Global Pollution: Is the Arctic Haze Actually Industrial Smog?

The pollution that produces acid rain, known to travel hundreds of kilometers from its source, may continue its travels into the pristine Arctic

Flying over the Arctic Ocean, thousands of kilometers from the murky skies of New York, London, or Hamburg, pilots often spend hour after hour in a haze so thick that any view other than nearly straight down is obliterated. First reported by weather reconnaissance crews in the 1950's, the heavy haze is a regular springtime feature of the Arctic, often reducing visibility aloft from over 100 to below 10 kilometers.

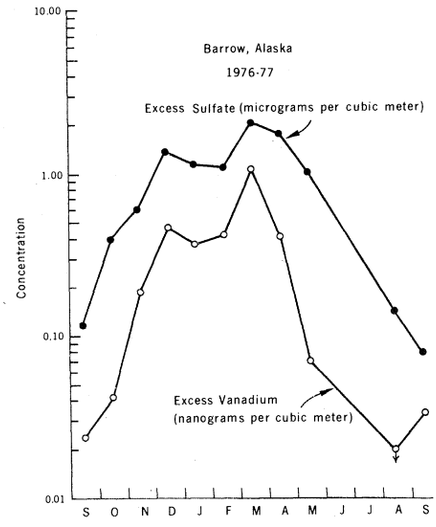
A haze so far from the factories and cars that smudge the air of major cities would seem to require a wholly natural explanation. But evidence has begun to accumulate that a part of the Arctic haze may have its origins 10,000 kilometers away in the same polluted air that produces acid rain over the United States and Europe. Acid rain has wiped out the fish of some lakes in Scandinavia and upstate New York and possibly altered forest ecosystems, but the environmental effects of the Arctic haze, if any, are as yet unknown. In any case, the existence of significant pollution in the Arctic would greatly extend the documented extent of the long-range transport of pollutant particles in the lower atmosphere.

In the conventional sense, long-range transport has implied the movement of dirty air from, say, the highly industrialized Rhine Valley in West Germany to southern Scandinavia, a distance of about 1500 kilometers. The pollution itself, which includes sulfuric and nitric acids, heavy metals, soot, and organic matter, falls out or is washed out as acid rain all along the way. Likewise, pollutants generated in the eastern United States move similar distances before they rain down on New England and probably Canada. Evidence recorded in ice cores suggests that these pollutants may eventually reach Greenland, a distance of as much as 3000 kilometers.

Although some of these pollutants are released as gases, such as sulfur dioxide and hydrocarbons, they eventually form small, submicron particles of sulfuric acid and organic matter through chemical reactions with pollutants and naturally occurring chemicals under the influence of sunlight. If enough of these particles of the proper size are suspended in the air, they become visible as haze. Such a polluted haze can look like a haze made up solely of natural particles.

Atmospheric chemists had generally believed that suspended particles, or aerosols, either fell to the ground from their own weight, stuck to solid objects that they ran into, or were washed out by rain before they could travel much more than a thousand kilometers. If the Arctic haze actually does contain particles derived from the major pollutant sources in the middle latitudes, the distances involved could exceed 10,000 kilometers, a range not seriously considered before for such pollution.

Analyses of samples collected from the Arctic Air-Sampling Network,* a loose alliance of researchers interested in Arctic atmospheric chemistry, tend to support such extremely long-range transport of pollutants into the Arctic. The most likely source, according to Kenneth Rahn of the University of Rhode Island, seems at the moment to be Europe, although the northeastern United States cannot be ruled out. Rahn believes that the summer hazes are uncontaminated but that during the winter the Arctic haze consists largely of droplets containing sulfate and organic matter with relatively small amounts of heavy metals, such as vanadium and manganese.



Monthly mean concentrations, plotted on a logarithmic scale, of atmospheric sulfate and vanadium at Barrow, Alaska, that could not be attributed to natural processes. Such excess vanadium is generally considered to result from the burning of heavy industrial fuel oils. [Source: Kenneth Rahn and Richard McCaffrey, University of Rhode Island]

These chemicals are found in urban air pollution, but their relative proportions are quite different. In fact, the composition of the haze gives a clue to how these substances may have gotten into the Arctic, according to Rahn. For example, over the winter of 1976–1977, excess sulfate, which is the amount above that contributed by natural sea salt particles, increased 10- to 20-fold to about 2 micrograms per cubic meter of air at Barrow, Alaska. The mean concentration during the winter for the northeastern United States is about 6 micrograms per cubic meter, or only about three or four times the concentration in northernmost Alaska. On the other hand, excess vanadium, which is the amount above that contributed by natural dust particles, also increased dramatically during the winter to 1 nanogram per cubic meter, but these values are 20 to 30 times less than winter values in the northeastern United States.

Therefore, if the sulfate and vanadium in the winter haze at Barrow started out as part of a typical polluted parcel of air, a much larger proportion of the vanadium was lost en route to Barrow than of the sulfate. Rahn believes that this is consistent with a distant source in the middle latitudes, because the sulfate would start out as gaseous sulfur dioxide. Although sulfate particles would be removed continuously, their concentra-

*The principal participants in the Arctic Air-Sampling Network are as follows: Kenneth Rahn, University of Rhode Island; Brynjulf Ottar, Norwegian Institute for Air Research, Lillestrøm; Hans Flyger and Niels Heidam, Air Pollution Laboratory, Roskilde, Denmark; and Leonard Barrie, Atmospheric Environment Service, Downsview, Ontario, Canada.

0036-8075/79/0720-0290$01.00/0 Copyright © 1979 AAAS

tion would tend to be maintained by the conversion of sulfur dioxide into sulfate. A similar gas-particle conversion process is known to occur between hydrocarbons and organic matter, but vanadium is released as a particle and its concentration would not be supplemented by conversion from a gaseous form. Thus, sulfate and organic matter would get a bit of a free ride on their way to the Arctic.

But the gas-particle conversion explanation is not in itself sufficient to account for the amounts of apparent pollutants in the Arctic haze. Rahn and his colleagues are suggesting that, in addition, the unusual weather conditions in the Arctic, especially in the winter, allow the polluted aerosol to stay in the air longer than would otherwise be expected and to produce the relatively high pollutant concentrations observed.

At least one situation in which special weather conditions allow the transport of particles between continents many thousands of kilometers apart has been thoroughly documented. Joseph Prospero and his group at the University of Miami have shown that some of the fine dust lifted as high as 6000 meters by dust storms over the Algerian Sahara does not come down until it is over Barbados, 7000 kilometers away. At times, some dust may even reach Florida or Mexico, almost 10,000 kilometers away.

Left to themselves, these relatively large particles (up to 20 micrometers in diameter) would fall out far short of Barbados, but several processes intervene to minimize their removal. One is the input of lifting energy from turbulence between the dust layer and the northeasterly trade winds that undercut it. Removal by rainfall is minimized by the rain-suppressing effect of the anomalously warm dust layer itself, which is enhanced by the dust's absorption of heat from the sun.

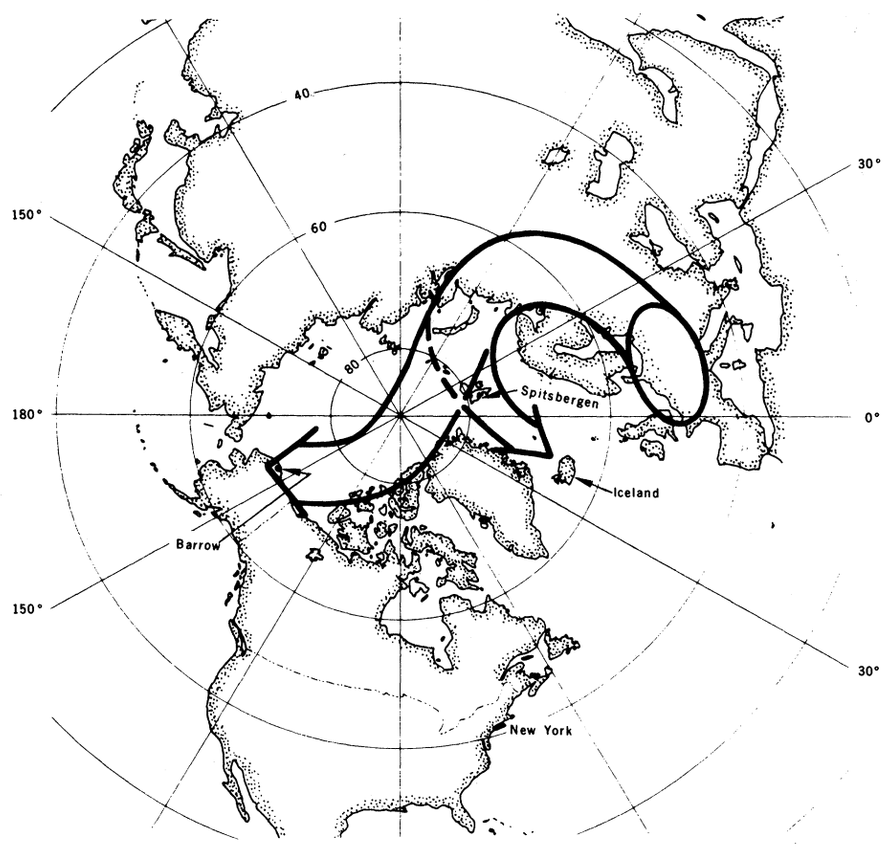
A similar instance of very long-range transport was the discovery that dust from the Gobi Desert of Mongolia can be carried out over the Pacific. In 1971, Kenji Isono, now retired, and his group from the Water Research Institute at Nagoya, Japan, reported that they had observed dust pass over Japan from Asia and days later collected dust in Hawaii and then Alaska. On the basis of the timing of the observations, the calculated paths of the air mass involved, and mineralogical analyses of the dust, they concluded that a single surge of dust from the Gobi had arced across the Pacific for well over 10,000 kilometers. Rahn and Glenn Shaw of the University of Alaska encountered a similar episode in 1975 when they began sampling the Arctic haze aloft near Barrow, but subsequent samplings at the surface have failed to capture much Gobi dust.

The Arctic has its own ways of minimizing the removal of aerosol particles, according to Rahn. One is the relatively short, direct paths that air masses follow from pollution sources in the middle latitudes into the low-lying Arctic. In contrast, the sources of pollution for the Antarctic, one of the cleanest places on the earth, are farther away and the winds between them and the 3000-meter-high interior follow long, rising spirals. Also, the Arctic, like the Antarctic, is something of a desert. Barrow receives only 10 centimeters of precipitation a year and most of that falls in the summer. Thus, the amount of pollutants that would be removed by rain or snow would be small, especially during the winter, which is the time when the large amounts of sulfate and gray organic matter show up on aerosol-sampling filters at Barrow.

An alternate explanation for these dirty samples of Arctic air would be a local Arctic source, which could be either a natural or pollutant source. Rahn believes that the chemical evidence against this is now considerable. "We're almost positive that much of the winter haze is pollution-derived," he says, "and that it comes from outside the Arctic."

One reason Rahn and the other researchers in the Arctic Air-Sampling Network are reasonably confident is that they have found excess vanadium all around the Arctic, but they cannot find a likely source for it other than the major industrial centers of the middle latitudes. Vanadium is a natural component of crude oils and is concentrated in heavy, industrial fuel oils after refining. Atmospheric chemists have found that, when excess vanadium is found in the atmosphere, it invariably is a pollutant.

The vanadium in the air at Barrow does not appear to have a local origin because vanadium-laden heavy fuel oils are too thick to be used in the extreme cold of the Arctic. In the village of Barrow, for example, mainly natural gas, which contains no vanadium, and small amounts of light distillate fuels are burned. Normally, when air is filtered to collect aerosols near Barrow, it is only



A possible path for pollutants originating in Europe and carried to Barrow, Alaska, during the winter. Such a proposed path is speculative, according to Kenneth Rahn of the University of Rhode Island, in that it depends on the results of atmospheric chemical analyses of aerosols but draws only on general, qualitative meteorological patterns. Also, data on the meteorology of the Arctic are relatively scarce, and aerosol data from Euopean and Asian U.S.S.R. are not available. Although the exact pollutant path should vary from season to season, Rahn is confident that it passes over the Arctic Ocean from Asia.

done when the wind is blowing from a "clean" direction. But, regardless of whether it is collected from the "dirty" direction of the village or from the apparently clean direction of the Prudhoe Bay end of the Alaska pipeline (320 kilometers to the east), the results are the same, Rahn reports. The phenomenon is not limited to the Barrow area because simultaneous sampling of a northerly wind at Barrow and Narwahl Island, 32 kilometers north of Prudhoe Bay, gave the same results.

Data from the rest of the Network also support a very distant source for the winter haze, possibly Europe. Several chemical clues point to that part of the world as a likely source. Samples collected in Greenland, which straddles likely routes from the United States, contained several times less vanadium and sulfate than those collected at Spitsbergen, which is due north of Scandinavia. The ratio of sulfate to vanadium, the proposed indicator for aging of a polluted air mass, progressively increases from western Europe through northern Norway, to Spitsbergen. And the relative proportions of manganese, an apparent marker for pollutants from heavy industry, and vanadium appear to be the same in Europe, Spitsbergen, and Barrow, but differ significantly from that in the northeastern United States.

These chemical characteristics of the winter Arctic haze have been used in simple calculations by Rahn and Richard McCaffrey of the University of Rhode Island to determine which sources and paths into the Arctic could be responsible. In addition to the expected behavior of atmospheric sulfur and vanadium, they included in their model lead-210, the particulate decay product of the gas radon. Radon is added to continental air from the soil, providing another gas-particle conversion process that can be measured as it progresses.

Combining the results of the model with the pattern of general circulation into the Arctic, Rahn and McCaffrey are able to produce the chemical composition of the winter haze at Barrow from values for the aerosol over Europe. The best path between the two appears at the moment to be northeastward into European U.S.S.R. and then northward into

Ten Years Later: Whence the Moon?

Moon rocks were to form the Rosetta stone of the solar system, the key to unlock the mystery of the moon's history and origin. Preserved on the moon's primitive, geologically dead surface, the samples returned by the Apollo astronauts would contain the clearly legible record of early lunar history, unmuddled by the destructive forces so active on Earth. Or so the public came to believe. Some scientists as well believed, or hoped, that the moon would be a simple place with simple answers.

Although the moon rocks have greatly improved scientists' understanding of the moon's history, the origin of the moon remains a mystery. After six manned landings, the return of more than 2000 samples totaling almost 400 kilograms, and $25 billion in expenses, researchers are still mulling over the same three theories that were in vogue before the first Apollo landing on 20 July 1969. Did Earth capture the moon or the material to make the moon as it approached from another part of the solar system? Could the moon have been pinched off from the early, nearly molten Earth? Or, did Earth and the moon form in orbit about one another as a "double planet" system? The answer, if it is to be found at all on the moon, has been badly garbled by unexpectedly vigorous geological activity in the early days of the moon. Simply determining what has happened since its origin has been so demanding that discussion of how it got there has been subdued until recently. Now, the subject is becoming popular again. But important, perhaps essential, experiments designed to resolve the remaining ambiguities will be carried out not by the United States, but possibly by the U.S.S.R. using American equipment.

Opinion varied as to how geologically complex the moon would be, according to William Quaide of the National Aeronautics and Space Administration (NASA), but "still, no one expected the moon to be quite so complicated as it turned out to be." The complications set in soon after the moon formed. Researchers studying the moon rocks have found that the moon formed at the same time as Earth, 4.5 billion years ago. The moon then melted to a depth of 400 kilometers, which led to the formation of a variety of types of rocks from the moon's original starting material. The complexity increased as huge planetoids collided with the ancient crust, widespread volcanism brought deep magmas to the surface, and further heating altered the original rocks.

In spite of this often violent activity, each of these major stages of formation has been dated by the use of isotopic techniques. In addition, chemical analyses have shown that the moon has a very different overall chemical composition than Earth. The main differences are that moon rocks are deficient in water, easily volatilized elements such as chlorine, and elements called siderophiles that are usually associated with iron, such as nickel. Researchers have felt all along that these chemical findings were trying to tell them something fundamental about the origin of the moon. Exactly what they say remains unclear, but, fueled by the extensive Apolla data, the controversy is heating up again.

None of the competing theories for the moon's origin has gained a lead on the basis of the Apollo data, but advocates of each have some new support. The moon's oxygen isotopic composition tends to support the simultaneous formation of Earth and the moon from the same part of the solar nebula, perhaps while in orbit around each other. Researchers found that the ratios of all three oxygen isotopes in lunar rocks and in terrestrial rocks are essentially identical but differ from those of meteorites, which apparently formed between Mars and Jupiter. If Earth and the moon were so closely related, however, the other chemical differences between them must be explained.

To do this, a few researchers have suggested that the composition of the moon was determined when it split off from Earth, a theory that was first proposed in the 19th century. The Pacific Ocean basin was seen as a mammoth scar where the moon had been ripped out of Earth. Plate tectonics has since supplied a much tidier explanation for the Pacific Ocean, but the discovery of the moon's deficiency in siderophiles has revived interest in the idea. The latest version has the moon split off from the mantle of the rapidly spinning, nearly molten Earth after the siderophiles had been removed by formation of Earth's iron core. Detractors question whether such fission could ever occur,

0036-8075/79/0720-0292$00.50/0 Copyright © 1979 AAAS

the Arctic and on to Barrow. The travel time would be on the order of 20 days. According to the model, U.S. pollution could not contribute significantly to the Arctic haze. Rahn warns that the model is "only a first approach to determining a route to Barrow that makes good physical sense and satisfies the aerosol data. The truth is undoubtedly much more complicated."

Although data on the chemistry and meteorology of the Arctic haze continue to be collected, the possible environmental effects remain entirely speculative. John Miller of the National Oceanic and Atmospheric Administration's Air Resources Laboratory in Silver Spring, Maryland, has found that the acidity of fallen snow at Barrow (*p*H 4.7 to 4.8) is only slightly greater than that of the rain in Samoa (about *p*H 5.0), one of the cleanest places measured. Miller cautions that the data are still very preliminary. "We have no complete proof," he says, "but there are obviously some indications of acid precipitation." The effects of this amount of acidity, if it is indeed man-made, on the Arctic tundra are unknown.

Effects on the weather are also possible. The haze might influence cloud properties by changing the concentration of particles that are capable of becoming the nuclei of new ice crystals or cloud droplets. The haze seems to cause a heating effect by absorbing additional sunlight, according to Glenn Shaw. The problem, he says, is determining exactly how much heating occurs and what, if any, climatic effect it has.

In the case of the Arctic haze, the increasingly sensitive tools of atmospheric chemists seem to have revealed a potential problem where it was least expected. In other places considered to be among the cleanest in the world, such as Hawaii, Samoa, Greenland, and Antarctica, apparent excesses of heavy metals, sulfate, and acidity remain to be fully explained. Some of these may in fact be natural, perhaps resulting from volcanic emissions, for example, but the environmental effects, if any, of true pollutants will have to be evaluated. That analysis will undoubtedly be even more complex than unraveling their chemistry.

—RICHARD A. KERR

Photograph from National Aeronautics and Space Administration

and, if so, how the moon lost the volatile elements so abundant on Earth.

The similarities and differences in composition might also be explained if the moon formed outside the immediate vicinity of Earth. The capture theory also has a new look in the post-Apollo period, although not as a direct result of moon rock analyses. Rather, theoreticians have finally given up trying to find a reasonable way for Earth to capture the moon as a single body. Like any man-made planetary probe, the incoming moon would have had to be slowed or it would have whizzed on by without going into orbit. More realistic theories now include breaking up a large body by tidal forces and capturing only part of its stony mantle. Or, whole swarms of small bodies might be captured because of the slowing effect of collisions between them.

With no consensus on the moon's origin 10 years after the first moon landing, scientists are wondering whether this central question can be answered without more samples or missions to the moon. Most think it can . . . maybe. They are expecting more analyses of the moon rocks, as well as a bit more comtemplation, to help. "You have to work at these things a while," says James Arnold of the University of California at San Diego, "to sort out what is just peculiar from what is basic. Five years from now, we'll be getting down to some really serious talk."

Even now, researchers are becoming less tolerant of scenarios that are based on "too many ad hoc suppositions and even miraculous coincidences," as one meeting report put it. Greater rigor may also be introduced into this traditionally controversial field from the study of a windfall of new meteorite finds in Antarctica and of extraterrestrial material floating as dust in the upper atmosphere and mixed with the sediments of the deep sea. Planetary scientists expect that these studies, combined with the developing understanding of the planets, asteroids, and especially the satellites of Jupiter and Saturn, could lead to an understanding of the origin of not only the moon but planetary bodies in general.

An important step in that direction, many believe, would be a lunar satellite that could extend the Apollo data to a global scale. The idea is widely seen as having considerable scientific merit, but it has been dropped by NASA in favor of planetary probes. But official interest in a lunar orbiter persists outside the United States. In fact, the U.S.S.R. has approached American investigators, through NASA, about the experiments that the scientists had initially proposed to NASA. The possibility exists that American experiments could fly on a Soviet mission intended to continue the job started by the Apollo missions.

—RICHARD A. KERR