

Black carbon in seasonal snow across northern Xinjiang in northwestern China

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Abstract

Black carbon (BC) particles in snow can significantly reduce the snow albedo and enhance the absorption of solar radiation, with important impacts on climate and the hydrological cycle. A field campaign was carried out to measure the BC content in seasonal snow in Qinghai and Xinjiang provinces of western China, in January and February 2012. 284 snow samples were collected at 38 sites, 6 in Qinghai and 32 in Xinjiang. The observational results at the sites in Xinjiang, where the absorbing impurities in snow are dominated by BC particles, are reported in this work. The BC mass fractions in seasonal snow across northern Xinjiang have a median value of $\sim 70 \text{ ng g}^{-1}$, much lower than those in northeast China. The estimated concentration of BC at the cleanest site in Xinjiang is 20 ng g^{-1} , which is similar to that found along the coast of the Arctic Ocean. It is found that the BC content of snow decreases with altitude. Taking into account this altitude dependence, our measured BC contents in snow are consistent with a recent measurement of BC in winter snow on Tianshan glacier. The data from this field campaign should be useful for testing transport models and climate models for the simulated BC in snow.

Keywords: black carbon, seasonal snow, Northern Xinjiang, climate change

1. Introduction

Black carbon (BC) particles are products of incomplete combustion related to burning of fossil fuel and biomass (e.g., Bond *et al* 2004). When BC particles are emitted into the atmosphere, they can be transported long distances before being removed by wet deposition, such as rain and snow, or by dry deposition (e.g., Flanner *et al* 2007, Shindell *et al* 2008). The BC particles strongly absorb solar visible radiation and thus impose an important positive radiative forcing to the climate system (e.g., Jacobson 2001, Hansen *et al* 2005, IPCC 2007).

Since snow is the most reflective natural surface on Earth, small amounts of absorptive impurities such as BC and dust particles deposited into snow can reduce the albedo of snow significantly (e.g., Warren and Wiscombe 1980, Warren 1982). The quantitative link between BC concentration and reduction of snow albedo has been established through both radiative transfer modeling and field and controlled experiments (e.g., Warren and Wiscombe 1980, Grenfell *et al* 1994, Brandt *et al* 2011, Hadley and Kirchstetter 2012). Recent modeling studies indicate that the radiative forcing caused by BC in snow has been an important anthropogenic forcing for climate change of the past century, producing warming both in the Arctic and across the Northern Hemisphere (e.g., Hansen and Nazarenko 2004, Jacobson 2004, Flanner *et al* 2007). Such model studies, however, need to be tested by, among other things, comparing simulations with observations of BC concentration in snow. Notably, BC



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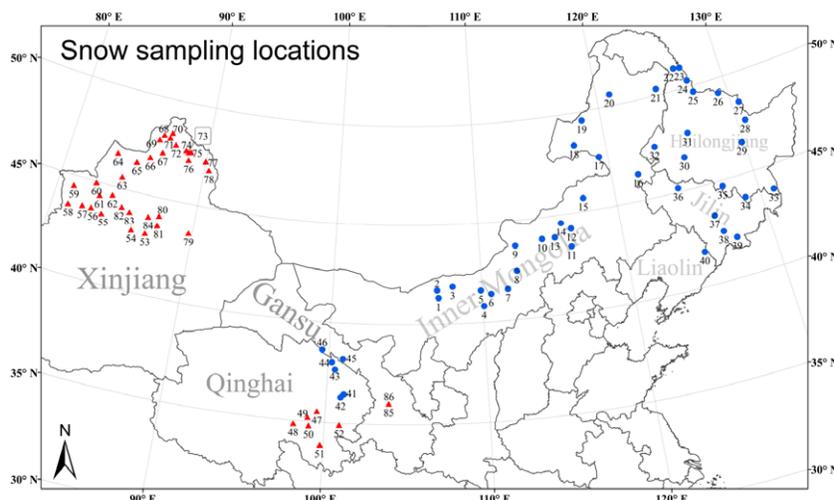


Figure 1. Snow sampling locations in the 2010 and 2012 campaigns. The blue circles are the 46 sites sampled in 2010 (Huang *et al* 2011) and the red triangles are the 40 sites sampled in 2012. The sites are numbered in chronological order. The locations range in latitude from 33° to 51°N and in longitude from 81° to 131°E. The regions with no samples between Sites 1 and 45, and between Sites 46 and 79, are regions with no snow cover at the time of the expeditions (far western Inner Mongolia, northwest Gansu and northwest Qinghai).

in snow and ice is one of the largest sources of uncertainty in the assessment of various radiative forcings for climate change (Hansen *et al* 2005).

While BC has been measured in Arctic snow (Clarke and Noone 1985, Grenfell *et al* 2002, Forsstrom *et al* 2009, Doherty *et al* 2010), it now appears that the larger effect may be in the midlatitudes, where the snow is closer to the sources of BC and also exposed to more sunlight. Radiative forcing due to BC in snow in middle latitudes may impact the timing and rate of snow melt (e.g., Qian *et al* 2009, 2011). Thus, similarly comprehensive field campaigns need to be conducted across the Northern Hemisphere midlatitudes.

The first large-area survey of absorbing impurities in seasonal snow over northern China was conducted in the winter of 2010 (Huang *et al* 2011). It covered six provinces including Qinghai, Gansu, Inner Mongolia, Heilongjiang, Jilin and Liaoning (figure 1). The absorbing impurities were principally dust and BC particles, respectively, in northwestern and northeastern China. The estimated concentration of BC was only $\sim 40 \text{ ng g}^{-1}$ in the far north of Heilongjiang province, but increased to several hundred ng g^{-1} in heavily-industrialized Liaoning, Jilin, and the southern part of Heilongjiang. The BC content of snow in northeast China was comparable to values found in Europe (Huang *et al* 2011). The further analyses of this survey were reported by Wang *et al* (2012).

This work describes a field campaign carried out in the winter of 2012, following the campaign in 2010, to measure the absorptive impurities in seasonal snow in western China, covering the northern part of Xinjiang Uyghur Autonomous Region (hereafter Xinjiang) and the southeast of Qinghai province (figure 1). The preliminary results of BC content of snow in northern Xinjiang are reported here (i.e., the sites from 53 to 84).

2. Field campaign

During a road trip in January–February 2012, seasonal snow was collected at 38 sites: 6 in Qinghai and 32 in Xinjiang. Snow samples were also obtained at two sites on the campus of Lanzhou University in early March 2012. The sampling site locations in both 2010 and 2012 campaigns are shown in figure 1, which are numbered chronologically. Between the clusters of sampling locations in figure 1 are some large blank areas (far-west Inner Mongolia, northwestern Gansu, northwestern Qinghai, eastern Xinjiang and central Xinjiang). These are desert regions with little snowfall; the ground was bare when we passed through these regions, so no snow was available for collection.

The sampling sites (except two sites on the campus of Lanzhou University) were chosen to be distant from roads and villages so as to avoid local pollution, so that the results can represent large areas. At each site, a snow pit was dug and snow samples were gathered in two vertical profiles separated by $\sim 50 \text{ cm}$ (‘left’ and ‘right’) to check for consistency. The snow was stored in plastic bags and kept frozen during the trip until we stopped to filter the samples. The influence of the plastic bags on the composition analysis is negligible (Doherty 2012). The vertical profiles of snow density were also measured for a depth of 5 cm of each layer downward while the temperatures were measured at the center of each layer. These data may be used, together with the concentrations, to quantify the deposition flux of BC and/or dust. Two pictures taken while collecting snow samples are shown in figure 2.

We normally collected the snow samples from adjacent vertical layers from the top to bottom with a depth of $\sim 5 \text{ cm}$ for each layer (figure 3), and the reported BC concentration is considered to represent the corresponding layer. In Qinghai and Xinjiang, some sites had very thin snow and strong wind, so that sampling was only possible in snow drifts. In Qinghai,

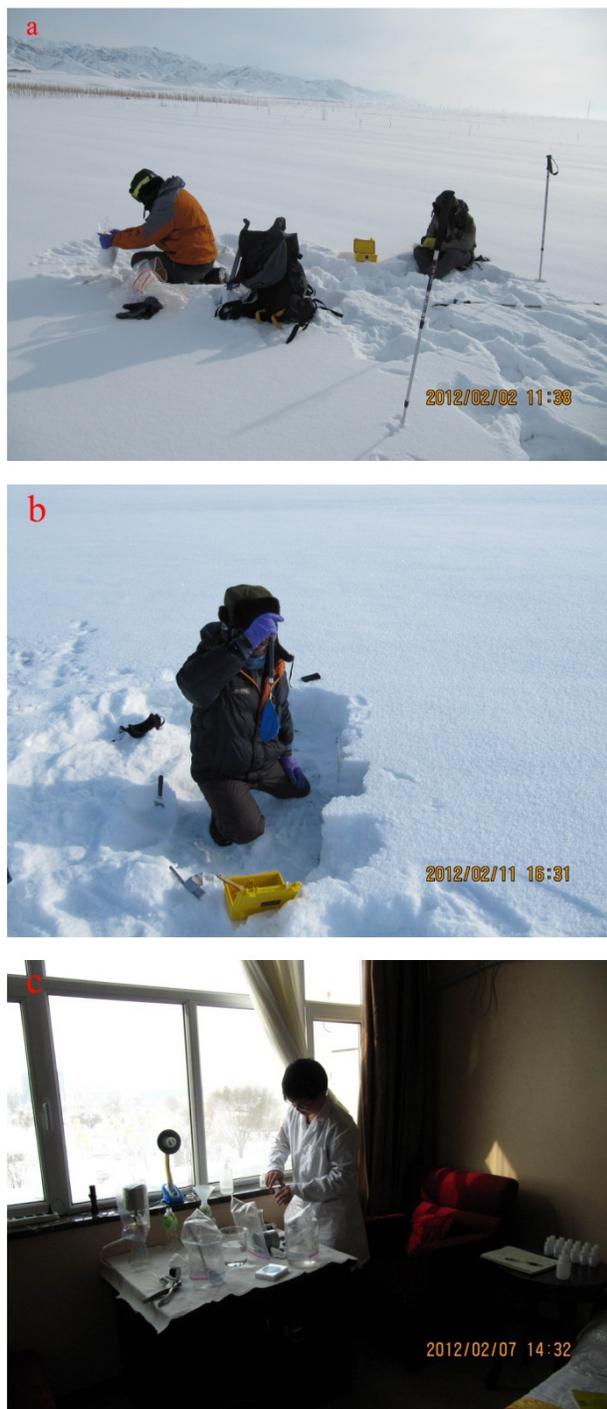


Figure 2. (a) Snow collection in a pasture in the Tianshan Mountains (Site 55), (b) snow collection in Altai Mountains (Site 68) and (c) filtering meltwater in a hotel room in Jinghe.

the snow at sites 47–49 was collected in snow drifts and the corresponding sites are shown in figure 1. If there was obvious layering in the cross-sections of the snow drifts, we sampled those obvious layers individually. The snowfall events in Qinghai and Xinjiang mostly occur during winter and early spring. If snow was falling at the time of sampling, we collected the freshly fallen snow separately; this was

accomplished at 13 sites, one in Qinghai at Site 52 and the others in Xinjiang shown in figure 4.

284 snow samples were collected in Qinghai and Xinjiang, which were processed at four temporary laboratories en route, one in Qinghai and three in Xinjiang (figure 2(c)). The samples collected in Lanzhou were processed at Lanzhou University. The processing method is the filtering technique which was first used by Clarke and Noone (1985) and recently employed by Doherty *et al* (2010) and Huang *et al* (2011). Each snow sample was spooned into a large beaker which was then put into a microwave oven. The snow was melted rapidly to minimize adherence of BC particles to the wall of the beaker. A measured volume of meltwater was sucked into a syringe and immediately filtered through a $0.4 \mu\text{m}$ nuclepore filter, using a hand pump to maintain a partial vacuum. Small samples of meltwater, both before and after filtration, were saved in 60 ml bottles and refrozen for further chemical analysis to enable source attribution (Hegg *et al* 2009, 2010). After drying, the filters were compared visually against a set of standard filters with known BC loading provided by Clarke, to obtain an estimate of equivalent BC loading of the samples. Together with measurement of the exposed area of each filter, and the volume of meltwater passed through the filter, BC mass fractions in snow can be derived. These values are ‘equivalent BC’, as defined by Grenfell *et al* (2011), meaning the amount of BC that would be needed to explain the total wavelength-integrated absorption by particulate impurities, if BC were the only absorber on the filter. In our follow-on study, the filters will be measured by an integrating-sandwich spectrophotometer (Grenfell *et al* 2011, Wang *et al* 2012), and our visual estimates will be compared with these measurements. Previous studies showed that the visual estimates of equivalent BC concentrations agree with those derived from the integrating-sandwich spectrophotometer within about a factor of 2 (e.g., Grenfell *et al* 2011, Wang *et al* 2012). The equivalent BC concentrations in snow reported here have been multiplied by 1.15 to account for the under-catch of the $0.4 \mu\text{m}$ filter, based on prior measurements indicating that approximately 15% of BC passes through the $0.4 \mu\text{m}$ filter (Clarke and Noone 1985, Doherty *et al* 2010).

The equivalent BC loading cannot be estimated accurately by visual inspection if the filter is heavily loaded with soil dust, because of the color difference between the sample filter and the calibration filters. Therefore, the results of the Qinghai sites, where the filters are yellow due to heavy loading of soil dust, are not reported here. On the other hand, the filters from all but two of the Xinjiang sites are gray in color, indicating that the impurities are dominated by BC particles. This work reports the visual estimate of filters for the equivalent BC content of snow in northern Xinjiang.

3. Analysis of preliminary results

3.1. Surface and depth-integrated BC concentration

We collected samples at 32 sites in Xinjiang, with freshly fallen snow at the surface layer at 12 sites. The surface and depth-integrated BC concentrations are shown in figure 4 and

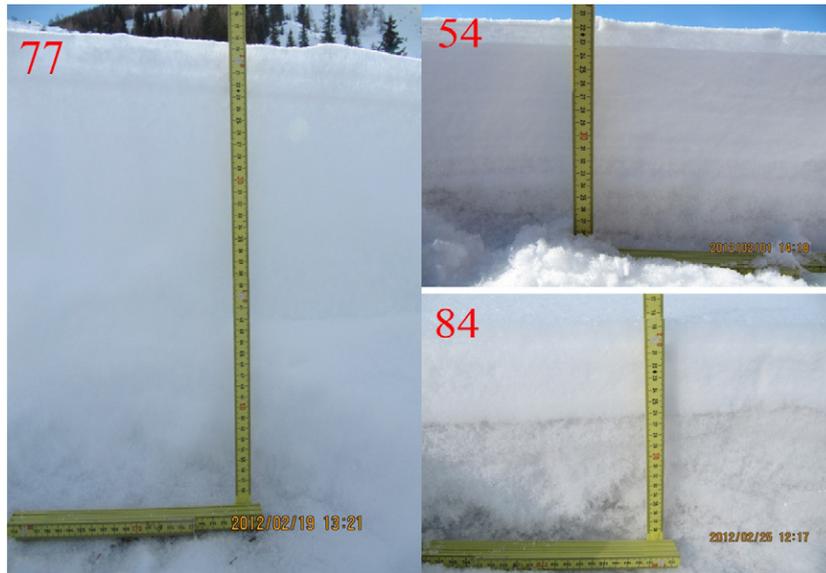


Figure 3. Examples of snow pits at sites 54, 77, and 84.

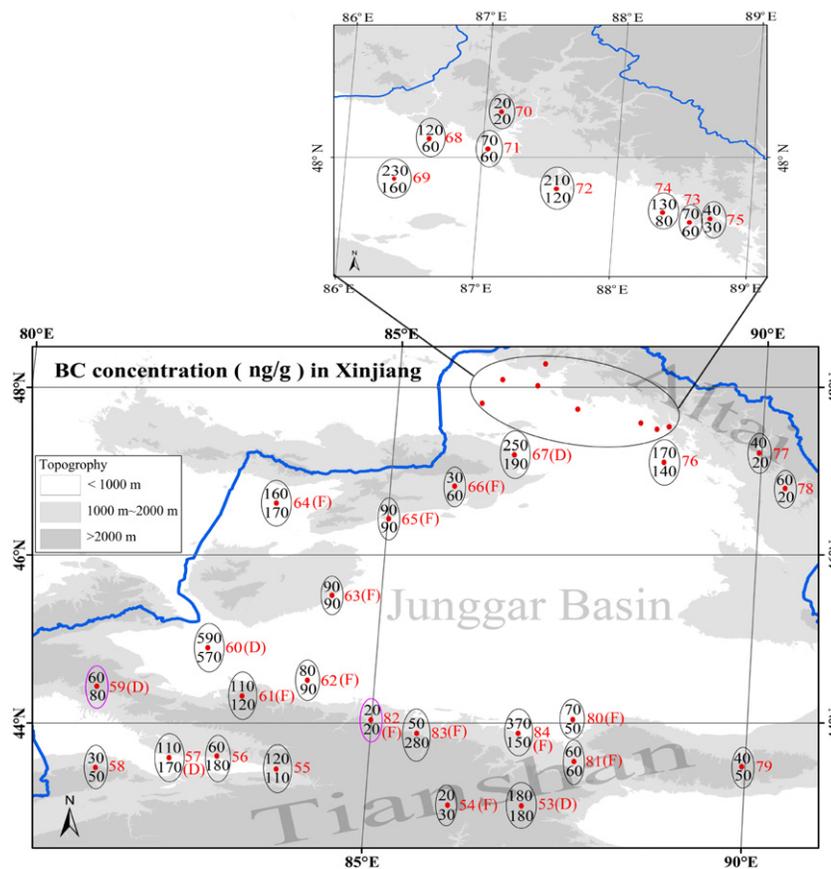


Figure 4. BC content of snow at the 32 sampling sites in Xinjiang. The numbers above red points are visual estimates of the BC-equivalent concentrations in the top layer at each site; the numbers below are depth-integrated values and the sites number is in red beside. The ‘D’ indicates that the snow samples were collected in snow drifts and the ‘F’ indicates that there was fresh snow at the surface layer at these sites. At the two sites with pink circles the filters were yellow, indicating that the light absorption was probably dominated by dust. The topography data is from NASA Shuttle Radar Topographic Mission (SRTM) V4 digital elevation models (DEM) data (<http://srtm.csi.cgiar.org>).

also in table 1, and the vertical profiles of BC concentrations are shown in figure 5. The surface BC concentrations are the values in the top layer, while the depth-integrated BC

concentrations are average values of all the snow-sampled layers, weighted by the snow mass in each layer. The density of snow and temperature for each layer at each site are shown

Table 1. The sampling site information including site number, sampling date, location (latitude and longitude), altitude, snow depth, total sampling depth, the number of sampling layers, and top layer depth. The surface and depth-integrated BC concentrations shown in figure 4 are also listed along with the ratio range of BC concentrations from the left vertical profile to the right.

Site	Sampling date	Lat. N (deg)	Lon. E (deg)	Altitude (m)	Snow depth (cm)	Total sampling depth (cm)	Sampling layers	Top layer depth (cm)	Surface BC concentration (ng g ⁻¹)	Depth-integrated BC concentration (ng g ⁻¹)	Ratio range of left to right
53	Jan. 31	43.072	86.805	3526	33	26	3	8	179	147	0.74–1.13
54	Feb. 1	43.080	85.821	3131	24	17	3	2	15	30	0.68–1.84
55	Feb. 2	43.506	83.541	988	24	8	2	4	118	107	0.68–1.32
56	Feb. 2	43.661	82.750	1327	22	12	3	4	58	177	0.73–1.38
57	Feb. 2	43.643	82.114	831	18	13	3	4	111	174	0.80–1.33
58	Feb. 3	43.525	81.133	1505	37	30	6	4	28	54	0.41–1.07
59	Feb. 4	44.495	81.152	2127	86	36	6	5	56	80	0.72–1.19
60	Feb. 4	44.956	82.629	237	8	5	2	2	587	567	1.24–1.37
61	Feb. 5	44.380	83.086	1250	24	19	4	3	112	122	0.87–1.21
62	Feb. 8	44.565	83.957	240	9	4	2	1	77	85	0.84–1.06
63	Feb. 9	45.579	84.285	1150	16	1	1	1	91	91	1.06
64	Feb. 9	46.679	83.544	674	25	15	4	2	161	173	0.71–1.29
65	Feb. 10	46.493	85.040	1033	5	2	1	2	89	89	0.99
66	Feb. 10	46.880	85.916	1461	15	10	2	5	31	56	0.86–1.02
67	Feb. 11	47.256	86.714	750	32	16	3	4	253	191	0.71–1.50
68	Feb. 11	48.147	86.557	693	30	20	4	5	121	62	0.77–1.27
69	Feb. 11	47.863	86.285	438	4	4	2	1	227	159	0.96–1.08
70	Feb. 12	48.333	87.128	1606	66	40	8	3	17	17	0.92–1.50
71	Feb. 12	48.072	87.026	934	40	30	5	5	73	55	0.86–1.52
72	Feb. 14	47.793	87.557	560	19	12	3	3	208	124	1.30–1.96
73	Feb. 14	47.553	88.612	1103	38	32	6	4	71	60	0.54–1.17
74	Feb. 14	47.627	88.396	818	35	25	5	4	125	77	0.59–1.56
75	Feb. 17	47.583	88.776	919	48	45	8	5	35	32	0.73–1.89
76	Feb. 18	47.167	88.704	717	26	16	4	2	171	135	1.01–1.22
77	Feb. 19	47.274	89.973	1362	45	45	9	4	36	15	0.80–1.27
78	Feb. 20	46.854	90.319	1438	35	27	6	2	57	20	0.80–1.05
79	Feb. 21	43.534	89.739	2185	47	40	7	6	37	51	0.87–1.15
80	Feb. 23	44.096	87.490	474	18	7	2	3	70	50	1.23–1.32
81	Feb. 23	43.596	87.506	1264	7	6	2	3	62	64	1.01–1.24
82	Feb. 24	44.093	84.802	1864	15	9	2	5	22	20	1.10–1.28
83	Feb. 24	43.934	85.413	1239	12	12	3	3	54	281	1.03–1.10
84	Feb. 25	43.932	86.763	1055	25	6	2	2	373	154	0.86–0.87

in table 2. Snow at two of the sites (59 and 82) contained significant amounts of dust as indicated by the yellow-brown color of the filters, but at other sites the filters were all gray, with no visually apparent dust. The sites in Xinjiang are mainly along the Tianshan Mountains in the south (Sites 53–62, 79–84), Altai Mountains in the north (Sites 68–78) and hilly areas between these two mountain ranges (Sites 63–67).

Sites 53–54 along the Tianshan Mountains are at high altitudes. The higher BC-equivalent at Site 53 may be related to the large exposure of gray limestone dust and the sparse vegetation. At Site 53 there was little snow, so the snow was sampled in a snow drift and the gray limestone can be blown into snow which significantly affected the visual estimated result. At Site 54, the snow depth was deeper. There the BC concentrations were low, i.e., 20–30 ng g⁻¹; this value may represent the background BC content of snow in the region. Sites 55–62 are located on basins with farmland and pastures; their BC values are mostly between 30 and 200 ng g⁻¹. One exception is Site 60 where the BC-equivalent value is 590 ng g⁻¹. This is probably because the snow was very patchy above local black soil and the sampling was only

possible in a snow drift. The surface snow at Sites 79–84 was freshly fallen; there are industrial cities nearby which could contribute BC. The estimated concentrations of BC near the large city Urumqi (Site 80 to the north and Site 81 to the south, each ~30 km distant) are lower than 100 ng g⁻¹ (i.e., 70 ng g⁻¹ at Site 80 and 60 ng g⁻¹ at Site 81 in the surface layer), so they seem to be only slightly influenced by the city. The high average BC concentrations found in the lowest layer of Site 83, 610 ng g⁻¹, may have resulted from sublimation of snow (Liston and Sturm 2004) and dry deposition of BC between snowfall events. However, the high surface BC concentration observed at Site 84 in new snow (i.e., 370 ng g⁻¹) is undoubtedly the result of wet deposition of local pollution by snowfall.

As we moved north from the Tianshan to the hilly areas (Sites 63–67), most places were grassland (Wu *et al* 2010). In this particular year, this area had experienced little snowfall, so the snow was thin and patchy there. The high surface BC concentration at Sites 64, which was collected in freshly fallen snow, should come from the wet deposition of local pollution. On the other hand, the high surface BC concentration from the samples collected in snow drift at Site 67 may be a

Table 2. The snow density (g cm^{-3}) and temperature ($^{\circ}\text{C}$) profiles at each sampling site, which were measured every 5 cm downward.

Site	Layer depth from the surface downward (cm)																
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85
	Snow density (g cm^{-3})																
	Temperature ($^{\circ}\text{C}$)																
53	0.43	0.41	0.39	0.27	0.27	0.285											
	-18.0	-20.0	-20.5	-21.0	-20.0												
54	0.14	0.19	0.19	0.16													
	-18.0	-21.5	-20.5	-19.0													
55	0.1	0.19															
	-8.0	-10.0															
56	0.12	0.17	0.18														
	-5.0	-7.0	-7.0														
57	0.21	0.23	0.2	0.24													
	-5.0	-5.0	-5.0	-5.0													
58	0.11	0.21	0.15	0.2	0.23	0.23	0.21										
	-8.0	-10.0	-10.0	-9.0	-7.0	-6.0	-6.0										
59	0.17	0.14	0.32	0.12	0.28	0.23	0.21	0.22	0.23	0.23	0.23	0.3	0.31	0.29	0.29	0.28	0.31
	-10.0	-10.0	-11.0	-10.0	-10.0	-9.0	-8.0	-7.0	-7.0	-6.0	-6.0	-6.0	-6.0	-6.0	-5.0	-5.0	-4.0
60	0.11																
	-6.5																
61	0.09	0.15	0.18	0.21													
	-9.0	-9.0	-9.0	-9.0													
62	0.14																
	-7.0																
63	n/a																
	n/a																
64	0.14	0.14	0.16	0.13	0.26												
	-9.0	-9.0	-9.0	-10.0	-10.0												
65	n/a																
	n/a																
66	0.11	0.18															
	-10.0	-10.0															
67	0.42	0.38	0.28	0.24	0.19												
	-20.0	-24.0	-24.0	-23.0	-22.0												
68	0.1	0.14	0.16	0.18	0.21	0.24											
	-8.0	-12.0	-12.0	-12.0	-11.0	-9.0											
69	n/a																
	n/a																
70	0.15	0.15	0.16	0.18	0.21	0.24	0.26	0.29	0.31	0.32	0.34	0.33	0.29				
	-14.0	-14.0	-13.0	-12.0	-11.5	-11.0	-10.0	-9.0	-9.0	-8.0	-7.5	-6.0	-5.0				
71	0.16	0.15	0.2	0.22	0.24	0.27	0.28										
	-14.0	-13.0	-13.0	-12.5	-12.0	-11.5	-10.5										
72	0.12	0.14	0.17														
	-20.0	-19.5	-18.5														
73	0.13	0.13	0.17	0.2	0.23	0.26	0.26	0.29									
	-10.0	-11.0	-12.0	-13.5	-13.0	-12.0	-11.0	-10.0									
74	0.15	0.12	0.16	0.2	0.24	0.23											
	-16.0	-13.0	-11.0	-11.5	-11.5	-11.5											
75	0.13	0.14	0.16	0.17	0.19	0.22	0.24	0.28	0.28	0.3							
	-7.5	-10.0	-10.5	-11.5	-10.5	-10.5	-10.0	-9.0	-8.0	-8.0							
76	0.13	0.09	0.19	0.2													
	-6.0	-6.0	-6.5	-7.5													
77	0.15	0.15	0.17	0.2	0.25	0.26	0.27	0.29	0.31								
	-10.0	-15.0	-15.0	-14.5	-13.5	-12.5	-12.5	-11.5	-11.0								
78	0.16	0.16	0.18	0.21	0.21	0.24	0.24										
	-8.5	-9.5	-10.0	-10.0	-10.0	-9.0	-8.5										
79	0.14	0.16	0.16	0.16	0.17	0.2	0.2	0.22	0.27								
	-10.5	-12.0	-13.0	-11.5	-9.0	-6.0	-6.0	-6.0	-4.0								

result of sublimation as well as dry deposition. The low BC concentrations at other sites occurred in the snow layers that existed for less than half a month based on meteorological data of nearby weather stations from China Meteorological Data Sharing Service System.

The far north of Xinjiang is occupied by the Altai Mountains. The natural vegetation there is forest and grassland; part of this region is now farmed (Wu *et al* 2010). The cleanest snow was found at our northernmost site, Site 70, near the borders of Russia, Kazakhstan and Mongolia. Its

Table 2. (Continued.)

Site	Layer depth from the surface downward (cm)																
	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50–55	55–60	60–65	65–70	70–75	75–80	80–85
	Snow density (g cm ⁻³) Temperature (°C)																
80	0.13																
	-10.0																
81	0.17																
	-7.5																
82	0.09	0.13															
	-11.5	-11.5															
83	0.13	0.13															
	-7.0	-5.0															
84	0.11																
	-6.5																

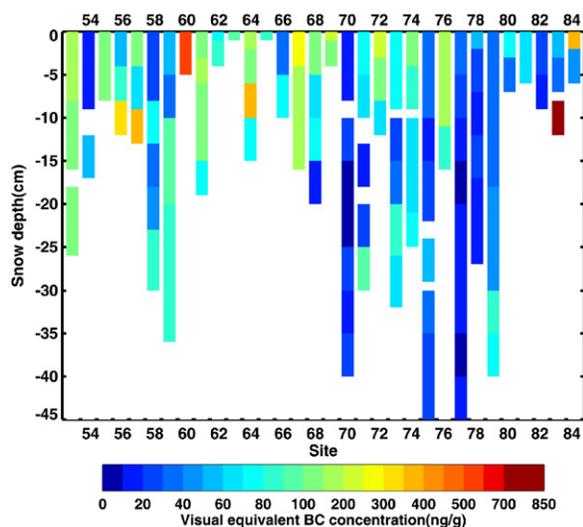


Figure 5. Vertical profiles of visually-determined BC-equivalent concentrations at Sites 53–84 in Xinjiang. The depths and layers of snow are different from one site to another. At some sites the concentrations are discontinuous (as indicated by gaps in the color bars) because samples were not collected at these layers.

BC values were 20 ng g⁻¹, which are comparable to those of Canadian Arctic, Alaskan Arctic and Svalbard (Doherty *et al* 2010). The higher BC concentrations occurred near cities or large villages such as at Sites 69 and 72, with BC values of 230 ng g⁻¹ and 210 ng g⁻¹, respectively, at the top layers.

In the 2010 campaign in the northeast China, the estimated surface concentrations of BC in seasonal snow ranged from 40 to 1600 ng g⁻¹, with a median value of 500 ng g⁻¹ (Huang *et al* 2011). The BC contents of snow over northern Xinjiang, which have a median surface value of 70 ng g⁻¹ (figure 4), are thus much lower than those in northeast China.

3.2. BC distribution with altitude

A previous investigation by Ming *et al* (2009a) on the Tibetan Plateau and Tianshan Mountains found that BC concentrations showed a negative correlation with the

altitudes of the sites, and suggested that altitude was the dominant factor influencing BC concentrations. We find that the BC content of seasonal snow in northern Xinjiang also shows similar behavior, decreasing with altitude (figure 6). In contrast to the studies of Ming *et al* (2009a, 2009b), whose sampling sites were all above 3700 m, our sampling sites in Xinjiang were at altitudes 240–3500 m, which were more likely to be influenced by local pollution transported within the atmospheric boundary layer. Note that the BC-equivalent concentrations at Site 53 were relatively high for both surface and layer-averaged values. This may be due not to BC, but rather to the natural limestone soil there, which was visually gray. Forthcoming chemical analysis of the meltwater may be able to distinguish these possibilities.

BC content has been reported for snow and ice core in numerous glaciers on the Tibetan Plateau and in the Tianshan Mountains, using the thermo-optical (controlled-combustion) method (Ming *et al* 2008, 2009a, 2009b, Xu *et al* 2006, 2009, 2012). The derived BC contents range from 4 to 141 ng g⁻¹ (Ming *et al* 2012). The values from Tianshan glaciers ranged from 87 to 141 ng g⁻¹ with an average of 112 ng g⁻¹ (Ming *et al* 2009a, 2009b, 2012). Note that these data refers to BC contents in summer snow where BC are largely enriched. A recent measurement by Xu *et al* (2012) showed that the winter BC contents in surface snow at altitude of 4100 m on Tianshan glacier are only 27–31 ng g⁻¹, which is consistent with our measurements by taking into account the altitude dependence of BC concentrations.

4. Discussion and conclusions

The snow depth in Xinjiang has increased over the past several decades, according to Qin *et al* (2006) and Peng *et al* (2010). Northern Xinjiang is an arid/semiarid region, so the main vegetation there is grass (the grasslands have largely turned into farms in the basin valley regions) (Wu *et al* 2010), and the snow is exposed to sunlight more than would be the case in forested regions. Therefore, the planetary albedo of northern Xinjiang in winter is dominated by snow, so it can be affected by absorptive impurities.

The absorptive impurities in snow in Xinjiang are dominated by BC particles. The BC content of snow in

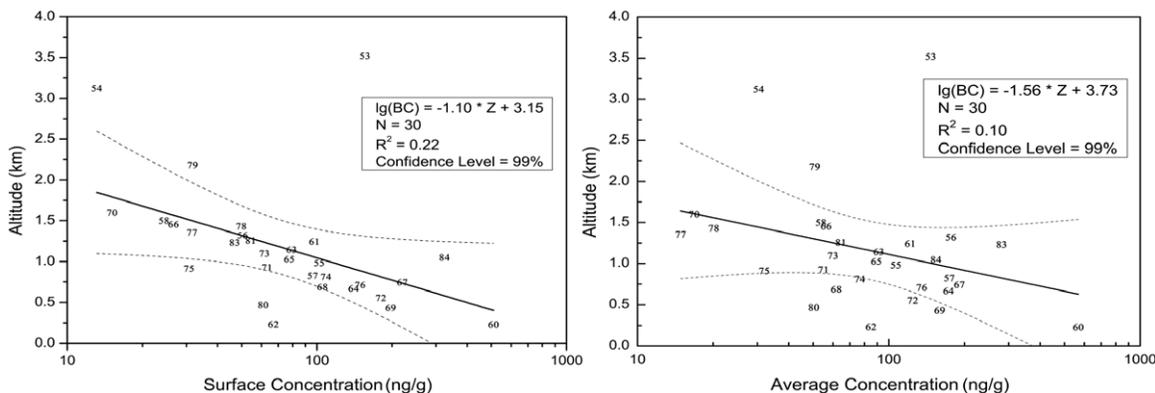


Figure 6. BC content (a) in the top layer of snow and (b) averaged over all layers, for each site as a function of altitude, for the 30 sites sampled in Xinjiang, with the site numbers shown. The two sites probably dominated by dust (Sites 59 and 82) are excluded. The black solid line is a least squares fit to the data points; the dashed curves represent the confidence level of 99%.

Xinjiang is much lower than that in northeast China. Despite the farmland and pastures spreading over the basin regions, the sources of BC particles are still mainly residential fossil fuel burning in winter (Cao *et al* 2006). But the smaller population in northern Xinjiang and relatively smaller cities lead to much less BC emission than in northeast China. At the cleanest site in the far north of Xinjiang, the estimated concentration of BC is about 20 ng g⁻¹, similar to that found at the coast of Arctic Ocean (Doherty *et al* 2010). The BC content of snow is found to decrease with altitude. Taking into account this altitude dependence, our measured BC contents in snow are consistent with a recent measurement of BC in winter snow on Tianshan glacier (Xu *et al* 2012).

The field campaigns conducted in 2010 and 2012 together provide a comprehensive survey of absorbing impurities in seasonal snow over northern China. The dataset will be useful to test models and to evaluate the effect of BC on snow albedo and thus the radiative forcing caused by BC in seasonal snow.

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