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Chemical Composition of Fresh Snow on Xixabangma Peak, Central Himalaya, During the Summer Monsoon Season

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The physical and chemical analyses of ice cores recovered from glaciers in the Himalaya provide some of the best records of past climate change in the region (e.g. Qin and others, 2000; Thompson and others, 2000; Kang and others, 2001, 2002). In order to better understand the climatic and environmental records preserved in snow and ice, studies have investigated the precipitation chemistry in the high Himalaya, notably that of the northern slopes of the central Himalaya (Mayewski and others, 1986; Jenkins and others, 1987) and the southern slopes of the central Himalaya (Shrestha and others, 1997; Marinoni and others, 2001). Short-term aerosol/fresh-snow chemistry sampling during monsoon and post-monsoon seasons has shown low pollutant concentrations, suggesting these Himalayan sites are representative of the remote troposphere (Wake and others, 1994; Shrestha and others, 1997; Marinoni and others, 2001). Here we present chemistry data of fresh snow sampled from the northern slope of Xixabangma peak (28°33′ N, 85°44′ E), central Himalaya, during the 1997 summer. The main purpose is to expand the fresh-snow chemistry database for the high mountain regions in the Himalaya.

During August and September 1997, fresh-snow samples were collected within 12 hours of deposition at two camps (5400 and 5800 m a.s.l.) and along the climbing route (5400–7000 m a.s.l.) in the Dasuopu glacier region on the northern slope of Xixabangma peak. Methods of sampling were the same as those used by Mayewski and others (1986) and Wake and others (1994). Care was taken during sample collection and transfer to avoid contamination (Kang and others, 2000). Oxygen isotope, pH and conductivity analysis were performed using a Finnigan MAT-252 spectrometer (accuracy of 0.5‰), pH meter (model PHS-2) and conductivity meter (model DDS-11A), respectively, at the Laboratory of Ice Core and Cold Regions Environment, Chinese Academy of Sciences (CAS). Ion concentrations were measured at the Climate Change Research Center, University of New Hampshire, U.S.A., using a Dionex ion chromatograph model 2010.

The mean, maximum and minimum values of ion concentrations are shown in Table 1. The mean Na^+/Cl^- ratio of 0.85 in snow is close to that of 0.86 found in sea water, suggesting that Cl^- and Na^+ mainly come from sea salt during the summer monsoon season. From Table 1, the ion balance ΔC (sum of cations − sum of anions) equals 3.55 μeq L^{-1}, indicating that there is an excess of cations. Studies from the Tien Shan and Qomolangma (Mount Everest; about 100 km away from Xixabangma) suggest that the ΔC term is made up primarily of CO_3^{2-}/HCO_3^- (Williams and others, 1992; Wake and others, 1994). Generally the excess ΔC may indicate that the atmosphere in this region is alkaline as has been noted previously (Galloway and others, 1987; Wake and others, 1994).

Chemistry data from fresh-snow samples collected in

Table 1. Chemical composition of fresh snow from Xixabangma during the summer monsoon season

	Na^+	K^+	Cl^-	NH_4^+	Mg^{2+}	Ca^{2+}	NO_3^-	SO_4^{2-}	*pH*	*Conductivity*	$\delta^{18}O$
	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μS cm^{-1}	‰
Minimum	0.08	0.03	0.24	0.25	0.10	0.60	0.03	0.13	4.34	1.21	−30.29
Maximum	7.93	2.50	7.34	27.96	2.17	13.00	5.99	30.25	7.13	19.10	−9.53
Mean	1.35	0.40	1.59	3.02	0.33	2.60	1.53	1.03	5.96	3.58	−18.35
Std dev.	1.28	0.46	1.29	3.49	0.27	2.08	1.17	2.96	0.54	3.00	4.61
N	102	102	102	102	102	102	102	102	178	178	94

Table 2. Comparison of chemical composition of fresh snow from Xixabangma with those from other remote regions of the world

Site	*Date*	*Altitude*	Cl^-	NO_3^-	SO_4^{2-}	Na^+	NH_4^+	K^+	Mg^{2+}	Ca_2^+	*N*	*Source*
		m a.s.l.	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}	μeq L^{-1}		
Himalaya												
Dasuopu glacier	Aug.–Sept. 1997	5400–7000	1.6	1.5	1.0	1.4	3.0	0.4	0.3	2.6	102	This work
Southern slope of Qomolangma	Sept.–Oct. 1998	5050–6050	2.4	1.0	0.7	2.2	1.5	1.6	0.4	1.9	17	A
Northern slope of Xixabangma	May 1984	6300	5.3	6.3	7.7	5.2					6	B
Northern slope of Qomolangma	Apr.–May 1986	5600–7100	4.0	4.0	5.8	3.6				38.0	96	C
Qinghai–Tibetan Plateau												
Wudaoliang station	Aug. 1989	4612	32.2	17.3	38.0	28.2	30.7	6.7			8	D
Glacier No. 29 (Qilian Shan)	Aug. 1994	3540	4.0	3.6	6.6	2.6		1.1	206.4	170.8	4	E
Other remote regions												
Amsterdam Island, Indian Ocean	May 1980–Apr. 1981	180	406.0	2.7	52.2	334.0	5.1	7.2	72.8	15.5	26	F
Katherine, Australia	Nov. 1980–Apr. 1981	108	20.6	5.9	8.3	11.3	2.8	1.2	3.6	5.7	40	F

Notes: A, Marinoni and others (2001); B, Mayewski and others (1986); C, Jenkins and others (1987); D, Yang and others (1991); E, Ren (1997); F, Galloway and others (1982).

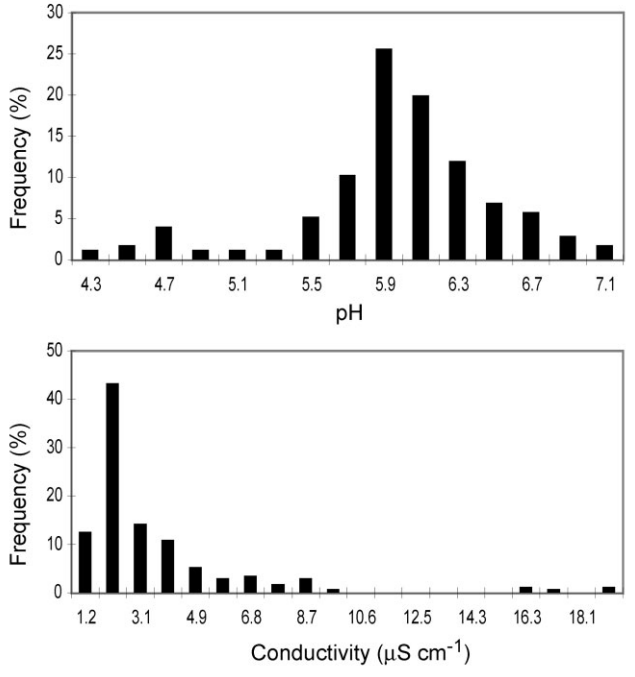

Fig. 1. Frequencies of pH (upper) and conductivities (lower) of fresh snow during the summer monsoon season from Xixabangma.

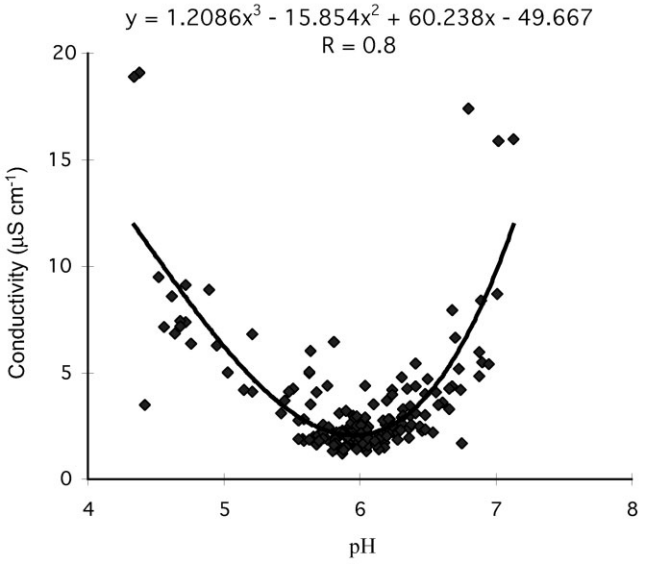

Fig. 2. The polynomial regression between pH and conductivity of fresh snow during the summer monsoon season from Xixabangma.

high-altitude regions in the Himalaya and other remote regions are presented in Table 2. Ion concentrations in summer fresh snow from our work are similar to those from the southern slopes of Qomolangma (Marinoni and others, 2001), indicating that the atmospheric environment is consistent on both slopes of the central Himalaya during the summer monsoon season. Ion concentrations (e.g. Ca^{2+}, SO_4^{2-}) in fresh summer snow are lower than those in fresh spring snow from the same region. This observation is consistent with results from firn-core samples (Kang and others, 2000), suggesting snow chemistry over the central Himalaya is influenced by Asia dust storms during spring (Wake and others, 1994). Compared to other remote regions in the Qinghai–Tibetan Plateau (from the Himalaya to the north), ion concentrations in fresh snow are also much lower on Xixabangma. Higher ion concentrations in summer snow over the central and northern plateau may be related to the local arid conditions (more dust aerosols) (Yang and others, 1991). Na^+ and Cl^- concentrations in fresh snow on Xixabangma are two orders of magnitude lower than those of remote marine regions, such as Amsterdam Island in the Indian Ocean (Galloway and others, 1982), indicating that the depletion of sea-salt aerosol is very effective during the transport of marine air masses from the Indian Ocean to the Himalayan range. The mean NH_4^+ concentration is similar to those from other remote regions, but SO_4^{2-}, NO_3^- and crustal ion concentrations are lower than background values reported from other remote regions of the world (Galloway and others, 1982). This indicates that the Xixabangma region is minimally influenced by anthropogenic emissions during the summer monsoon season.

Conductivity of the snow ranged from 1.2 to 19.1 μS cm^{-1}, with a mean value of 3.6 μS cm^{-1} (Table 1; Fig. 1). The consistent chemistry of precipitation during the summer monsoon season is indicated by the narrow conductivity range (0.7–4.5 μS cm^{-1}) of 80% of our data and by the low variability (standard deviation of 3.0). Using data from remote regions of the world, Galloway and others (1982) estimated that the low limit of the natural mean pH of precipitation is 5.0. The mean pH of 6.0 and very low frequency of pH < 5.0 (Fig. 1) in our samples also suggest that the atmosphere around Xixabangma peak is minimally influenced by anthropogenic-acids emissions (sulfate, nitrate and others) during the summer monsoon season. The polynomial regression curve of pH vs conductivity shows a strong correlation between the two variables (Fig. 2). The minimum conductivity occurs when pH = 6.0, and the negative and positive correlation between the two parameters occurs when pH < 6.0 and pH > 6.0, respectively. This indicates that the dominant chemical species of precipitation are changing between acid anions and crustal cations during the summer monsoon season in the Xixabangma peak region (Galloway and others, 1987). Specifically, acid anions are dominant when pH < 6.0, and crustal cations are dominant when pH > 6.0.

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