Pollution of the Arctic Atmosphere Confirmed

Although it is not as severe as in most cities, Arctic air pollution concerns scientists

When atmospheric chemists set up their air samplers in Barrow, Alaska, 600 kilometers into the vastness of the Arctic, they expected to be analyzing only telltale chemical traces of the sea and land. Instead, the filters that they used to collect atmospheric particles turned a grimy gray. In some ways, the particles bore a chemical resemblance to pollutants produced thousands of kilometers to the south. A few researchers became convinced that industrial pollution at times penetrates into the Arctic, a region that everyone had assumed remained pristine (*Science*, 20 July 1979, p. 290).

Now, researchers have sampled elsewhere in the Arctic and performed more kinds of analyses.* This new evidence has helped form a consensus that during winter and spring pollutants travel 5000 kilometers and more from industrial areas in Europe, Asia, and perhaps North America into the Arctic, producing a pervasive haze there. Although the amounts of pollutants in the Arctic are much smaller than those nearer industrial areas, they may still be sufficient to affect regional climate.

Part of the new evidence supporting Arctic air pollution comes from the air-sampling network established by Leonard Barrie and his colleagues at Canada's Atmospheric Environment Service, Downsview, Ontario. They collected aerosols, the microscopic particles suspended in the air that in sufficient numbers produce haze, at Mould Bay (1300 kilometers northeast of Barrow) and Igloolik (2500 kilometers east of Barrow). The aerosols at these locations turned their filters "flannel gray" and "sooty black" only during winter and spring, as happens at Barrow. At the Canadian sites, too, sulfate, vanadium, and other trace elements appeared in amounts too large to be accounted for solely by the sea salt or soil dust particles in the aerosol.

Because the only other likely source of vanadium is the burning of heavy fuel oil and coal, the Canadian group attributes the excess sulfate and vanadium to industrial sources in mid-latitudes. This same conclusion was reached earlier by Kenneth Rahn of the University of Rhode Island on the basis of sampling at Barrow. A third group, headed by James Peterson of the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratories in Boulder, Colorado, also studied the Barrow aerosol. They found that it increased when the wind blew from the north off the ice-covered Arctic Ocean, which suggested that the dirtied aerosol did not have a local origin.

A variety of chemical analyses now supports the polluted nature of much of the winter-spring Arctic aerosol. Joan Daisey of the New York University Medical Center examined the collected aerosols with a scanning electron microscope and found pollen in summer samples but fly ash and what appear to be black particles of carbon in spring samples. Hal Rosen of Lawrence Berkeley Laboratory, using Raman spectroscopy, identified "a major component of the aerosol" as graphitic carbon or soot. Charles Weschler of Bell Telephone Laboratories in Holmdel, New Jersey, identified organic compounds in the Arctic aerosol with a gas chromatograph–mass spectrometer system. He found numerous organic compounds typical of polluted air, including dimethyl silicones, synthetic compounds that are found, among other places, in photocopier chemicals.

Pollutants make up much but not all of the winter-spring Arctic aerosol.

According to Rahn's calculations, pollutants make up much but not all of the winter-spring Arctic aerosol. Of the total aerosol mass (not counting water), about 50 percent is pollutant sulfate, organic matter, soot, and other pollutants. If soil dust and sea salt particles, which are larger than 1 micrometer and contribute little to the haze, are excluded, pollutants compose about 80 percent of the haze during the winter and spring. Thus, even in the absence of pollution, there would still be some aerosol in the winter and spring, similar perhaps to the unpolluted summer aerosol, Rahn says.

The pollution of the Arctic atmosphere is not as heavy as that near most cities, but it is still considerable. The average concentrations of soot in New York City's air are ten times greater than the peak values of the Arctic haze. On the worst days in New York, there is 50 times more soot in the air than on the worst days in the Arctic. But peak Arctic values are as much as one-third of the average values in Berkeley, California. The winter-spring concentrations of sulfate, which can start out in the form of sulfuric acid, in the Arctic are one-fifth of those on the north shore of Lake Erie—midway between Detroit, Cleveland, Toronto, and Buffalo—and are about equal to the average winter values of the northeast United States. The Arctic concentrations are about ten times higher than "background levels" in other remote areas of the Northern Hemisphere, according to Rahn.

Researchers now agree that Arctic air can become dirty during winter and spring because of an unusual combination of meteorological and geographical circumstances. At that time there is little rain or snow to strip pollutants from the air as it moves northward into the Arctic. The Arctic in winter is something of a desert, Rahn notes. Some pollutants, such as sulfate and organic matter, can start out as gases, which will not fall out as particles do. Only later do the gases form particles. Also, the air masses injected into the Arctic by winter-spring circulation patterns can pick up pollutants from heavily industrialized areas in the northern reaches of eastern North America, Europe, and Siberia.

Researchers are still debating which one of these areas is the predominant source at any one time. The evidence at issue is the varying abundance of trace constituents of the aerosol. The amount of carbon and the amount of manganese in the Arctic aerosol, each measured relative to the amount of vanadium, vary through the year. Both of these ratios seem to be higher in coal-burning, metal-processing regions, where less heavy oil

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(a vanadium source) is burned. High early-winter aerosol ratios in the Arctic suggest that sources in the central Soviet Union predominate then, adding soot and metals to the air before it sweeps into the Arctic east of the Urals.

As winter progresses, the dominant source seems to shift to the west toward western Europe. Barrie believes that by spring this shift can extend to eastern North America, which could contribute by a route west of Greenland. Rahn favors a shift to a western European source but he thinks it seldom shifts farther. The route from western Europe is normally directly north over Scandinavia and the island of Spitsbergen. In either case, the longest routes into the Arctic are 5000 kilometers or more, requiring a travel time of at least 5 to 10 days. The most far-reaching pollutant transport pathway known until recently covered 2000 to 3000 kilometers.

Researchers still have only the vaguest ideas about how an enhanced, dirtied haze might affect the Arctic. The present center of attention is the black soot of the aerosol, a highly efficient absorber of solar radiation. Everyone agrees that it will heat the lower Arctic atmosphere in the spring—the question is how much. Rosen has made a "very preliminary" calculation suggesting that the rate of heating in the Arctic due to soot could be as much as that resulting from a doubling of the atmospheric carbon dioxide content. At a recent workshop in Boulder sponsored by NOAA, researchers interested in the effects of carbon in the atmosphere scrutinized those calculations and found them to be sound, within the severe limitations of the available data. In order to make more than a guess, they say, sampling must now be extended above ground level.

Although the discovery of pollution in the supposedly pristine Arctic atmosphere has startled scientists, pollutants probably do not travel in that fashion elsewhere. Rahn has been unable to identify other parts of the world where extremely long-range transport near the surface might occur. But pollutants that travel higher in the troposphere (see box) might similarly escape rapid removal, he says.

Efforts to further understand the origin and effects of the Arctic haze continue, with one handicap—disinterest on the part of the Soviet Union. Although it borders on fully one-half of the Arctic and apparently makes a sizable contribution to the problem, the Soviet Union continues to limit cooperative studies to the natural aerosols of its southern deserts.—RICHARD A. KERR

Is All Acid Rain Polluted?

Acid rain is falling on some of the most remote, isolated places on Earth. Whether this scourge of industrial pollution has spanned unexpected distances or whether rain can be acidified naturally, scientists cannot say yet. But they have already traced a 5000-kilometer pathway between Asian sources and the Pacific that carries pollutants in much the same way as the polluted air entering the Arctic (see accompanying story).

A thoroughly documented case of acid rain in the Hawaiian Islands has been developed by National Oceanic and Atmospheric Administration researchers John Miller (Air Resources Laboratory, Silver Spring, Maryland) and Alan Yoshinaga (Mauna Loa Observatory, Hilo, Hawaii). Since 1974, they have analyzed more than 1700 rainwater samples collected at nine sites on the island of Hawaii at altitudes of 0 to 3400 meters. Most of the rain collected was acid rain, according to the rule that acid rain has a *p*H below 5.6—the *p*H of pure water acidified by atmospheric carbon dioxide. The *p*H of rain decreased with increasing altitude, averaging 5.2 at sea level and 4.3 at 2500 meters. The annual average *p*H of the northeast United States is also about 4.3. The observed *p*H in the Hawaii samples ranged from about 3.7 to about 5.7.

Miller and Yoshinaga found that the primary acid in the rain was sulfuric acid, the principal acid in polluted rain. But they could not find a sufficient source anywhere on the islands for the sulfuric acid found at their sites. In addition to ascertaining that Hawaii's active volcanoes are insignificant sources, Miller and Yoshinaga set up a collection site on the island of Kauai, 500 kilometers northwest of the island of Hawaii. Kauai has a smaller population, is upwind of the rest of the major islands, and has no active volcanoes. Even so, the annual average *p*H at the site was 4.8, the same as at a Hawaii site at the same altitude.

Acid rain also falls in the central Indian Ocean. On Amsterdam Island, midway between Australia, South Africa, India, and Antarctica, the *p*H of rain ranges from about 4.5 to 5, according to James Galloway of the University of Virginia, who is studying remote sites with Miller and Gene Likens of Cornell University. As in Hawaii, the Amsterdam Island samples had been acidified by sulfuric acid.

In contrast, the average *p*H of 26 samples of rain on Samoa in the South Pacific was 5.6, the calculated *p*H of uncontaminated rain, according to Robert Duce and Alex Pszenny of the University of Rhode Island. Duce heads the Sea-Air Exchange (SEAREX) program studying the transport of pollutant and natural substances over the oceans. Although rain *p*H has not been measured at another Pacific SEAREX site on Enewetak, north of the equator, the air there is much dirtier than at Samoa. In addition to desert dust from Asia, it contains pollutant lead and synthetic organic chemicals. The difference between the two sites, Duce says, is that pollution from the Northern Hemisphere, the dirtier of the two, has trouble crossing the equator, where the trade winds converge.

If the sulfuric acid in the rain of Hawaii and Amsterdam Island has a pollutant source, it may be transported thousands of kilometers in the same way that Asian dust reaches Enewetak. It travels at altitudes of at least several kilometers, where contact with the surface cannot remove it and less rain occurs to wash it out of the air. Pollution on its way to the Arctic from northern industrial centers also escapes removal during winter and spring because of the small amount of precipitation there, even though it travels near the surface. The high-altitude air masses crossing the Pacific eventually subside toward the surface, Duce notes. Miller and Yoshinaga suggest that in Hawaii convective rainstorms may actually reach up into the mid-troposphere and wash out the acid.

If some or all of the observed remote acid rain has a natural origin, the ocean may be its source. Duce points out that some evidence suggests that biological processes in the ocean produce reduced sulfur compounds, such as dimethyl sulfide. This compound could oxidize in the atmosphere to form sulfuric acid. If so, researchers and politicians will have to distinguish between natural and man-made acid rain.—R.A.K.

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