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The evolution and environmental significance of glaciochemistry during the ablation period in the north of Tibetan Plateau, China

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A B S T R A C T

In order to explore the glaciochemistry of Shiyi glacier in the central Qilian Mountains, a total of 142 samples have been collected for fresh snow, surface snow, snowpit and meltwater from July 2012 to November 2013. The results indicated cations dominated the glaciochemistry, especially the high Ca^{2+} concentration. Relatively high Cl^- and Na^+ concentrations were mainly contributed by desert dust aerosols and the atmospheric aerosols from warm water bodies such as the Black, Caspian, and Aral seas. The analysis also confirmed the chemical ions in fresh snow are mainly contributed by atmospheric wet deposition. Surface snow is mainly influenced by dry deposition, and snowpits are influenced by both atmospheric deposition and leaching process, while meltwater is influenced by water–rock interactions. The profile of ionic concentration in the snowpit became more smoothed during ablation period owing to the influence of leaching. The elution sequence of the snowpit in the Shiyi Glacier was: $SO_4^{2-} > K^+ > Ca^{2+} > Mg^{2+} > Na^+ > Cl^- > NO_3^-$. The chemical concentrations for meltwater are mainly influenced by water dilution and soil thawing. The ions in snow in the central Qilian Mountains showed relatively lower concentrations than in the western Qilian Mountains, Tianshan Mountains and Altai Mountains. It was closer to balance than in glaciers in the central Tibetan Plateau, but was higher than in the southern Tibetan Plateau. Different ionic sources and dissolution process had caused the differences of chemical composition for fresh snow, surface snow, snowpit and meltwater, and these chemical compositions reflected the atmospheric background values in the northern Tibetan Plateau.

1. Introduction

Chemical studies of snow are important because snow and glaciers, as sites of deposition of chemical components of the atmosphere, can provide crucial information about climatic and environmental changes (Johnsen et al., 1972; Barrie et al., 1985; Yao et al., 1989), and many researches have been made in Tibetan Plateau (Wake et al., 1993; Shrestha et al., 1997; Huang et al., 1998; Kang et al., 2000, 2004, 2007; Xiao et al., 2002a, 2002b; Wu et al., 2011; Guo et al., 2012; Yue et al., 2013), Tianshan Mountains (Wang et al., 2011a, 2011b; Zhang et al., 2011, 2012; Dong et al., 2013a, 2013b; Feng et al., 2014) and Hengduan Mountains (He et al., 2002a, 2002b; Pang et al., 2007, 2012; Li et al., 2008a, 2008b, 2009a, 2009b, 2010; Zhu et al., 2012; Niu and He, 2014). Analysis of snow and ice chemistry could provide valuable information on the sources of atmospheric aerosols (Wolff, 1990; Legrand and Mayewski, 1997), atmosphere circulation (Kang et al., 2002; Xiao et al., 2002a; Aizen et al., 2004) and past climatic and environmental evolution (Hou et al., 2003; Li et al., 2009a; Niu and He, 2014). Identification of the origins of the ions present in snow may provide information about changes in the atmosphere, lithosphere, hydrosphere, and cryosphere. Wet/dry deposition plays an important role in the transfer of chemical constituents from atmosphere to snow. In recent years, snow and ice chemistry investigations have been conducted in western China (Kang et al., 2004, 2007; Li et al., 2006; Wang et al., 2011a, 2011b; Zhang

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et al., 2012; Niu et al., 2013; Dong et al., 2013a), but such studies in Qilian Mountains in the northern Tibetan Plateau are rare up to now.

This paper systematically presents the snowpit, meltwater, fresh and surface snow chemistry research collected from the Shiyi Glacier in the central Qilian Mountains. This area is interesting for water resources, as the source of the Heihe River, the second largest inland river of China. However, little literature has comprehensively focused on snow chemistry and atmospheric circulation in this region, although the aerosol particles deposited in snow/ice have been well recognized as an important medium and can provide valuable information on environmental changes (Pereira et al., 2004; Cong et al., 2009). In this study, factor and correlation analysis are employed to examine chemical composition and the temporal variation of major ions in the Shiyi Glacier. The Hysplit4 transporting mode is applied to identify the possible new and potential source regions for major ions, and the influence of transport on the chemical signals. Comparison with the existing results of other sites in western China is also conducted in the analysis to expand current knowledge of the spatial and temporal characteristics of snow chemistry. In particular, a focus is in the ion elution sequence and enrichment factors, verifying the dominant depositional process and influence of local dusts on snow chemical fluctuation and temporal variations. The study further investigates the climatic and environmental implications of snow chemistry recorded in the central Qilian Mountains.

2. Sampling collection and experimental methods

The Qilian Mountains in the hinterland of Eurasia are a marginal mountain system in the northeastern Tibetan Plateau (36.5°–39.5° N, 93.5°–103° E). The mountains traverse the border between Gansu and Qinghai Provinces, and consist of a series of roughly parallel ridges and ravines trending NW–SE. According to Chinese glacier inventory, there were 2859 glaciers with a total area of 1972.50 km^2 in these mountains in 1981. The central Qilian Mountains contain 1078 glaciers, with 428 and 650 glaciers in the Heihe and Beidahe river basins, respectively. These glaciers have a total area of 420.55 km^2 and a total volume of 13.67 km^3, which account for 37.7% and 21.3% of those throughout the entire Qilian mountain range (Wang et al., 1981). The Hulugou Basin is located in the central Qilian Mountains, at 38.2°–38.3° N, 99.8°–99.9° E (Fig. 1). With a catchment area of 23.1 km^2, the basin has a gourd shape, and elevations of 2960–4820 m. There were 5 glaciers with a total area of 0.827 km^2 in 2011, and these glaciers constitute the runoff area and the headwater conservation zone of the Heihe River (Chen et al., 2013). The Shiyi Glacier is the largest with an area of 0.463 km^2. Dominant atmospheric circulation in this region is the westerlies. The temperature varies with altitude from valley to mountain. The annual precipitation, with a decreasing trend from east to west and from south to north, varies from 400 mm to 700 mm.

Snow samples including fresh snow, surface snow, snowpit, and meltwater were continuously collected from July 2012 to November 2013. The fresh snow samples have been collected from 3400 m to 4680 m in May and from 3600 m to 4130 m in November. For surface snow, one is continuous sampling at the elevation of 4680 m once a month during the whole ablation period; the other is the sampling at different altitudes on July in 2012 and 2013. Snowpit samples were collected from a snowpack at 4680 m in the accumulation area of Shiyi Glacier once a month during the ablation period, from July to September in 2012 and from April to August in 2013. The collection for meltwater included two aspects of work: continuous sampling at the front of Shiyi Glacier in the ablation period (4450 m), and meltwater sampling on the glacier surface (including the collection of the fresh snow meltwater at 3600 m). Extreme care and stringent sampling protocols were taken at all times during sample collection and handling to assure samples were not contaminated at the ueq/L level. A pre-cleaned stainless-steel sampling tool was used to pack samples directly into pre-cleaned 200 ml polypropylene containers, and non-particulating suits, polyethylene gloves and masks were worn at all times during the sampling campaign. All sampling equipment and sample containers were precleaned with distilled water. A total of 142 snow samples were collected for major ion analyses. All

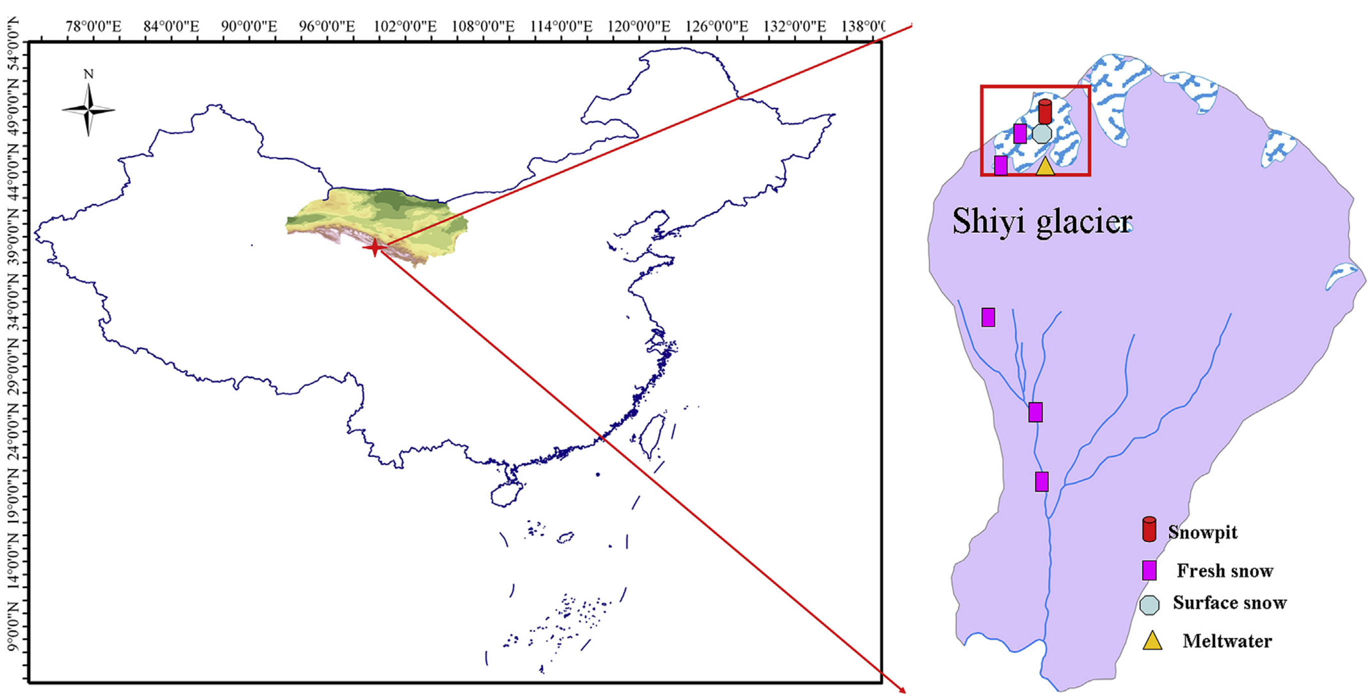

Fig. 1. Location of Shiyi glacier and sampling sites.