



National Aeronautics and Space Administration
Goddard Institute for Space Studies

Science Briefs

As Pure as Snow

By James E. Hansen —December 2003

Be thou as chaste as ice, as pure as snow, thou shalt not escape calumny.—William Shakespeare, *Hamlet*

Popular perceptions about the purity of fresh snow persist. However, examination under an electron microscope shows that the typical snowflake in the Northern Hemisphere contains thousands of aerosols (fine particles). The aerosols, mostly picked up as the snowflake falls, include soil dust and various chemicals, but perhaps the most important constituent is "soot".

Soot is carbonaceous matter that comes from incomplete combustion of fossil fuels and biofuels such as wood, field residue, cow dung and other organic matter. Soot usually includes light-colored organic carbon, but its dark appearance is caused by black carbon (BC). BC is responsible for the black smudge on chimneys, and it is visible in the exhaust plumes of diesel-powered trucks and buses.

In a new paper (Hansen and Nazarenko 2003), we suggest that the effect of soot on snow albedo (reflectivity), not included in climate studies such as those by the Intergovernmental Panel on Climate Change, is important. This contrasts with the impact of soot on cloud albedos, which has been shown to be small. In 1989, Twohy et al. noted that "about 1000 times higher concentrations of soot are needed for clouds than for snow to cause a given albedo reduction." The reason is that snow crystals are much larger than cloud drops and a snow deck has greater "optical depth", i.e., it is more opaque. Thus, typical photons of visible sunlight are scattered hundreds of times within a snow deck, so they have a good chance of being absorbed by a soot particle before they can escape.

A soot content of only a few parts per billion (ppb) is needed to reduce snow albedo by 1%. We estimate that soot reduces snow albedos about 3% in Northern Hemisphere land areas, 1.5% in the Arctic, and 0.6% in Greenland. Climate simulations show that this modest albedo effect would cause a global warming (see Fig. 3) that is more than a quarter of the warming observed in the past century (Fig. 4).

"It's just good clean soot", says Dick Van Dyke as the chimney-sweep in *Mary Poppins*. Environmentalists and climatologists are not as sanguine about soot, but they have devoted greater attention to sulfates, which cause "acid rain". However, soot may be a more all-around bad actor than has been appreciated.

We suggest that, in addition to being a major cause of global warming, soot may directly contribute to near world-wide melting of ice that is usually attributed solely to global warming. For any given soot amount, its destruction of ice is greatly magnified by positive feedbacks. Increased absorption of sunlight causes snow to "age" more rapidly, thus increasing the ice crystal size and causing more absorption of sunlight. Soot absorption causes the melt season on glaciers to begin earlier and last longer. This has a large impact, because wet snow is much darker than dry snow. Further, as melting occurs, BC accumulates as "crud" on the surface, making the ice even darker. The added melt-water seeps to the base of the ice, providing lubrication that speeds glacier movement and disintegration.

Soot's other roles: Soot's effect on snow and ice is only one aspect of its practical impact. Just as brilliantly as Van Dyke plays both the decrepit banker and the chimney sweep in *Mary Poppins*, so ignominiously does soot play multiple roles in the environment.

Soot particles are like tiny sponges that soak up toxic organic material and metals in fossil fuel and biomass burning. Because they are so small, they penetrate human tissue deeply when breathed into the lungs. Soot is suspected of being a major contributor to approximately one million premature deaths globally per year that are blamed on particulate air pollution.

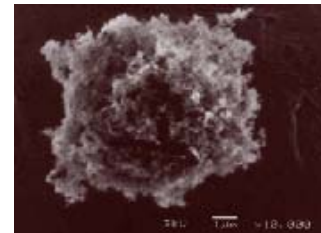
Soot is the aerosol most responsible for reducing atmospheric transparency and visibility, by so much in India and China that agricultural productivity is reduced an estimated 10-20% with additional loss

Click on any figure to view a large version.



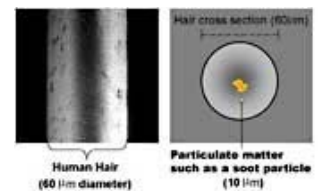
Snowflake Under a Microscope

(Image: USDA Beltsville Agricultural Research Center, Electron Microscopy Unit)



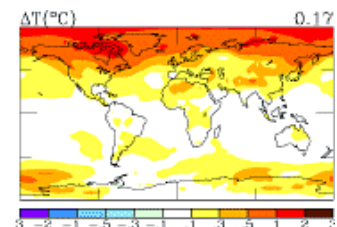
Soot Particle Under a Microscope

(Image: D.M. Smith, Univ. Denver)



Size of a Soot Particle

Soot particles are measured in micrometers (μm), and are smaller than the diameter of a human hair. (Image: NASA)



from soot deposited on plant leaves. Soot is also esthetically displeasing as it is responsible for a brown appearance of urban hazes and soiling of buildings. Finally, soot may affect regional climate, as well as global climate, e.g., it has been suggested that the heavy concentration of soot over China and India may be responsible for a trend toward increased flooding in the south and drought in the north.

The good news: Restoration of snow albedos to pristine pre-anthropogenic values would have the double benefit of reducing global warming and global ice melt, with its impact on sea level. Technology is within reach that could eliminate most soot, restoring snow albedo to near pristine values, while having many other benefits for climate, human health, agricultural productivity and environmental esthetics. The largest source of soot in developed countries is now diesel fuel, while in developing countries biofuels are also important. Much cleaner diesel engines and biofuel technologies are being developed. There are opportunities for scientific and technologic cooperation among developing and developed countries with widespread mutual benefits.

Related Research News

[Black Soot and Snow: A Warmer Combination](#) (Dec. 22, 2003)

[NASA Finds Soot has Impact on Global Climate](#) (May 13, 2003)

[Black Carbon Contributes to Droughts and Floods in China](#)(Sep. 26, 2002)

Reference

Hansen, J., and L. Nazarenko 2004. [Soot climate forcing via snow and ice albedos](#).*Proc. Natl. Acad. Sci.* **101**, 423-428, doi:10.1073/pnas.2237157100.

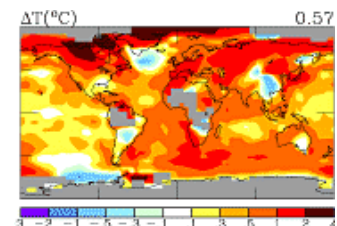
Twohy, C.H., A.D. Clarke, S.G. Warren, L.F. Radke and R.J. Charlson 1989. Light-absorbing material extracted from cloud droplets and its effect on cloud albedo.*J. Geophys. Res.* **94**, 8623-8631.

Contact

Please address all inquiries about this research to [Dr. James Hansen](#) or [Dr. Larissa Nazarenko](#).

Modeled Surface Temperature Change

Global map of the simulated 1880 -2002 surface temperature change caused by soot. (View as [largeGIF](#) or [PDF](#))



Observed Surface Temperature Change

Global map of the observed 1880 -220 surface temperature change, based on adjusted meteorological station data over land and sea surface temperature for the ocean. (View as [largeGIF](#) or [PDF](#))



NASA Official: James E. Hansen
GISS Website Curator: Robert B. Schmunk
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