



# Editorial: Impure Snow and Ice in Remote Areas: Arctic, Antarctica and High Mountains

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## Editorial on the Research Topic

### Impure Snow and Ice in Remote Areas: Arctic, Antarctica and High Mountains

Emissions of pollutants are transported to some of Earth's most remote areas. Increasingly intensified human activities into the industrial era, including industries, agriculture, transportation, and tourism continue to enhance pollutant depositions onto the surface. Snow and ice at these remote places are tainted with pollutants and are the carriers of such impurities. This topic issue, "Impure Snow and Ice in Remote Areas: Arctic, Antarctica and High Mountains," hosted by Frontiers in Earth Science, presents ten important papers to demonstrate the kinds of pollutants deposited as well as how, and where these pollutants get deposited and their impacts on the cryosphere.

The Arctic, home to snow and ice, is one of the most sensitive areas to climate change and a natural reflection of the environmental impacts from human activities. Matoba et al. found insoluble particles on the surface and in the deeper layers of the Qaanaaq Glacier, Greenland. The insoluble-particle concentration in the glacier ice at intermediate sites was approximately ten times larger than at low sites on this glacier. The resurfacing of the insoluble particles in ice due to ablation, and their coexistence in surface snow, enhanced the surface absorption of solar radiation and favoured the surface melting at the higher area of the glacier, an important climate feedback of such pollutants. Anthropogenic and natural metal and metalloid elements were found deposited in the snow of Svalbard (Kozioł et al. and Spolaor et al.) via long-range transports. The on-site snow sampling in the Finish Arctic and the lab modelling work revealed a median black carbon (BC) concentration of 21–57  $\mu\text{g kg}^{-1}$  depending on the seasons deposited in the snow during 2009–2013.

In the mid-latitudes, the High Asian Mountains host a vast area of mountainous glaciers as the vital water resources to the livelihood of billions of people. These mountainous glaciers are rich in dust, BC, and debris in the surface snow and beneath ice. These impurities contribute to the surface absorption of solar radiation and hence to the melting of glaciers. On Urumqi Glacier No. 1, there were more than 300  $\text{g m}^{-2}$  of insoluble particles or dust covering the glacier on average, of which approximately 10% were organic matter. These particles largely darkened the glacier surface by reducing its albedo from 0.62 to 0.32 in summer (Yue et al.). The average concentration of BC mixed in the insoluble particles in snow reached as high as  $\sim 600 \mu\text{g kg}^{-1}$ , ten times more than that in the Arctic, and may reduce the surface albedo by 13–23% (Zhang et al.). A more eastern glacier, Yushugou Glacier No. 6, also preserved heavily dusty snow as Urumqi Glacier No. 1, and  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  dominated the chemistry in the soluble components of the snow samples (Liu et al.). In the Hunza Valley of Karakoram, the supra-glacial debris showed an upward expansion during 1990–2019, suggesting the glaciers here would be more extensively covered by the heat-absorbed debris (Xie et al.).

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There is evidence that the impurities also influence the snow albedo in Antarctica. However, the particle emissions from the biomass burning in the Southern Hemisphere swept across the peripheral snow-ice covered area only occasionally. The reconstruction of biomass burning history relies largely on deep ice cores, and the Chinese Taishan Station in East Antarctica showed stable glaciology and ideal meteorology for a super-deep ice core drilling (Tang et al.). The ice-core explorations here will provide an essential background to evaluate future climate and environmental changes in Antarctica.

## AUTHOR CONTRIBUTIONS

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