperature (AT<sub>3</sub>=2.76 °C) increased (Fig. 4), meltwater appeared in snow pit, which assembled the ions and increased the peaks of pH and EC as they moved downward. And at the same time, the increasing precipitation (Fig. 4) resulted in successive peak values  $(>20 \ \mu\text{S/cm})$  at about 0 to 50 cm below the surface, especially in snow-firn pack T9. P1, P2 and P3 are still obvious in snow pit, and moved downward to heights



Fig. 4. Daily variability of air temperature and precipitation from October 4, 2003 to September 8, 2004 recorded at the Daxigou Meteorological Station. The dashed line is the temperature line at zero,  $AT_1$ ,  $AT_2$ ,  $AT_3$  and  $AT_4$  mean that average air temperature during the periods W1, W2, W3 and W4, respectively.

of 125 cm, 75 cm and 40 cm, respectively from the bottom of the snow pit T11. From July 7 to September 8 (W4), as temperature reaches maximum in one year, and it is above zero completely (Fig. 4), meltwater percolated through the snow pit, and leached the ions; the upper part of the snow pit experienced the most post-depositional alteration. With increasing temperature (AT<sub>4</sub>=3.9 °C) (Fig. 4), larger volumes of meltwater began to percolate deeper into the snow pit along with the EC, which is indicated by the reduced peaks. When the water encountered the superimposed ice in the bottom of the course-grained firn layer, it refroze resulting in accretion (mass gain) at the superimposed ice surface. During this period, P1, P2 and P3 are not easy to distinguish, the distances to them from the bottom of the snow pit T12 visibly diminished to 111 cm, 71 cm and 35 cm, respectively. Although two peaks exceeding  $20 \mu$ S/cm as the thick arrow pointed also take place in the top parts of snow pit T15 and T20 in August 5, 2004 and September 8, 2004 respectively, peaks on all accounts take on a steady-going fluctuation trend. The peaks traced are not prominent, other peaks ranged between 10–20  $\mu$ S/cm as indicated with the thin arrow (Fig. 3).

The P1, P2 and P3 merged into superimposed ice at the bottom of snow-firn pack T13 (late July), T15 (early August) and T20 (early September), respectively, as the inclined arrows point, and was henceforth preserved in the glacier. By the beginning of September, there were only three peaks observed in the snow pit T20, this demonstrates that in spite of considerable loss of soluble ions through post-depositional processes, the general information of pH and EC is still preserved. The P1 merges into the superimposed ice is about 34 days ahead of large particles peak that relates to P1, which can be attributed to that elution velocity of soluble ions is faster than that of insoluble microparticles. Furthermore, pH and EC peaks occur around dust layers in some snow firn-packs as the rectangular boxes show (Fig. 3). Especially, they occur above dust layers, and are adjacent to dust layers in some snow-firn packs. This implies that dust layers may have an influence on the elution processes of pH and EC. As Fig. 3 shows, the elution process of pH profile is similar to that of EC, which can be favored by the good correlation between pH and EC in surface snow (r=0.752). Unnecessary details for that of pH are not added here.

#### 3.3. The factors to determine pH and EC

Table 2 shows the correlation coefficients of pH and EC between different chemical species in surface snow. The ions whose correlation coefficients of pH exceed 0.600 are Mg<sup>2+</sup> (r=0.624) and Ca<sup>2+</sup> (r=0.779) and the ions whose correlation coefficients of EC exceed 0.700 are Cl<sup>-</sup> (r=0.885), SO<sub>4</sub><sup>2-</sup> (r=0.727), Ca<sup>2+</sup> (r=0.960), Na<sup>+</sup> (r=0.879) and K<sup>+</sup> (r=0.716). This indicates that the dominant ions of pH and EC are Mg<sup>2+</sup>, Ca<sup>2+</sup> and Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Ca<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, respectively. In particular, Ca<sup>2+</sup> is the dominant ion determining pH and EC.

Ca<sup>2+</sup> is a good indicator of dust, and the most dominant ion in surface snow. It accounts for 56% of total loading of surface snow ( $\sum$ an (114.2 µeq/l) +  $\sum$ cat (434.7 µeq/l)=548.9 µeq/l), followed by SO<sub>4</sub><sup>2-</sup> (10%), NH<sub>4</sub><sup>+</sup> (9%), Mg<sup>2+</sup> (8%), Cl<sup>-</sup> (6%), Na<sup>+</sup> (5%) and NO<sub>3</sub><sup>-</sup> (5%). Moreover, the Ca<sup>2+</sup> concentration in spring reaches maximum and is about 3 times higher than that in fall or winter, subsequently decreases and reaches the background values in fall and winter. Ca<sup>2+</sup> derives from a local-plus-regional source component, and the long-distance sources are also a major contributor. Potential sources include local mineral aerosol entrained in the atmosphere by the strong winds that prevail during spring along with a more regional Asian dust flux (Li et al., 2006). Previous studies indicate that local bare

Table 2

The correlation coefficients of pH and EC between different chemical species in surface snow, significant at the p=0.001 confidence level (N=107)

Elements	EC	$\mathrm{NH}_4^+$	$NO_3^-$	Cl	$SO_4^{2-}$	$Mg^{2+}$	Ca <sup>2+</sup>	Na <sup>+</sup>	$K^+$	pН
EC	_	0.446	0.313	0.885	0.727	0.660	0.960	0.879	0.716	0.752
$\rm NH_4^+$		_	0.490	0.464	0.610	0.161	0.322	0.413	0.483	0.338
NO <sub>3</sub>			_	0.380	0.674	0.191	0.215	0.242	0.323	0.241
Cl_				_	0.720	0.559	0.792	0.956	0.729	0.520
$SO_4^{2-}$					_	0.390	0.623	0.662	0.551	0.531
$Mg^{2+}$						_	0.631	0.575	0.511	0.624
Ca <sup>2+</sup>							_	0.820	0.638	0.779
Na <sup>+</sup>								_	0.734	0.524
$K^+$									_	0.532
pН										_

rock and glacial sediments are readily available sources for Cl<sup>-</sup>, Ca<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> (Luo, 1983; Williams et al., 1992; Sun et al., 1998; Hou et al., 2002), which is also enhanced by the fact that the calcification is the major soil formation process in semiarid and arid regions. where abundant calcites (CaCO<sub>3</sub>) are produced (Kailai, 1951; He, 1980; Zhang et al., 2002).  $NH_4^+$  and  $NO_3^$ derive from anthropogenic source component that includes emissions from fossil fuel combustion and biomass burning, livestock manure, and commercial and natural fertilizers. Mg<sup>2+</sup> derives from a long-distance source component, mainly deposited by wet deposition. Potential sources are mineral dust and evaporate aerosols entrained along the trajectory of the air masses that bring moisture to the region.  $SO_4^{2-}$ , except for anthropogenic sources, can be widely derived from terrestrial materials, e.g., pyrite minerals and evaporates, on local and regional scales (Li et al., 2006). Previous study demonstrates that natural sources associated with mineral dust aerosols are basic contributors of  $SO_4^{2-}$  in snow, but anthropogenic sources also have a large impact on the snow chemistry (Tianshan Glaciological Station, 2006).

## 4. Conclusions

Generally, pH and EC values in surface snow are high, and strongly coincide with period of greatest NE and ENE wind velocity in spring and early summer. This suggests that high peaks of pH and EC mainly result from the input of local-to-regional dust aerosols derived by strong winds during this period. In addition, pH and EC values are low in late summer, and pH values indicate more and less alkalinity in spring and winter, respectively. pH and EC peaks during July to August likely result primarily from wet deposition and long range transport to the glacier. The dominant ions contributing to pH and EC, respectively are Mg<sup>2+</sup>, Ca<sup>2+</sup> and Cl<sup>-</sup>, SO<sup>2+</sup>, Ca<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>; Ca<sup>2+</sup>, in particular, is the dominant ion determining pH and EC.

After deposition, from early October through winter, the formation of the vertical stratigraphy of pH and EC peaks was mainly related to snow compaction. From March to April, large peaks of pH and EC in the upper layers of snow pit resulted from limited precipitation, sublimation and dry deposition. From May to June, with the increasing precipitation and temperature, successive peaks of pH and EC occur at about 50 cm below the surface. From July to September, as temperature reaches maximum in one year, and it is above zero completely, the snow in the pit experienced the maximum post-depositional alteration through the percolation of the meltwater; however, alteration deeper in the snow-firn pack was slight and the general information was still preserved. Furthermore, both pH and EC peaks occur around dust layers; especially they occur above dust layers, and are adjacent to dust layers in some snow-firn packs. This implies that dust layers may have an influence on the elution process of soluble ions.

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