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# Expeditions to the Russian Arctic to Survey Black Carbon in Snow

Snow is the most reflective natural surface on Earth, with an albedo (the ratio of reflected to incident light) typically between 70% and 85%. Because the albedo of snow is so high, it can be reduced by small amounts of dark impurities. A few tens of parts per billion (ppb) amounts of black carbon (BC) can reduce the albedo by a few percent depending on the snow grain size [Warren and Wiscombe, 1985; Clarke and Noone, 1985].

An albedo reduction of a few percent is not detectable by eye and is below the accuracy of satellite observations. Nonetheless, such a reduction is significant for climate. For a typical incident solar flux of 240 watts per square meter at the snow surface in the Arctic during spring and summer, an albedo change of 1% modifies the absorbed energy flux by an amount comparable to current anthropogenic greenhouse gas forcing. As a result, higher levels of BC could cause the snow to melt sooner in the spring, uncovering darker underlying surfaces (tundra and sea ice) and resulting in a positive feedback on climate [Hansen and Nazarenko, 2004].

BC particles are produced by incomplete combustion from diesel engines, coal burning, forest fires, agricultural fires, and residential wood burning [Bond and Bergstrom, 2006]. When injected into the atmosphere, these particles may travel thousands of kilometers before they are removed by rain or

snow precipitation. In 1983–1984, a wide-area survey of BC concentrations in Arctic snow was carried out by Clarke and Noone [1985] across the western Arctic; however, access was not available to the eastern Arctic at that time.

During the 2007–2009 International Polar Year (IPY) an opportunity arose for collaboration between U.S. and Russian scientists to organize a survey of BC in the snow across the Russian Arctic during springtime expeditions in 2007 and 2008. The expeditions were carried out as a central part of a comprehensive IPY survey over the entire Arctic.

## Survey Results

The surveys were conducted in April and early May so that the entire winter snow accumulation could be studied and snowpack conditions could be documented just prior to the onset of the spring melt (see Figure 1). The observation areas were reached by commercial airlines to locations near the Arctic coast spanning longitudes 50°E–170°E. Local transportation provided access to individual sites 30–100 kilometers away from these centers.

At each site, samples were gathered from individual snow pits at several depths to examine snow deposited at different times throughout the winter and spring. About 500 snow samples were analyzed. Processing

of the samples for BC was carried out using the filtering techniques pioneered by Clarke and Noone [1985]. Each sample was melted rapidly in a microwave oven and immediately drawn through a 0.4-micrometer Nuclepore filter to extract the BC and other particulates. Meltwater samples were also saved for chemical analysis to assist in evaluating the sources of the BC. Because the filtering apparatus can be set up on a small table in a hotel room, snow samples could be processed at each location, avoiding the need to transport large quantities of snow back to St. Petersburg. Each filter was compared visually against a set of standard samples provided by A. D. Clarke (University of Hawaii, Honolulu) to allow an initial estimate of the equivalent BC loading of the samples. More precise analysis using an integrating-sandwich spectrophotometer was carried out after returning the filters to Seattle, Wash.

The median background BC levels were 15–25 ppb on or near the coasts of the Barents and Kara seas, and near a polynya (an area of open water surrounded by sea ice) found within the Laptev Sea. Values were 15–20 ppb on the Chukchi Peninsula but only 5 ppb in a fresh snowfall event at the end of April. Farther south or west, background BC levels were 20–80 ppb in the Sakha Republic and 40 ppb on the Taymyr Peninsula. At some locations, the concentrations were higher at the surface, perhaps because of sublimation in regions where heavy autumn snowfall is followed by a dry winter.

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Fig 1. (Left) Sampling snow on the sea ice north of Tiksi, Russia, and (right) surface transportation west of Tiksi.

## BC Values Across the Arctic

The surveys from Russia have produced a more complete picture of BC distribution. The BC values found in Russia were higher than elsewhere in the Arctic. The cleanest snow is on the Greenland Ice Sheet, with about 2–3 ppb BC, similar to that reported by *Clarke and Noone* [1985], and similar to that reported for the 1980s from ice core measurements by *McConnell et al.* [2007]. Snow in Canada, Alaska, and the Arctic Ocean has 5–15 ppb, which is less than what *Clarke and Noone* [1985] found in these regions. Part, but not all, of this difference may be explained by a difference in the photometer design. A decline in the BC content of Arctic snow over the past 25 years is consistent with the decline in atmospheric BC measured continuously since 1989 at the atmospheric monitoring station at Alert on Ellesmere Island [*Quinn et al.*, 2007].

Factor analysis using 22 chemical species in the meltwater indicates that in Russia, Greenland, and North America the BC originated primarily from biomass burning [*Hegg et al.*, 2009]. In the Arctic Ocean, industrial pollution is apparently the dominant source.

It is important to recognize that BC is only one of the determinants of snow albedo. For example, snow on the tundra is often thin and patchy, so the area-averaged albedo may often be determined more by the frequency distribution of snow depth than by absorptive impurities. The measured BC amounts are being used to test models of atmospheric transport into the Arctic. Information about snow depth and snow grain sizes, together with the measured BC amounts, will be used to estimate the climatic effects of BC in snow.

Photographs from the expeditions are available at <http://www.atmos.washington.edu/sootinsnow>.

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