

IPY Expeditions to the Russian Arctic to Survey Black Carbon in Snow.

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Snow is the most reflective natural surface on Earth, with an albedo typically between 70 and 85%. Because the albedo 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 this magnitude is not detectable by eye and is below the accuracy of satellite observations, but it is significant for climate. For a typical incident solar flux of 240 W/m^2 at the snow surface in the Arctic during spring and summer, an albedo change of 1% modifies the absorbed flux by 2.4 W/m^2 , 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 the darker underlying surface and resulting in an amplifying 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 1983-84, 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 International Polar Year (IPY), an opportunity arose for collaboration between the U.S. and Russian authors of this report. We organized 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 survey over the entire Arctic with funding support from the U.S. National Science Foundation. Russian sponsorship of the expeditions was provided by the Arctic and Antarctic Research Institute in St. Petersburg. The logistics were supported by V. F. Boyarsky and the staff of the Arctic and Antarctic Museum in St. Petersburg. We are also indebted to Prof. A. Helbig of the University of Trier, and members of the Russian-German "Transdrift XIII" expedition who expanded our survey by collecting samples near the Laptev Sea Polynya. We also thank S. Kogan, V. Ippolitov, S. Hudson, and M. Lamakin for invaluable assistance in the field.

The survey was 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. The observation areas were reached by traveling via commercial airlines to

locations near the Arctic coast spanning longitudes 50 to 170°E. Local transportation provided access to individual sites 30-100 km away from these centers. At each site, samples were gathered from individual snow pits at several depths to sample 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- μ m nuclepore filter to extract the BC and other particulates. We also saved samples of meltwater for chemical analysis to assist in evaluating the sources of the BC. Since our filtering apparatus can be set up on a small table in a hotel room, we were able to process snow samples 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 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.

The median background BC levels were 15-25 ppb on or near the coasts of the Barents, Kara, and Laptev Seas (Nar'yan-Mar, Dikson, and Laptev Polynya, respectively); 15-20 ppb in Chukotka (Bilibino and Pevek, but 5 ppb in a fresh snowfall event at the end of April); 20-80 ppb in Yakutia (Yakutsk, Tiksi, Cherskiy); and 40 ppb on the Taymyr Peninsula (Khatanga). 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.

The BC values we found in Russia are higher than what we have observed 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 last 25 years is consistent with the decline in atmospheric BC measured continuously at Alert since 1989 [*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.

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. Photographs from the expeditions are available at www.atmos.washington.edu/sootinsnow.

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Fig. 1 – A. Sampling snow on the sea ice north of Tiksi; B. Surface transportation west of Tiksi.