Pollutant Haze Cools the Greenhouse

The miasma that cloaks much of the industrialized world is probably counteracting some of the greenhouse warming, but the greenhouse should prevail

INDIVIDUALLY, THEY ARE AS SMALL AND INVISIBLE as viruses, and quite impotent. En masse, they are another matter. The haze particles that blanket the eastern United States, Europe, and much of Asia carry acids that corrode statuary, poison lakes, and blight forests. And, based on a growing body of research, an international panel of experts has just concluded that hazes are probably having another effect on the environment—cooling it. Earth's protective umbrella of hazes may have reflected enough solar energy back into space, the United Nations' Intergovernmental Panel on Climate Change (IPCC) concluded last month, to counteract much of the warming caused so far by greenhouse gases.

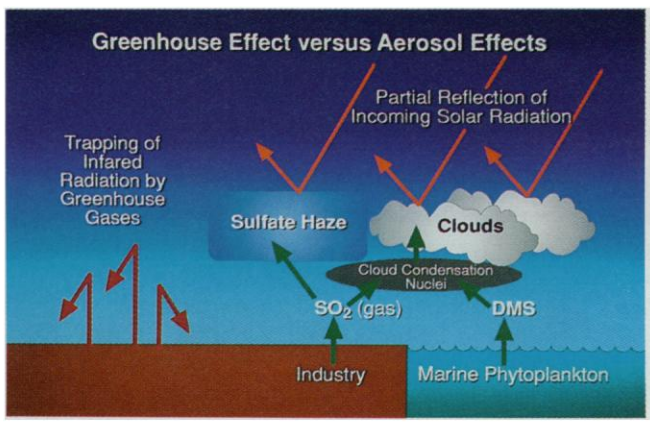
But don't look for an easy way out of global warming. The cooling effects of manmade aerosols "are helping us understand why the climate isn't warming as much as the models call for," says climate modeler Michael MacCracken of Lawrence Livermore National Laboratory, but hazy skies won't hold back the warming indefinitely, MacCracken and other researchers say. "My belief is that, even in the most extreme case, the greenhouse gases will win out," says atmospheric chemist Robert Charlson of the University of Washington.

Atmospheric particles are reemerging as major players in climate after more than a decade in eclipse. Back in the early 1970s, the talk among climate experts was of global cooling, not warming. The global temperature had been falling since about 1940, and the prospect of another ice age was all the rage. Researchers in search of a likely cooling mechanism recalled Ben Franklin's proposed explanation for the unusual chill of 1783-84. Franklin blamed a persistent "dry fog" that hung over Europe that winter—debris, he thought, from the huge eruption of the Icelandic volcano Lakagigar.

The particles that were worrying climate experts in the 1970s were coming from the "human volcano"—the smokestacks, tailpipes, tilled fields, and burning forests that mark civilization. Studies of air pollution had shown that while air at the cleanest, most remote points in the world such as the South Pole might have 10 to 100 aerosol particles per cubic centimeter, on a bad day in Los Angeles more than 10,000 particles could be found. And researchers knew that the most persistent haze particles—those a few tenths of a micrometer in diameter—were also the best at scattering light back into space.

But little more than that was known about the global distribution or the optical properties of these aerosols—the key elements in establishing them as a factor in climate change. In fact, researchers even began to doubt whether aerosols really would have a net cooling effect. Many specialists came to assume that aerosols from human activities, such as transportation and industry, were darkened by so much soot and grime that they absorbed at least as much sunlight as they reflected back to space, yielding no cooling—or even a warming. Then, in the midst of all those uncertainties, the global temperature started to rise again, and greenhouse warming displaced aerosol cooling as the topic of the day. "There does seem to be a correlation [of scientists' concerns] with which way the global temperature is going," notes climate expert James Hansen of NASA's Goddard Institute for Space Studies.

But even though the temperature has continued to rise, global cooling by aerosols is back in vogue, at least as an adjunct to greenhouse warming. It might have made a comeback sooner if communication among atmospheric scientists had been better, says Charlson. "All the pieces have been available to us for at least a decade," he says. "What was missing was an integrated approach." By the early 1980s, for example, researchers studying eastern North America had concluded that aerosols there were dominated by bright sulfuric acid droplets, formed from sulfur emissions from industry. The researchers went on to calculate that aerosols over the Eastern Seaboard were cutting out a whopping 7% of sunlight. But such regional findings were slow to affect the thinking of researchers who were studying global effects. "I'm just as guilty as anybody for not making the connection," says Charlson.



ROBERT CHARLSON

Global warming's ins and outs. *The balance of incoming and outgoing radiation is altered by sulfur that increases planetary reflectivity through hazes and brighter clouds.*

Quick to get over his guilt, Charlson joined with Swedish colleagues to make the best estimate yet of how sulfur pollution is affecting global temperature. They started with a computer model that simulates the fate of sulfur emitted as sulfur dioxide: its oxidation to sulfuric acid droplets, their distribution by the winds, and their eventual removal through precipitation and settling. Given the resulting density and distribution of the sulfate aerosols, the group calculated how much of the sun's 340 watts of radiation per square meter is being reflected back to outer space.

The model's answer, published last year in the Swedish journal *Tellus*, was 0.6 watt per square meter, with a factor of 2 uncertainty. That cooling effect may sound piddling, but it approaches the radiative energy trapped by all the carbon dioxide added to the atmosphere since pre-industrial times and half that trapped by all added greenhouse gases combined. According to this calculation, in other words, shading by the sulfate haze could be counteracting almost half of the global temperature increase that might otherwise have resulted.

And that's just part of the haze's impact on climate. An additional, indirect effect of aerosols became obvious during the 1980s from theoretical calculations and field studies. Aerosols from a source as small as a ship's smokestack can thicken and brighten the clouds overhead. The sulfate particles serve as centers for condensation of water, increasing the number of droplets in a cloud and thus increasing the surface area capable of scattering sunlight back to space.

Calculating the indirect cooling effect of pollution-brightened clouds is an even more uncertain business than estimating the direct effects of aerosols, so Charlson and colleagues did not include it in their model. But he and a half-dozen colleagues in a variety of fields attempted an estimate of its global impact in a recent paper in *Science* (24 January, p. 423). They concluded that aerosols' indirect effect through clouds could be roughly comparable to their direct effect. All told, then, the cooling due to manmade aerosols could conceivably equal—and thus largely cancel—the global warming by greenhouse gases, according to the calculations by Charlson and company.

Those theoretical calculations were enough to convince the UN's IPCC that sulfur emissions may have offset at least part of the greenhouse warming in recent decades. And though direct evidence is scarce, the greenhouse models may offer some corroboration: A countervailing cooling would help explain why the globe has so far warmed only half as much as the models—which don't take aerosols into account—have predicted. Then again, the models might simply be more sensitive than the real world to greenhouse gases.

The distribution of temperature change in recent decades also hints at a role for aerosols. Climatologist Tom Wigley of the University of East Anglia has compared the temperature trend in the hazy, industrial Northern Hemisphere with that in the relatively clean Southern Hemisphere. "If you're a believer," he says, you can see the Northern Hemisphere warming more slowly than models predict. But the differences, he points out, may simply reflect natural climate variation. And then there's the peculiar pattern of the Northern Hemisphere warming. Other workers have found that average nighttime temperatures have increased more than daytime temperatures, which is consistent with the theory that aerosols are moderating the warming trend by reflecting sunlight (see box).

Even if aerosols are giving the world a breather from a growing greenhouse effect, the long-term prognosis hasn't brightened much. In the long run, aerosols should lose out to the greenhouse effect, in part because they are so short-lived. Atmospheric carbon dioxide takes decades to a century to respond to changed inputs, while aerosols adjust in a week or two, so that at constant emission levels, carbon dioxide tends to build up, while aerosol concentrations stay constant. And efforts already under way to ameliorate the environmental damage caused by aerosols by reducing sulfur emissions would unleash even more warming.

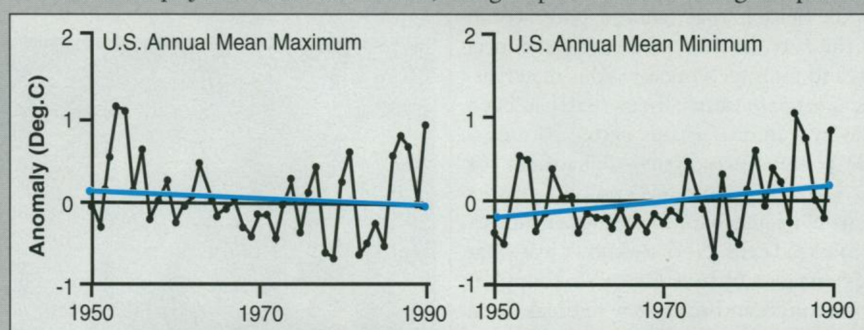
What's more, the sulfate hazes are geographically spotty. Even if they could provide long-term cooling, greenhouse warming would go on apace in the Southern Hemisphere. And in northern latitudes the aerosol sunshade would be riddled with holes, producing uneven heating that might alter weather patterns, with disastrous results. All in all, the human volcano seems unlikely to shake its deserved reputation as an environmental villain. ■ RICHARD A. KERR

Hot Nights in the Greenhouse

Something strange is going on in the night. Greenhouse warming, according to the climate models, should be reflected nearly equally in daytime and nighttime temperatures. But that's not what researchers, led by Thomas Karl of the National Climatic Data Center in Asheville, North Carolina, found in records from the past 40 years.

Curiously, much of the warming in the regions they studied has come during the night. Something not accounted for in the greenhouse models—perhaps daytime cooling because of pollution haze (see main text)—seems to be skewing climate change. But whatever the cause, predicting the effects of future climate change on living things will be far more difficult if the trend continues.

Karl and colleagues in the United States, the former Soviet Union, and the People's Republic of China found the odd imbalance by screening reports of minimum (mostly nighttime) and maximum (mostly daytime) temperatures from the three countries, which cover 25% of the globe's land area. As they reported in the December *Geophysical Research Letters,* the group found that during the past 40



SOURCE: KARL ET AL./GRL ILLUSTRATION: E. CARROLL

Nocturnal warming. *Minimum temperatures are rising. Blue shows the trend.*

years, average annual maximum temperatures in all three countries remained unchanged or rose only slightly. But minimum temperatures rose significantly.

Aerosol particles formed from the sulfur emitted by industry (see main story) might be part of the cause, says Karl. During the day they should reflect solar energy back into space, holding the greenhouse warming in check, but they have no effect at night when greenhouse gases continue to trap heat. But Karl doesn't think that's the whole story, at least in the United States. Sulfur emissions in the United States have decreased since 1970, he notes, but the daytime warming is still lagging behind the nighttime temperature increases. The continuing imbalance, he says, might reflect the observed increase in U.S. cloudiness over the same time, which in turn may have stemmed from natural variability or—by some feedback mechanism—from the warming climate itself.

Uncertainty about the cause of the nocturnal heating makes it hard to say whether it will continue. If it does, suggests climatologist Patrick Michaels of the University of Virginia, human society and the natural world will be getting a good deal. Compared to daytime warming, the trend would mean longer growing seasons but fewer droughts, less skin cancer (if cloudiness continues to increase), and a smaller sea level rise (because most polar ice melting occurs during the day).

Other researchers are not so sanguine. Karl notes that the heat wave that killed nearly 300 people in St. Louis in 1966 was so bad in part because it remained oppressively warm at night. And ecologist Herman Shugart of the University of Virginia worries that warmer nights might give an edge to insect pests while placing greater demands on plants' nocturnal energy consumption. Karl sums it up: Until a lot more research is done, "it's pretty hard to say whether this is a godsend or a curse." ■ R.A.K.