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# Electrical conductivity during the ablation process of the Glacier No. 1 at the headwaters of the Urumqi River in the Tianshan Mountains

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## Abstract

Electrical conductivity (EC) in aerosols, snow, and meltwater were evaluated at the headwater of the Urumqi River during the ablation seasons of 2003–2008. The results show that EC in meltwater can indicate the intensity of glacier ablation, which negatively correlated with air temperature and discharge. During the early ablation period, EC presents a fluctuation trend and runoff may be primarily from snow, frozen soil, and groundwater. EC decreases to the lowest level during the peak-flow period and runoff flows rapidly through a hydrological system predominantly in ice-walled conduits. EC increases to the highest level during the late ablation period, and runoff transports slowly through a distributed hydrological system at the ice-rock interface. EC in meltwater is far greater than in aerosols, surface snow, and precipitation, which are closely related to atmospheric circulation and dust loading. EC in snow pits denote the spatial variation of snow melting, the enrichment and loss of dissolved ions, and are affected by air temperature. The key ions to determine EC in meltwater are  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$ , and its dominant control might be biogeochemical pyrite oxidation coupled with calcite and/or dolomite dissolution.

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## Introduction

Electrical conductivity (EC) is closely associated with the concentration of total dissolved ions and is frequently used to estimate the mixing ratio of different water sources in hydrological systems (Hayashi et al., 2012). The EC in snow and ice varies with the loading of insoluble impurities in the atmosphere and subsequently glaciers, and can be used as an alternative indicator of atmospheric environment (Moore et al., 1992). Additionally, the EC in snow/ice provide valuable information about the source region of insoluble impurities and its transmission path (Hammer et al., 1985) and changes of a particular ion (Collins, 1981), and can be used as an indicator to track solute sources in glacier meltwater (Fenn, 1987). On a macroscopic scale, the EC in snow/ice over the Tibetan Plateau indicates the fluctuation of dust loading in the atmosphere, and positively correlates with  $\text{Ca}^{2+}$  in snow/ice from the continental source, suggesting that it is a good indicator of climate fluctuation in the arid and semiarid regions (Xiao et al., 2001). As a result, variations of the EC in snow/ice and glacier meltwater reflect the wet-dry deposition and the ablation intensity and process. In the wet (dry) years, less (more) dust is transported by the strong wind to the atmosphere above the glacier surface and then deposited in snow/ice through the wet/dry deposition processes,

leading to a low (high) EC (Dong et al., 2008). The glacier ablation intensity also has a great influence on the EC in glacier meltwater due to the dilution of meltwater. Yet there are few studies available on the temporal and spatial variations of the EC during the ablation process of an alpine glacier.

Previous research showed that the EC in aerosols, snow pits, and meltwater at the headwater of the Urumqi River is affected by various factors including glaciation, permafrost conditions, moraine composition, and the interactions between water, rock, and atmospheric environment (Sheng and Yao, 1996). The EC in snow/ice of Glacier No.1 (GN1) has obvious seasonal variations, which are mainly affected by dust in central Asia (Li et al., 2007). Dong et al. (2009) indicated that the EC in snow pits corresponds well to the concentration of dust. Dust activity that reflects the cold dry climate leads to high EC values, whereas a warm wet climate leads to low EC values. Liu et al. (2005) analyzed the physical and chemical characteristics of sediment at the GN1 basin and indicated that the subglacial debris undergoes hydrolysis or carbonation, which leads to chemical element migration and enrichment releasing  $\text{Ca}^{2+}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ , and silica sol. These processes directly cause spatial heterogeneity, periodic changes in chemistry, and variations in meltwater EC. This study, based on the EC in meltwater runoff from the GN1 at the headwater of the Urumqi River during the ab-

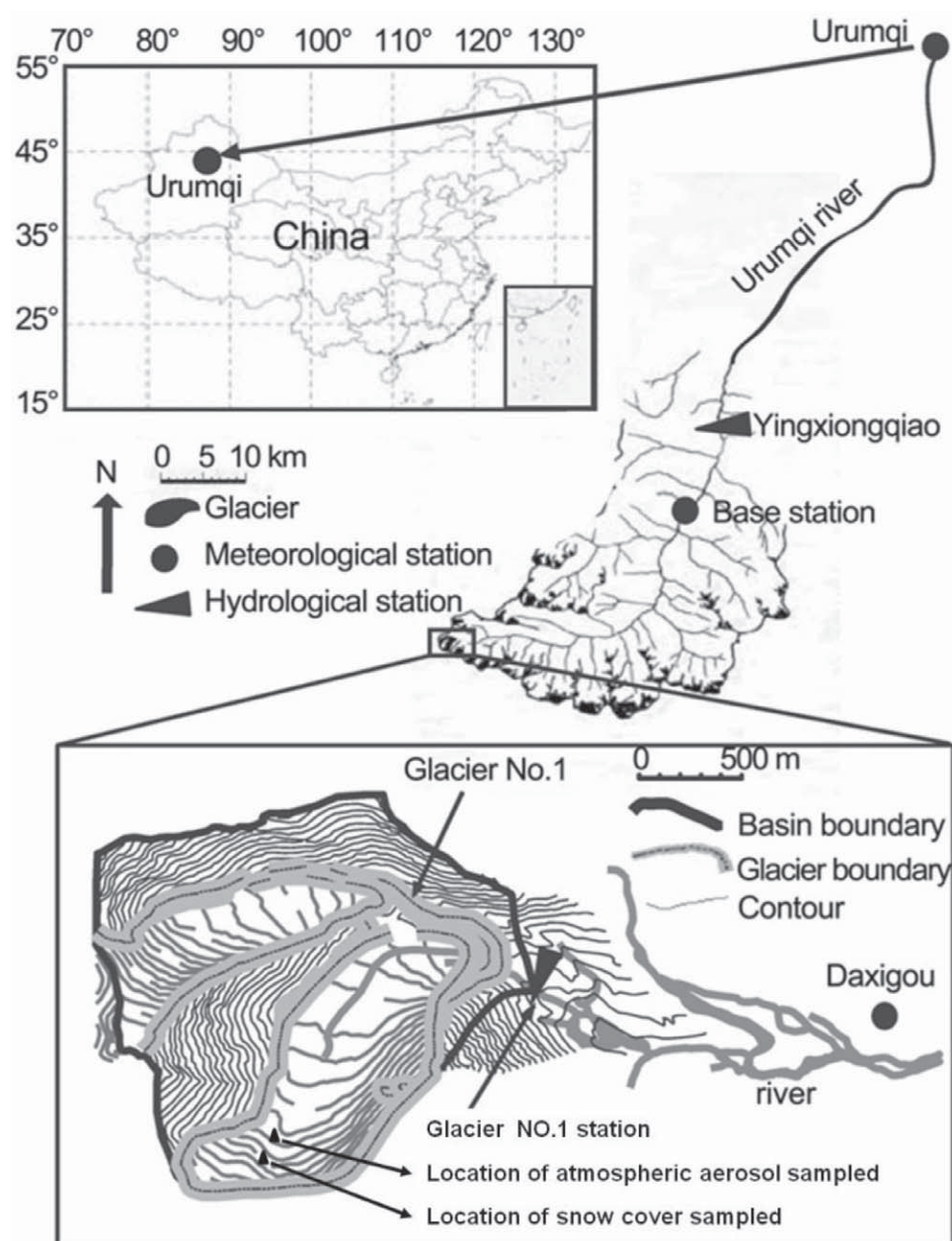
lation period over 2003–2008, evaluates the temporal-spatial variations of the EC in meltwater and its controlling factors. Various methods of parameter comparison and statistical analysis are used. By comparing the variation of EC in atmosphere aerosols, snow pits, and precipitation, the differences in temporal-spatial variation of hydrochemistry, the characteristics of climate change, and their environmental significance are discussed.

## Study Area and Methods

The GN1 (43°06'N, 86°49'E) is located at the headwater of the Urumqi River, eastern Tianshan Mountains (Fig. 1), and snow and ice meltwater from the GN1 is a major water source of the Urumqi River. The GN1 has an area of 1.65 km<sup>2</sup> and its drainage area is 3.34 km<sup>2</sup> (Liu et al., 2008). The GN1 gauging station is located at an elevation of 3659 m, about 300 m downstream of

the GN1 (Liu et al., 2011), where meltwater discharge was monitored. In addition, the lithology of moraine at the headwater of the Urumqi River is primarily siliceous crystalline schist, with liberal amounts of granodiorite, gabbro, gneiss, quartzite, and granite, and occasional deposits of limestone. The dominant minerals are biotite, breadalbaneite, quartz, and dolomite, with small amounts of gypsum, carbonate, and pyrite (Wang and Zhang, 1981; Liu et al., 1999).

Meltwater was sampled at the GN1 gauging station (Fig. 1) at 14:00 daily during the periods 26 June to 30 August 2003, 21 May to 30 August 2004, and 8 May to 2 September 2008, and at 9:00 and 17:00 daily corresponding to the diurnal lowest and highest water stages during 1 June to 30 September 2013 in which a diurnal cycle was sampled once every two hours each month. Precipitation was sampled during the periods 19 June to 27 August 2003 and 5 May to 30 August 2004 at the Daxigou weather station at 3539 m a.s.l. (belonging to the China Meteorological Administration)



**FIGURE 1.** Sketch map showing the sampling sites, the GN1 gauging station, and the Daxigou weather station.

where meteorological data have been available from 1958. Both meltwater and precipitation samples were stored in the low-density polyethylene (LDPE) plastic bottles purified with deionized water beforehand. Snow/ice was sampled at an elevation of 4130 m in the accumulation area at the east branch of the GN1 during the periods 26 June to 30 August 2003, 21 May to 30 August 2004, and 13 July 2006 (Fig. 1). Snow samples were collected with a sampling frequency of once a week, and surface snow samples were taken from the top 5 cm of snow pits. Each snow/ice sample was carefully placed in a widemouthed LDPE plastic bottle in a frozen state to avoid evaporation and diffusion. Atmospheric aerosols were sampled at an elevation of about 4030 m at the east branch of the GN1 with a sampling frequency of once a week during 26 June to 30 August 2003 and 21 May to 30 August 2004. Aerosol samples were collected using a solar-powered 12 V DC pump. The sampling membrane was a Zeflour Teflon membrane with a pore size of 2  $\mu\text{m}$  and a diameter of 47 mm. The volume of samples was measured using a volume flow meter. Atmospheric pressure and air temperature were measured every hour and used to calculate the standard volume of the air flowing through the membrane. Aerosol mass loadings were determined gravimetrically using a Sartorius MC5 electronic microbalance with a sensitivity of 1  $\mu\text{g}$ . To extract the water-soluble species from the filters, each filter was wetted with 50  $\mu\text{L}$  ultrapure ethanol, and the soluble components were then extracted with 10 mL Milli-Q water, followed by sonication in a water bath for 60 min. The samples were shaken twice on a mechanical shaker for 1 h each to completely extract the ionic compounds. The extracts were filtered with a 0.45  $\mu\text{m}$  pore size microporous membrane, and the filtrates were stored at 4  $^{\circ}\text{C}$  in a clean tube before analysis.

The EC in meltwater was determined using an Orion-125A conductivity meter (with  $\pm 0.5\%$  accuracy) in the field in order to reduce potential errors due to  $\text{CO}_2$  and  $\text{H}^+$  (Fenn, 1987). The EC in aerosol, snow/ice, and precipitation were determined using a DDSJ-308A conductivity meter (with  $\pm 0.1\%$  accuracy) in the State Key Laboratory of Cryospheric Sciences (SKLCS), Chinese Academy of Sciences (CAS). Major cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$ ) in meltwater were analyzed by a Dionex 600 ion chromatograph using an IonPac CS12A column, 20 mM MSA eluent, and CSRS-ULTRA-II suppressor. Major anions ( $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ ) in meltwater were analyzed by a Dionex 2500 ion chromatograph using an IonPac AS11 column, 25 mM KOH eluent, and ASRS-ULTRA-II suppressor. The detection limits for all measured ions were below 0.1  $\mu\text{g L}^{-1}$ .

## Results and Discussion

### SPATIAL AND TEMPORAL VARIATIONS

#### Interannual Variation

Table 1 shows the interannual variations of the EC in meltwater from the GN1 at the headwater of the Urumqi River over the period 1982–2008. Although the number of samples and the sampling time are not entirely consistent, the results reflect the interannual changes of the EC in meltwater relative to the changes in discharge, air temperature, and precipitation. Obviously, the EC in meltwater ranges from 27 (in 2007) to 537  $\mu\text{S cm}^{-1}$  (in 2006), and its higher (lower) values appear over the period 2004 to 2006 (2007 to 2008), which corresponds to the relatively lower (higher) air temperature and precipitation during the ablation seasons (Table 1). This suggests that the interannual variation of the EC in meltwater may be associated with the variations of meteorological

TABLE 1

Variations of mean, maximum (*Max*), and minimum (*Min*) values of the EC ( $\mu\text{S cm}^{-1}$ ) in meltwater from the GN1 over the period May to August of 1982–2008.  $T_m$ ,  $P_t$ , and  $Q_d$  indicate the corresponding mean air temperature ( $^{\circ}\text{C}$ ) and total precipitation (mm) at the Daxigou weather station and mean discharge depth (mm) at the GN1 gauging station, respectively.

	1982*	2003	2004	2005	2006	2007	2008
<i>n</i>	105	62	40	83	94	36	109
<i>Mean</i>	86	102	243	168	182	72	85
<i>Max</i>	245	223	438	364	537	137	179
<i>Min</i>	30	46	95	62	60	27	34
$T_m$	2.7	2.9	3.6	3.5	3.8	4.2	4.5
$P_t$	384	375	343	402	383	448	386
$Q_d$	430	779	739	751	1020	659	755

*n*: Number in sample.

\*From the Tianshan Glaciological Station (1982).

factors and may reflect the interannual differences in the glacier ablation intensity and associated water-rock interaction process in the subglacial/periglacial hydrological systems.

#### Seasonal Variations

The variations of EC in meltwater are closely associated with the bedrock mineralogy, the solution geochemistry (e.g., pH, mineral saturation states, and sediment concentrations), and the evolution of the subglacial hydrological system (Brown, 2002; Mitchell et al., 2004). Obviously, the EC in meltwater shows a clearly seasonal variation and a close association with meltwater discharge, air temperature, and precipitation during the ablation season (Fig. 2). During the period 8 May to 25 June ( $P_1$ ), the EC ranging from 51.4 to 161  $\mu\text{S cm}^{-1}$  (average value 91.1  $\mu\text{S cm}^{-1}$ ) presents a fluctuation trend. In detail, the EC shows lower values over 8 to 14 May and 28 May to 17 June and higher values over 15 to 27 May and 18 to 25 June, indicating a negative correlation with meltwater discharge ranging from 0.03 to 0.38  $\text{m}^3\text{s}^{-1}$  (average value 0.16  $\text{m}^3\text{s}^{-1}$ ). Correspondingly, air temperature ranging from  $-1.3$  to  $9.1$   $^{\circ}\text{C}$  (average value  $4.2$   $^{\circ}\text{C}$ ) presents an inverse fluctuation trend and a negative correlation with the EC in meltwater. Precipitation ranging from 0.2 to 14.3 mm (average value 3.8 mm) tends to present a relatively low fluctuation trend and an irrelevant association with the EC in meltwater. This suggests that lower (higher) temperature leads to weaker (stronger) ablation and less (more) meltwater during the early ablation period, in which meltwater may be primarily derived from snow cover, seasonally frozen soil, and groundwater. The melting of snow cover usually leads to an “ion pulse” phenomenon (Liu et al., 1997), suggesting that the retreat of snow cover may enhance variation of the EC in meltwater during the early ablation period, which is supported by the comparison between the EC in surface snow and meltwater (Fig. 3).

During the period 26 June to 13 August ( $P_2$ ), the EC ranging from 33.5 to 126.7  $\mu\text{S cm}^{-1}$  abruptly decreases to the lowest level and its average value (62.3  $\mu\text{S cm}^{-1}$ ) decreases by one-third relative to the period  $P_1$  (Fig. 2). Correspondingly, meltwater discharge and air temperature present a sudden increasing trend, and their average values (0.4  $\text{m}^3\text{s}^{-1}$  and 6.2  $^{\circ}\text{C}$ ) increase by almost double and

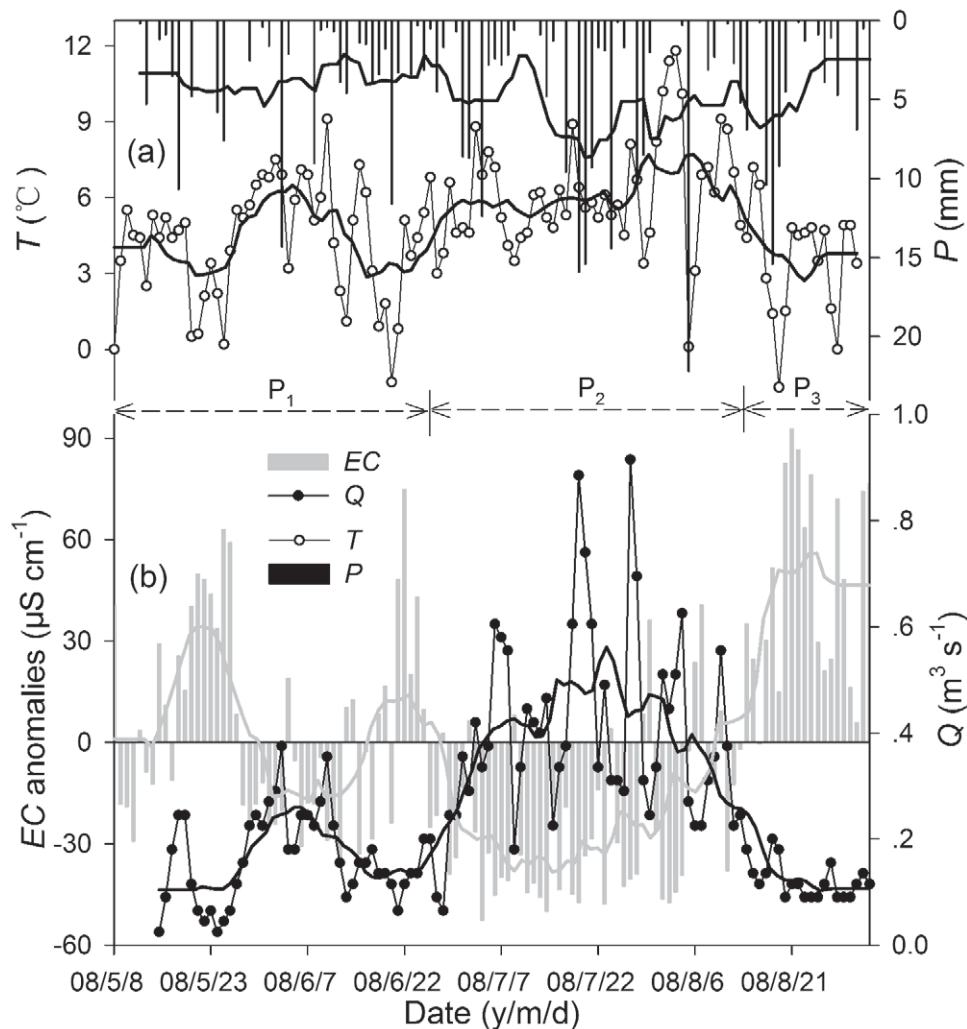


FIGURE 2. (a) Variations of air temperature and precipitation at the Daxigou weather station, and (b) the electrical conductivity (EC) in meltwater and meltwater discharge ( $Q$ ) at the GN1 gauging station over the period 8 May to 2 September 2008.

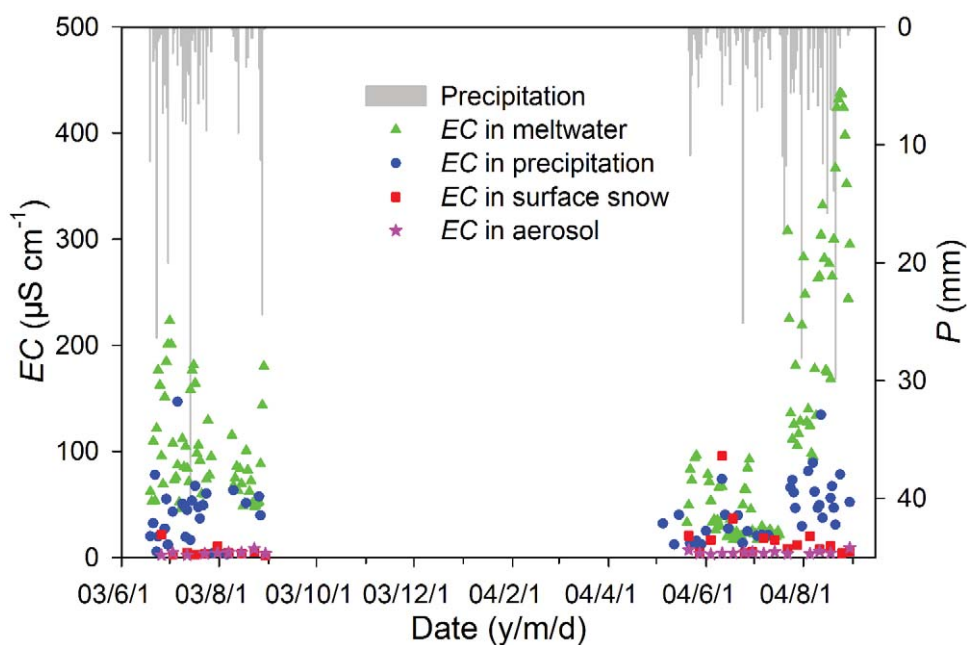


FIGURE 3. Variations of the EC in aerosols, surface snow, precipitation, and meltwater at the headwater of the Urumqi River over the ablation season of 2003 to 2004.

one-half, respectively, during the period  $P_2$ . Moreover, precipitation presents an obvious increasing trend and its average value (5.4 mm) increases by one-half relative to the period  $P_1$  (Fig. 2), suggesting that precipitation may reduce the loading of total dissolved ions in meltwater due to the dilution process (Fig. 3). A sudden heavy rainfall may enhance the EC in meltwater, however, due to the dissolution of more surface materials from the erosion of slope soil, which may be supported by high values of the EC in meltwater relating to high precipitation events during the rainy seasons (Fig. 2). This suggests that meltwater discharge is mainly composed of precipitation and glacier ice meltwater during the peak-flow period, in which meltwater discharge flows rapidly through a hydrological system predominantly in ice-walled conduits, limiting the potential for solute acquisition, leading to the lowest loadings of total dissolved ions and the lowest values of EC in meltwater. During the period 14 August to 2 September ( $P_3$ ), the EC, ranging from 85.8 to 178.8  $\mu\text{S cm}^{-1}$ , reaches the highest level and its average value (132.6  $\mu\text{S cm}^{-1}$ ) increases by one-half relative to the period  $P_1$  (Fig. 2), suggesting that the glacier ablation decreases during the late ablation period. Correspondingly, meltwater discharge and air temperature decrease to a lower level similar to those during the period  $P_1$  and their average values (0.12  $\text{m}^3 \text{s}^{-1}$  and 3.5  $^{\circ}\text{C}$ ) range from 0.09 to 0.20  $\text{m}^3 \text{s}^{-1}$  and -1.5 to 7.2  $^{\circ}\text{C}$ , respectively. Precipitation ranging from 0.1 to 15.4 mm (average value 4.4 mm) presents a decreasing trend. This suggests that meltwater runoff transports slowly through a distributed hydrological system at the ice-rock interface, encouraging the potential for solute acquisition, resulting in higher loading of total dissolved ions and a higher value of the EC in meltwater.

The conceptual hydrological model shows that total meltwater runoff consists of quick-flow and delayed-flow components at the glacier basins (Brown, 2002; Tranter et al., 1993). At the minimum discharge, discharge is composed mainly of “delayed-flow” water from an inefficient distributed system, and then passes into a channelized system owing to high and low pressures in the distributed and channelized system, respectively (Hubbard et al., 1995). This promotes protracted and intimate contact with subglacial sediments, allowing more concentrated meltwater runoff to evolve (Brown et al., 1994, 1996). Conversely, as discharge increases, meltwater runoff is increasingly routed directly through a channelized system (Nienow et al., 1996), and solute is generated from the interaction of the supraglacial meltwater runoff and subglacial sediments (Brown et al., 1994, 1996). As more dilute water is routed into the subglacial environment, the dilution of delayed-flow water and duration of water-sediment interaction declines and thus reduces solute acquisition, resulting in lower concentrations of dissolved ions and then lower EC.

#### COMPARISONS AMONG AEROSOLS, PRECIPITATION, SURFACE SNOW, AND MELTWATER

The dissolved species adsorbed by the dust are usually carried by the wind to the atmosphere above glaciers and then accumulate onto the glacier surface through dry/wet deposition processes. The dust storms usually occur in spring at the headwater of the Urumqi River, which enhances the enrichment of dissolved ions in aerosols and precipitation and then the deposition in surface snow (Sheng and Yao, 1996). Thus, the EC in aerosols, precipitation, and surface snow are closely related to the atmospheric circulation and associated dust loading in the atmosphere. Additionally, most of the dissolved ions in snow cover and meltwater will be more or less washed away and will finally enter meltwater runoff during the

**TABLE 2**  
Mean, maximum (*Max*), and minimum (*Min*) values of the EC ( $\mu\text{S cm}^{-1}$ ) in aerosols, surface snow, precipitation, and meltwater at the headwater of the Urumqi River over the periods from June to August 2003 and May to August 2004.

	Aerosols	Surface snow	Precipitation	Meltwater
<i>n</i>	26	26	64	152
<i>Mean</i>	4.3	13.4	42.4	116.0
<i>Max</i>	9.0	95.5	146.6	438.0
<i>Min</i>	2.0	2.1	2.8	16.4
<i>Max/Min</i>	4.5	45.5	52.4	26.7

ablation seasons, suggesting that the EC in snow cover is mainly affected by air temperature (not precipitation) during the elution process of dissolved ions (Li et al., 2006).

The data from aerosols, precipitation, surface snow, and meltwater during two summer ablation seasons are used here to systematically analyze the spatial change in the EC. The average value of the EC in meltwater is far greater than that in aerosols, surface snow, and precipitation, but its variation amplitude (*Max/Min*) is lower than that in surface snow and precipitation and higher than that in aerosols (Table 2; Fig. 3), suggesting that the EC in meltwater is determined by different factors from that in aerosols, surface snow, and precipitation. The EC in surface snow is lower than that in precipitation and higher than that in aerosols particularly for the ablation season of 2004 (Fig. 3), indicating that the EC in surface snow is closely related to the dry/wet deposition and elution processes. Moreover, the dissolved ions in surface snow are more or less washed away along with snow meltwater during the ablation seasons, resulting in lower EC values for surface snow than in precipitation. Thus, the EC provides a simple, convenient, and effective method of estimating the concentration and distribution of dissolved ions in different media (Smart, 1992). The variations of EC in meltwater reflect the characteristics of glaciations and the underlying surface, which are influenced by air temperature and precipitation. The EC in meltwater negatively correlates well with meltwater discharge and temperature, and meltwater discharge positively correlates well with air temperature, suggesting that the variations of EC in meltwater reflect the ablation intensity of glaciers due to changes in air temperature. Meltwater runoff and precipitation yield a poor correlation, indicating that the influence of precipitation on the dissolved ions is not as great as that of air temperature.

In addition, peak EC values for snow pits appear at the upper layers of snow pits at different altitudes on the GN1, and the EC decreases with the depth of snow pits (Fig. 4), suggesting the influence of the elution process on the EC in snow pits during the ablation season (Li et al., 2007). The profiles of the EC in snow pits change with their altitude (Fig. 4), denoting the spatial variation of snow melting and the enrichment and loss of dust-related dissolved ions in the process of glacier accumulation and ablation. This results in an increase in meltwater and a decrease in the EC in snow pits due to an increase in air temperature. Most of the high EC values for snow pits appear around the equilibrium line altitude (about 4068 m in 2006; Tianshan Glaciological Station, 2006), suggesting that the dissolved ions in snow pits are apt to gather in this area where snow pits are relatively stable and glacier accumulation equals glacier ablation.

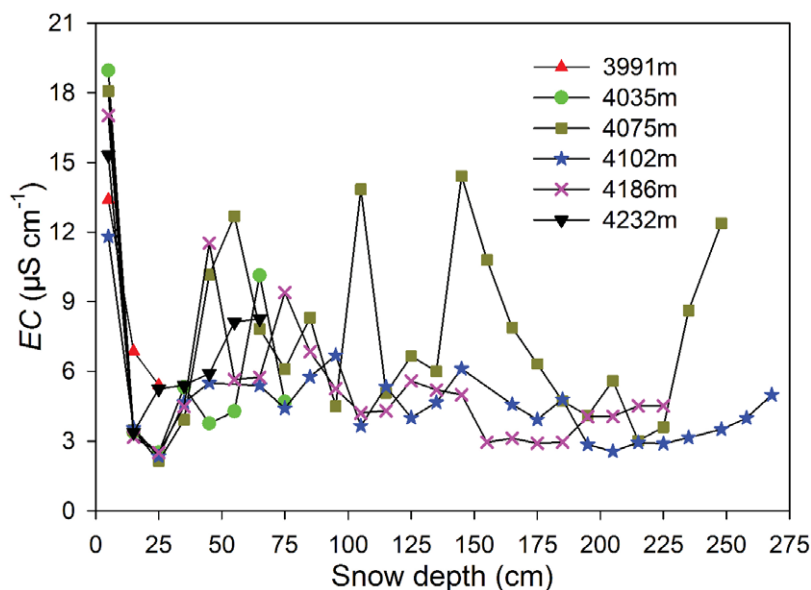


FIGURE 4. Variations of the EC in snow pits at different altitudes on the GN1 with the increase of snow depth during the ablation season (13 July 2006).

#### FACTORS TO DETERMINE THE EC

Studies indicated that the dust loading and related dissolved ions in surface snow are closely related to that in aerosols at the headwater of the Urumqi River (You and Dong, 2011). The dissolved ions to determine the EC in surface snow and precipitation are  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{SO}_4^{2-}$  (Li et al., 2007; Zhao et al., 2008). Significantly, the key ion to determine the EC is  $\text{Ca}^{2+}$  which derives from a local-plus-regional source and a long-distance source. Potential sources include local mineral aerosols 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 rock and glacial sediments are available sources for  $\text{Ca}^{2+}$  (Williams et al., 1992; Sun et al., 1998; Hou and Qin, 2002), which is enhanced by the fact that calcification is the major soil formation process in semiarid and arid regions where abundant calcites are produced (Zhang et al., 2002).

The dissolved ions in meltwater are principally derived from atmospheric deposition and water-rock interaction, which mostly take place in subglacial and ice-marginal environments (Brown et al., 1994; Yde and Knudsen, 2004; Yde et al., 2005). Acid hydrolysis dominates chemical weathering, and carbonation draws  $\text{CO}_2$  out of the atmosphere since it is a combination of relatively slow diffusion of gaseous  $\text{CO}_2$  into solution and acid hydrolysis of minerals (Hasnain and Thayyen, 1999). Pyrite is the most common sulfide mineral at the glacial basins, and other sulphide minerals, metallic sulfides and silicate minerals may be additional sources of sulfate (Plummer et al., 1983). Table 3 shows correlation coefficients between the EC and dissolved ions in meltwater. The ions whose EC correlation coefficients exceed 0.45 ( $p < 0.00001$ ) are  $\text{HCO}_3^-$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ , and  $\text{SO}_4^{2-}$ , indicating that these are the dominant ions to determine the EC in meltwater. In particular, the key ions dominating the EC in meltwater are  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$ , and  $\text{SO}_4^{2-}$  which account for 58.3%, 20.0%, and 15.4% of total ionic loading, respectively, followed by  $\text{Mg}^{2+}$  (2.0%),  $\text{K}^+$  (1.9%),  $\text{Na}^+$  (1.6%), and  $\text{Cl}^-$  (0.7%). Based on high loading of  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$ , and  $\text{SO}_4^{2-}$ , significant correlations for  $\text{Ca}^{2+}$  vs.  $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$  ( $r > 0.90$ ), and  $\text{SO}_4^{2-}$  vs.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ( $r \geq 0.70$ ) (Table 3), it is suggested that the dominant control of chemical species might be biogeochemical pyrite ( $\text{FeS}_2$ ) oxidation coupled with calcite

TABLE 3

Correlation coefficients between the EC and major dissolved ions in meltwater at the GN1 gauging station from June to September 2013. *Italic numbers indicate the significant level at  $p < .00001$  ( $n = 248$ ).*

	$\text{Na}^+$	$\text{K}^+$	$\text{Mg}^{2+}$	$\text{Ca}^{2+}$	$\text{Cl}^-$	$\text{SO}_4^{2-}$	$\text{HCO}_3^-$
EC	<i>0.49</i>	<i>0.54</i>	<i>0.54</i>	<i>0.58</i>	0.27	<i>0.55</i>	<i>0.47</i>
$\text{Na}^+$		<i>0.86</i>	<i>0.85</i>	<i>0.85</i>	<i>0.68</i>	<i>0.48</i>	<i>0.87</i>
$\text{K}^+$			<i>0.79</i>	<i>0.78</i>	<i>0.39</i>	<i>0.45</i>	<i>0.82</i>
$\text{Mg}^{2+}$				<i>0.95</i>	<i>0.39</i>	<i>0.70</i>	<i>0.90</i>
$\text{Ca}^{2+}$					<i>0.45</i>	<i>0.71</i>	<i>0.93</i>
$\text{Cl}^-$						<i>0.34</i>	<i>0.38</i>
$\text{SO}_4^{2-}$							<i>0.41</i>

( $\text{CaCO}_3$ ) and/or dolomite ( $\text{CaMg}[\text{CO}_3]_2$ ) dissolution under oxidizing conditions. Feng et al. (2012) showed that the weathering of carbonate, pyrite, and feldspar dominates the solute acquisition at the headwater of the Urumqi River. This can be supported by the fact that glacier meltwater tends to carry relatively high calcium loading (Anderson et al., 1997), that the carbonate dissolution and sulfide oxidation dominate the solute fluxes (Anderson et al., 2000; Tranter et al., 2002), and that the fluxes of solutes produced by silicate weathering are relatively low at the glacial basins (Anderson, 2005).  $\text{H}_2\text{CO}_3$ -driven calcite dissolution requires a  $\text{CO}_2$  source at the bed probably in the form of microbial respiration, and its extent reflects the water's residence time in a subglacial system, which modulates the accumulation of  $\text{CO}_2$  (Anderson et al., 2003).

#### Conclusions

EC in aerosols, snow, and meltwater were evaluated at the headwater of the Urumqi River during the ablation seasons of 2003–2008. EC in meltwater reflects the intensity of glacier abla-

tion and negatively correlates with air temperature and discharge. EC presents a fluctuation trend and a negative correlation with discharge and air temperature during the early ablation period ( $P_1$ ) in which runoff may be primarily from snow, frozen soil, and groundwater. EC abruptly decreases to the lowest level during the peak-flow period ( $P_2$ ), in which discharge, air temperature, and precipitation increase, and runoff is mainly composed of precipitation and ice meltwater, which flows rapidly through a hydrological system predominantly in ice-walled conduits. EC reaches the highest level during the late ablation period ( $P_3$ ), in which discharge and air temperature decrease to a lower level, precipitation presents a decreasing trend, and runoff transports slowly through a distributed hydrological system at the ice-rock interface. In addition, EC is far higher in meltwater than in aerosols, surface snow, and precipitation, and the factors to determine EC are different in each of these. EC in surface snow is lower than in precipitation and higher than in aerosols, and is closely related to the dry/wet deposition and elution process. EC in snow pits changes with the altitude, denoting the spatial variation of snow melting as well as the enrichment and leaching out of dissolved ions during accumulation and ablation. Dissolved ions in snow pits are apt to gather in the equilibrium line altitude area where snow pits are relatively stable and accumulation equals ablation. The key ions to determine EC in meltwater are  $\text{HCO}_3^-$ ,  $\text{Ca}^{2+}$ , and  $\text{SO}_4^{2-}$ , which account for 58.3%, 20.0%, and 15.4% of total loading, respectively, and the dominant control of chemical species might be the biogeochemical pyrite oxidation coupled with calcite and/or dolomite dissolution.

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