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SHORT CONTRIBUTION

On the climatic relevancy of Arctic Haze: static energy balance considerations

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ABSTRACT

Optical properties of Arctic Haze are known only roughly, but seem to be bracketed in the following ranges: optical depth, 0.1 to 0.5; haze asymmetry factor, 0.6 to 0.7; albedo of single scattering, 0.8 to 0.98. On the basis of these numbers, simple static energy balance considerations suggest that the light-absorbing haze over the northern reflecting ice cap creates an earth-atmosphere warming of 0.1 to 1.0 °C in comparison to a hypothetical haze-free Arctic. Before elaborate climatic models can be run with such meaning, the optical properties of the Arctic Haze, its geographical extent and seasonal variation have to be determined more accurately.

The intent of this note is to draw the estimated radiative and optical properties of Arctic Haze together as a group and consider them in the context of an extremely simple static energy balance climate model. On the basis of such a "first order" model it is suggested that the mean earth-atmosphere Arctic temperature may be 0.1 to 1 °C warmer than without haze. There is no point at this time to consider more refined modeling until the radiative parameters of Arctic Haze are known more precisely.

After a decade of research there is now general agreement that the Arctic aerosol has appreciable optical thicknesses (Shaw, 1982; Mendonca et al., 1981) especially in spring months, and contains graphitic (i.e., black) carbon which absorbs visible-band radiation (Heintzenberg, 1982; Patterson et al., 1982; Rosen et al., 1981; Rosen and Hansen, 1984). The Arctic Haze phenomenon is, as far as we know, industrial in origin, Arctic wide in scale (Rahn and Heidam, 1981) and possibly (though not certainly) has been increasing in intensity since about the time of WW II (Koerner and Fisher, 1982).

Tropospheric warming as the result of solar radiation absorbed by particles in the Arctic Haze, especially around the time of the vernal equinox, is to be expected, but in summer the haze disappears because of the onset of extensive cloudiness. Though the perturbation to the infrared radiation field is probably relatively small for the submicron aerosols in Arctic Haze, it lasts throughout the polar night and therefore cannot necessarily be discounted as a potential factor in inducing climatic alteration. We ignore the IR effects here, however.

The changes or perturbations to the "normal" visible-band radiative component of the polar heat balance (for cloudless skys) brought about by the presence of Arctic Haze requires, ultimately, knowledge of at least four parameters: (1) the underlying surface reflectivity, A_0, (2) the optical thickness, τ, (3) the so-called haze asymmetry factor, $\langle \cos(\theta) \rangle$, and (4) the albedo of single scattering, $\tilde{\omega}$ of the haze-laden air. The last three parameters are wavelength dependent.

The albedo of the polar surface lies in the range of 0.63–0.80 in spring. Representative values for τ in the Alaskan Arctic have been estimated to be ~0.1 (Shaw, 1982) to 0.5 (Mendonca et al., 1981). The last two parameters, however, $\langle \cos(\theta) \rangle$ and

ω_0, have unfortunately been estimated only roughly.

On the basis of (1) measurements of downwelling diffuse radiation in narrow spectral bandpasses during episodes of Arctic Haze and (2) simultaneous scans of sky radiance along the solar almuncatar, Shaw and Stamnes (1980) estimated $\langle\cos(\theta)\rangle$ to be between 0.6–0.8 and $\tilde{\omega}$ to be between 0.5–0.8. On the basis of (1) light absorption by soot particles collected on Nucleopore filters exposed at Barrow and (2) a rough knowledge of aerosol size distribution and light scattering, Patterson et al. (1982) estimated $\langle\cos(\theta)\rangle$ to be 0.67 and $\tilde{\omega}$ to be ~0.8, but sometimes rising as high as 0.9 during times of high relative humidity. Finally, on the basis of (1) broad-band hemispheric incoming radiation measurements at Barrow during haze and non-haze episodes and (2) for several assumed aerosol size spectra, Leighton (1983) deduced (by radiative transfer calculations) that the imaginary index of refraction for Arctic haze must be ~0.01 to 0.03, with the lower value being more probable. These data would suggest that $\omega > 0.9$. Clark et al. (1984) report values for single scattering albedo during spring, 1983, as $0.77 < \omega < 0.93$ with an average of 0.86.

Putting the (admittedly very few and quite diverse) data all together, the magnitude of the radiative parameters can be bracketed as follows: $0.6 < A_0 < 0.8$; $0.1 < \tau\,(0.55\mu) < 0.5$; $0.6 < \cos(\theta) < 0.7$; $0.8 < \tilde{\omega} < 0.98$. The most uncertain of the four parameters, for the purposes of estimating possible climatic change, is the parameter $\tilde{\omega}$.

At 72° North, radiative perturbation of Arctic Haze around the spring equinox was calculated for the range of parameters stated (see Shaw and Stamnes, 1980) and leads to an increased mean-monthly amount of absorbed solar radiation of 2 to 20 W m^{-2} in the lower (one or two kilometers) troposphere; similarly there would be a radiative cooling at the surface about one third the magnitude of the tropospheric warming. This, in effect, is equivalent to reducing the effective albedo of the earth near latitude 72°N by 2 to 8% during episodes of Arctic Haze around the time of vernal equinox. Reductions in effective albedo of this magnitude have been documented by radiation measurements carried out by Valero et al. (1984).

Now the average radiation balance (algebraic sum of incoming and outgoing solar and terrestrial radiation) of the Arctic around the time of vernal equinox is negative, going from about −30 W m^{-2} in March to ~0 by the end of April, after which time Arctic Haze virtually disappears. The estimated alteration in the radiative heat budget brought about by Arctic Haze (2 to 20 W m^{-2}) is therefore certainly significant in the relative sense, but the radiative component of the heat budget is fairly small.

Deficits in the radiation balance in the Arctic are balanced by heat from oceanic currents, latent heat and by the flow of sensible heat. On a yearly basis, Budyko (1974) estimates that 2.1–3.0 W m^{-1} of heat is gained by the atmosphere from the open leads in the polar ice and, in addition, another 2 W m^{-2} is gained by the latent heat at fusion of ice taken out of the Arctic by oceanic currents (~1900 km^3 ice yr^{-1}). As a result of oceanic circulation, therefore, the Arctic atmosphere receives an annual mean amount of ~4 W m^{-2}, but the annual mean radiative deficit is much larger at about 110 W m^{-2}. For most intents and purposes the negative radiation balance of the earth-atmosphere system in the Arctic is compensated by meridional heat transfer in the atmosphere, which we model by a simple conduction parameterization

$$R = \varepsilon(T(\phi) - \bar{T}), \qquad (1)$$

where R is the annually-averaged radiation balance, $\bar{T}$ is the annual hemispheric mean temperature, $T(\phi)$ is the annual mean zonally-averaged temperature at latitude ϕ and ε is a constant. Budyko estimates $\varepsilon \sim 3.8$ W m^{-2} K^{-1}.

As was pointed out, the presence of Arctic Haze will increase R by 2–20 W m^{-2}, but only during the 2 months in spring (March and April), which would be equivalent to increasing the annual-average of R by 0.3 to 3%. From eq. (1), the annual mean temperature at latitudes 72° N would rise by ~0.1 to 1 °C.

A temperature change of 0.1 to 1 °C, with no compensating feedback, would change the mean annual boundary of the Arctic ice northward by a few to a few tens of kilometers according to the present meridional temperature gradient. Before one can say anything more conclusively, climatic models incorporating the dynamics and feedback mechanisms have to be run, but right now the greatest need seems to be to sharpen our knowledge of the parameters ω_0 and $\langle\cos(\theta)\rangle$.

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