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Soot from Arctic Haze: Radiative Effects on the Arctic Snowpack

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The burning of fossil fuels adds not only CO_2 to the atmosphere but also particulates which are the products of incomplete combustion. The small soot particles, which seem to be largely responsible for the absorption of solar radiation in the Arctic haze, are eventually scavenged from the atmosphere and are incorporated in the Arctic snowpack. Here we examine the possible effects of these particulates on the snow albedo and the surface radiation budget, using a model for radiative transfer in snow.

The model (Wiscombe and Warren, 1980) was developed to explain the reasons for the large observed variability of snow albedo. It showed good agreement with available spectral measurements. The principal factor controlling snow albedo is the grain size (Figure 1a of Marshall and Warren, these proceedings), which normally increases with snow age due to metamorphism.

Small amounts of absorptive impurities in snow can reduce the albedo dramatically in spectral regions where the albedo is high (visible wavelengths). Warren and Wiscombe (1980) computed the radiative effects of graphitic carbon ('soot') distributed uniformly through a snowpack (shown in Figure 1d of Marshall and Warren, these proceedings). Subsequent experiments which measured both albedo and soot content (Grenfell et al, 1981) showed agreement with results of the radiation model to within the experimental uncertainty, which was about a factor of 2 in soot content (Sec. H1 of Warren, 1982).

Clarke and Noone (1985) collected snow samples from several locations in the Arctic (but none in the Siberian sector), shown here in Figure 1. They applied an optical method to the filter through which meltwater from these samples had been passed, to determine the concentration of soot in the snow. The mass fraction of soot ranged from about 5×10^{-9} to 5×10^{-8} (shaded area in Figure 2). Warren and Wiscombe (1985) then estimated the effect on snow albedo due to these soot concentrations. For the energy

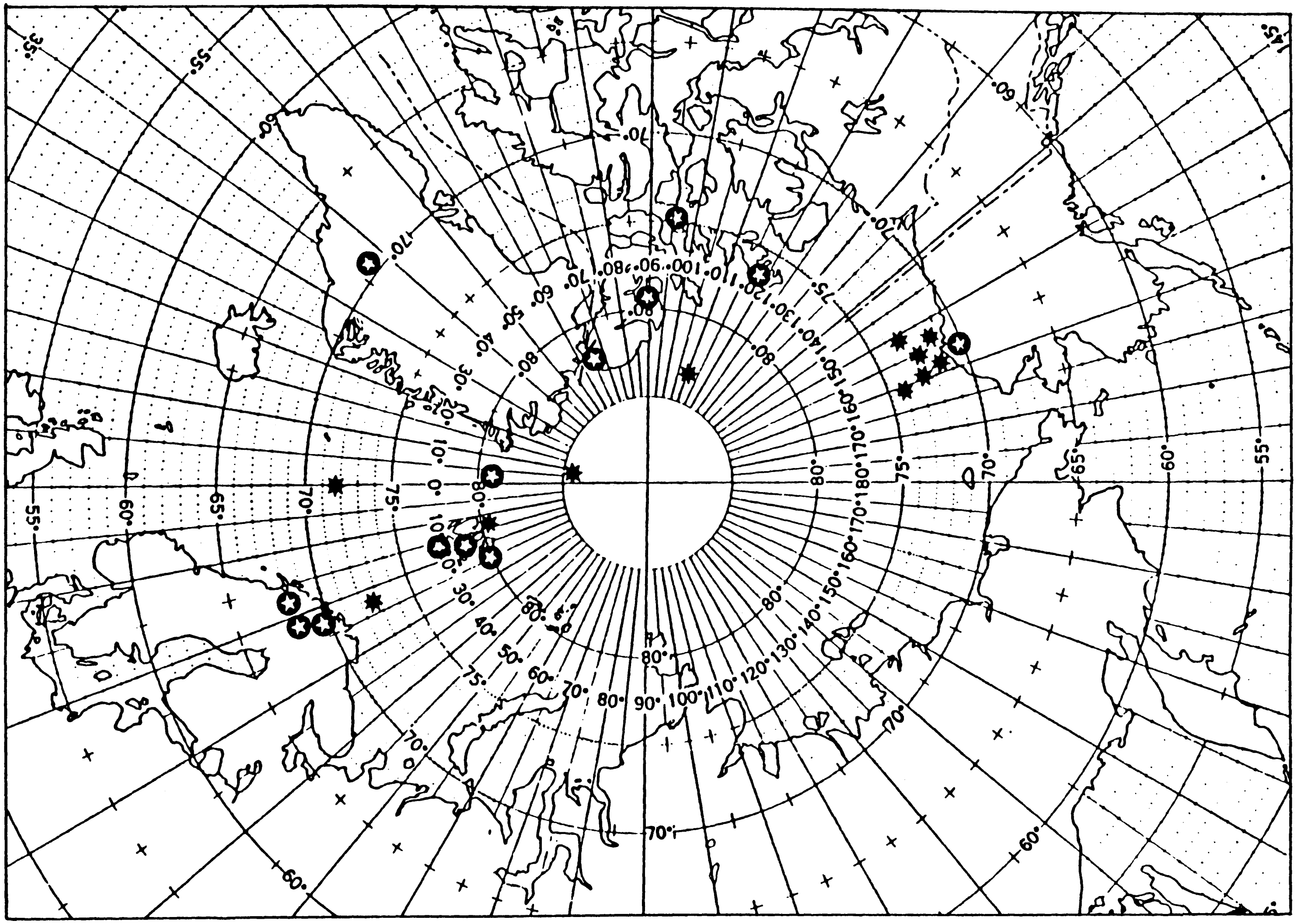

Figure 1. Map of Arctic sampling locations for the University of Washington atmospheric (✸) aircraft samples and snowpack (✪) samples for 1983 - 1984. (Figure 1 of Clarke and Noone, 1985).

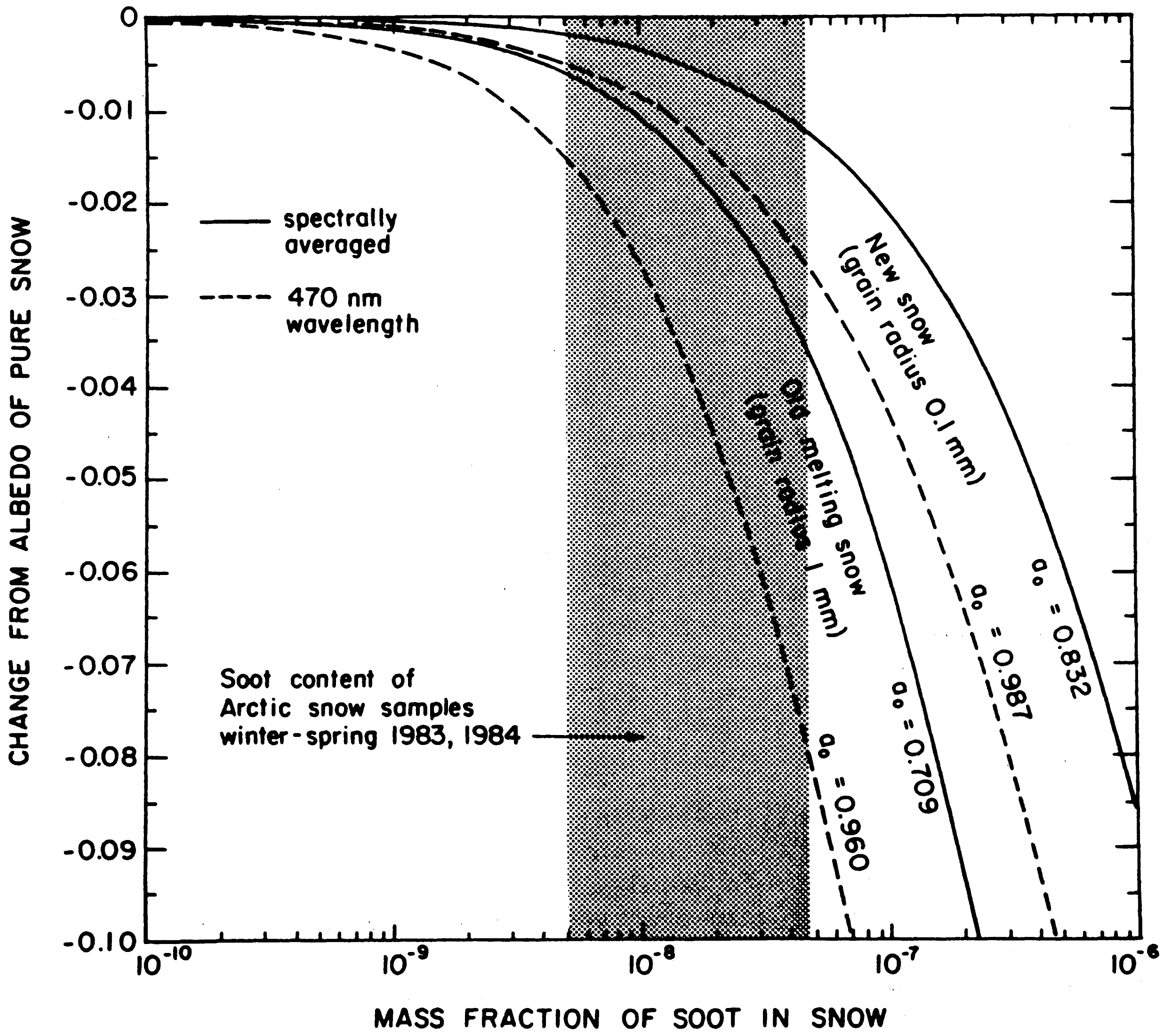

Figure 2. Computed effects on snow albedo due to small mass fractions of soot. Plotted is the change from the albedo values of pure snow, a_o. The spectrally-averaged changes are shown as solid lines. The dashed lines are calculations at the wavelength where snow albedo is most sensitive to soot content (470 nm wavelength). The reduction in spectrally-averaged albedo is thus about half as large as the reduction at visible wavelengths. The shaded region indicates the range of soot concentrations determined by Clarke and Noone (1985) in 12 samples of snowfall collected from Arctic Canada, Alaska, Greenland and Svalbard during winter and spring 1983, 1984. To ensure consistency between soot measurement and albedo calculation they have been multiplied here by the factor 0.85 because Clarke and Noone assumed a mass absorption coefficient $k_{abs} = 8.5\ m^2g^{-1}$ for ambient soot at 525 nm wavelength, whereas the Mie calculation for the soot parameters used by Warren and Wiscombe (1985) gave $k_{abs} = 10.0\ m^2g^{-1}$. [Figure and caption from Warren and Wiscombe (1985).]

budget of the snowpack, it is the spectrally-averaged albedo which is important. The solid lines in Figure 2 show that the reduction in spectrally-averaged albedo is in the range 0 to 0.035.

Clarke and Noone (1985) took 0.02 as a representative albedo reduction from Figure 2 and computed the effect on the radiation budget in the Arctic Ocean during spring and summer, using the solar radiation climatology of Fletcher (1965). The effect on the earth-atmosphere radiation budget is estimated to be $+4.6 \times 10^7$ J m^{-2} for the period 1 February - 15 July for 75°N (sunlight is negligible before February, and snow is mostly gone after mid-July). The positive sign means a net gain by the earth-atmosphere system. This compares to $+8.2 \times 10^7$ J m^{-2} estimated by Cess (1983) for the net effect of Arctic haze in the atmosphere on absorption of solar radiation by the earth-atmosphere system at 75°N. Cess's calculations were for clear sky conditions only. If clouds were included, his estimate would be smaller.

Thus we conclude that Arctic-haze soot in the snowpack should have an effect on the earth-atmosphere radiation budget comparable to that of Arctic haze in the atmosphere. However, the effects we calculated are based on soot concentrations measured in newly-fallen snow. The effect of soot during the melting season will be greater than we calculate if the soot particles tend to concentrate at the surface of melting snow, as do micron-size dust particles (Higuchi and Nagoshi, 1977).

These effects on absorption of solar radiation do not take into account any feedbacks. There is a positive feedback which would make the effect larger, but which would require a climate model to estimate it: The lower snow albedo could cause increased melting rates in summer, and cause the snow to disappear sooner than usual, thus uncovering the lower-albedo sea ice earlier in the season.

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