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Surveys for black carbon and other light-absorbing impurities in snow over large areas of North America, China, the Arctic and Antarctic

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Absorption of radiation by ice is extremely weak at visible and near-ultraviolet wavelengths, so small amounts of light-absorbing impurities (LAI) in snow can dominate the absorption of sunlight at these wavelengths, reducing the albedo relative to that of pure snow and leading to earlier snowmelt. For this study about 1600 snow samples were collected in Alaska, Canada, Greenland, Svalbard, Norway, Russia, and the Arctic Ocean, on tundra, glaciers, ice caps, sea ice, frozen lakes, and in boreal forests. Snow was collected mostly in spring, when the entire winter snowpack was accessible for sampling. Snow was also collected at 67 sites in western North America. Expeditions from Lanzhou University obtained black carbon (BC) amounts at 84 sites in northeast and northwest China. BC was measured at 3 locations on the Antarctic Plateau, and at 5 sites on East Antarctic sea ice.

The snow is melted and filtered; the filters are analyzed in a spectrophotometer to infer the mixing ratio of black carbon (BC) and the fraction of absorption due to non-BC light-absorbing constituents. The non-BC impurities, principally brown (organic) carbon, are typically responsible for $\sim$40% of the visible and ultraviolet absorption. In a global survey, we find BC mixing ratios in snow ranging over 4 orders of magnitude from 0.2 ng/g in Antarctica to 1000 ng/g in northeast China; the Arctic and North American values are intermediate between these extremes. Chemical analyses, input to a receptor model, indicate that the major source of BC in most of the Arctic is biomass burning, but industrial sources dominate in Svalbard and the central Arctic Ocean. In northeast China, BC is the dominant LAI, but in Inner Mongolia soil dominates.

When the snow surface layer melts, much of the BC is left at the top of the snowpack rather than carried away in meltwater, thus causing a positive feedback on snowmelt. This process was quantified through field studies in Greenland, Alaska, and Norway, where we found that only 10-30% of the BC is removed with meltwater. In the percolation zone of South Greenland at the end of July, the subsurface snow had 2 ng/g but the top 5 cm had 10-20 ng/g.

The BC content of the Arctic atmosphere has declined markedly since 1989, according to the continuous measurements of near-surface air at Alert (Canada), Barrow (Alaska), and Ny-Alesund (Svalbard). Correspondingly, our recent BC mixing ratios in Arctic snow are lower than those reported by Clarke and Noone for 1983-4. It is therefore doubtful that BC in Arctic snow has contributed to the rapid decline of Arctic sea ice in recent years.

In much of the Arctic, the snow cover, even at its maximum depth in April before melting begins, is thin and patchy; in these regions the albedo is determined more by snow thickness than by impurities.