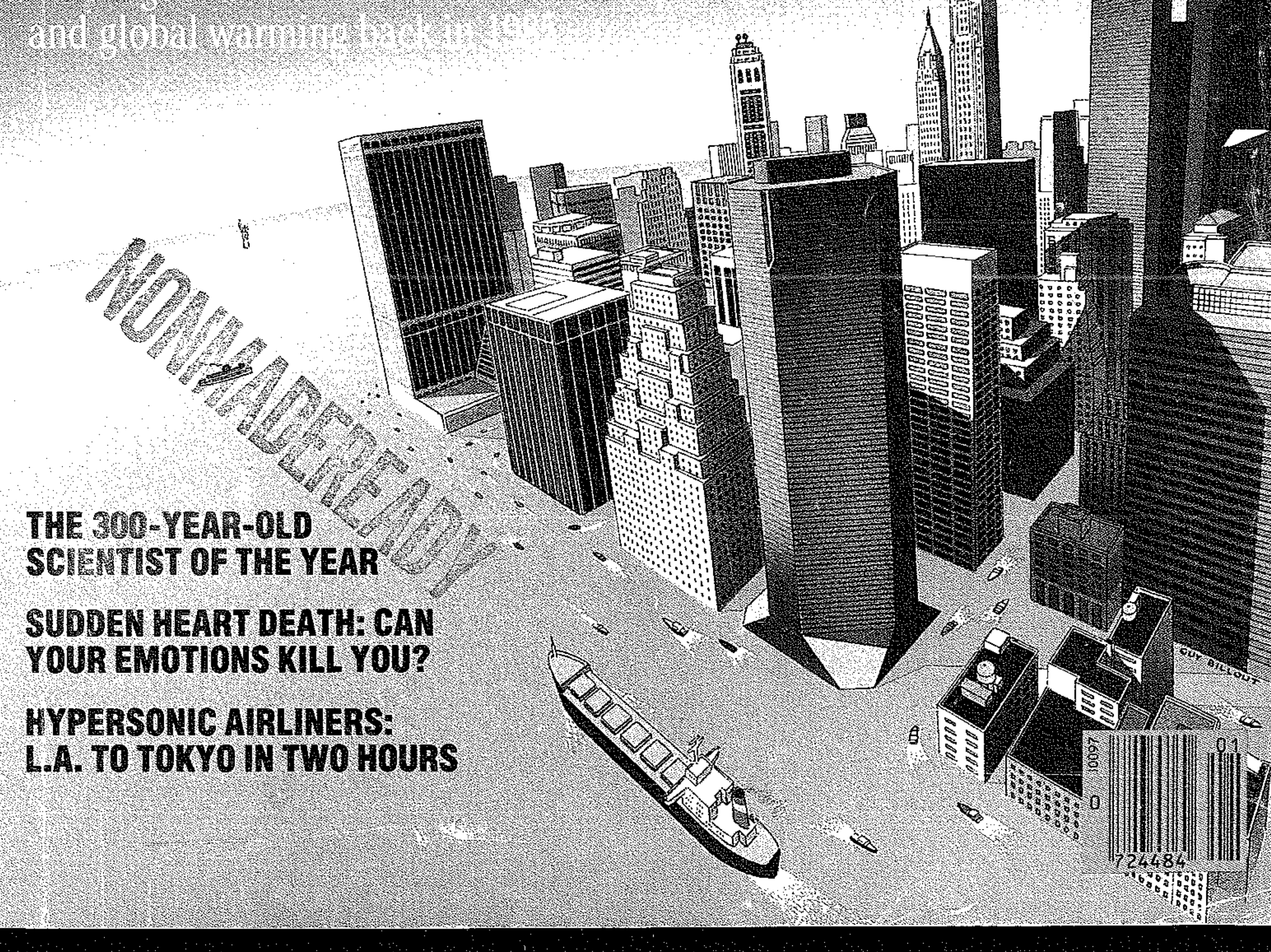
DISCOVER

SPECIAL REPORT

AMERICA IN 2035? New York and other coastal cities are permanently flooded. Grain won't grow in the nation's breadbasket, and everything west of the Rockies is a desert. If only politicians had heeded warnings about carbon dioxide build-up and global warming back in [illegible]



THE 300-YEAR-OLD SCIENTIST OF THE YEAR

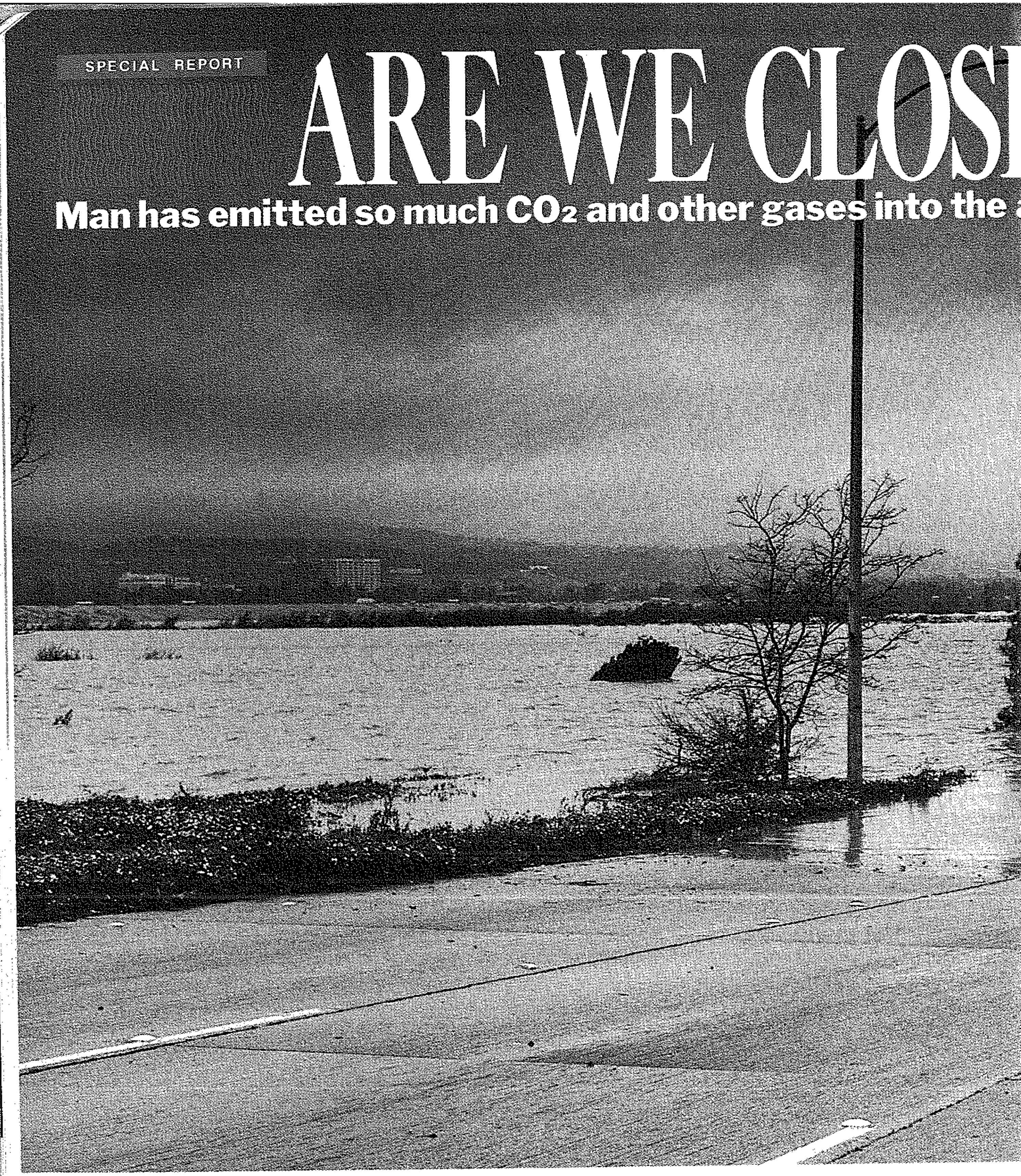
SUDDEN HEART DEATH: CAN YOUR EMOTIONS KILL YOU?

HYPERSONIC AIRLINERS: L.A. TO TOKYO IN TWO HOURS

SPECIAL REPORT

ARE WE CLOS

Man has emitted so much CO_2 and other gases into the



This is a fine mess you've gotten us into now, Stanley.
—Oliver Hardy

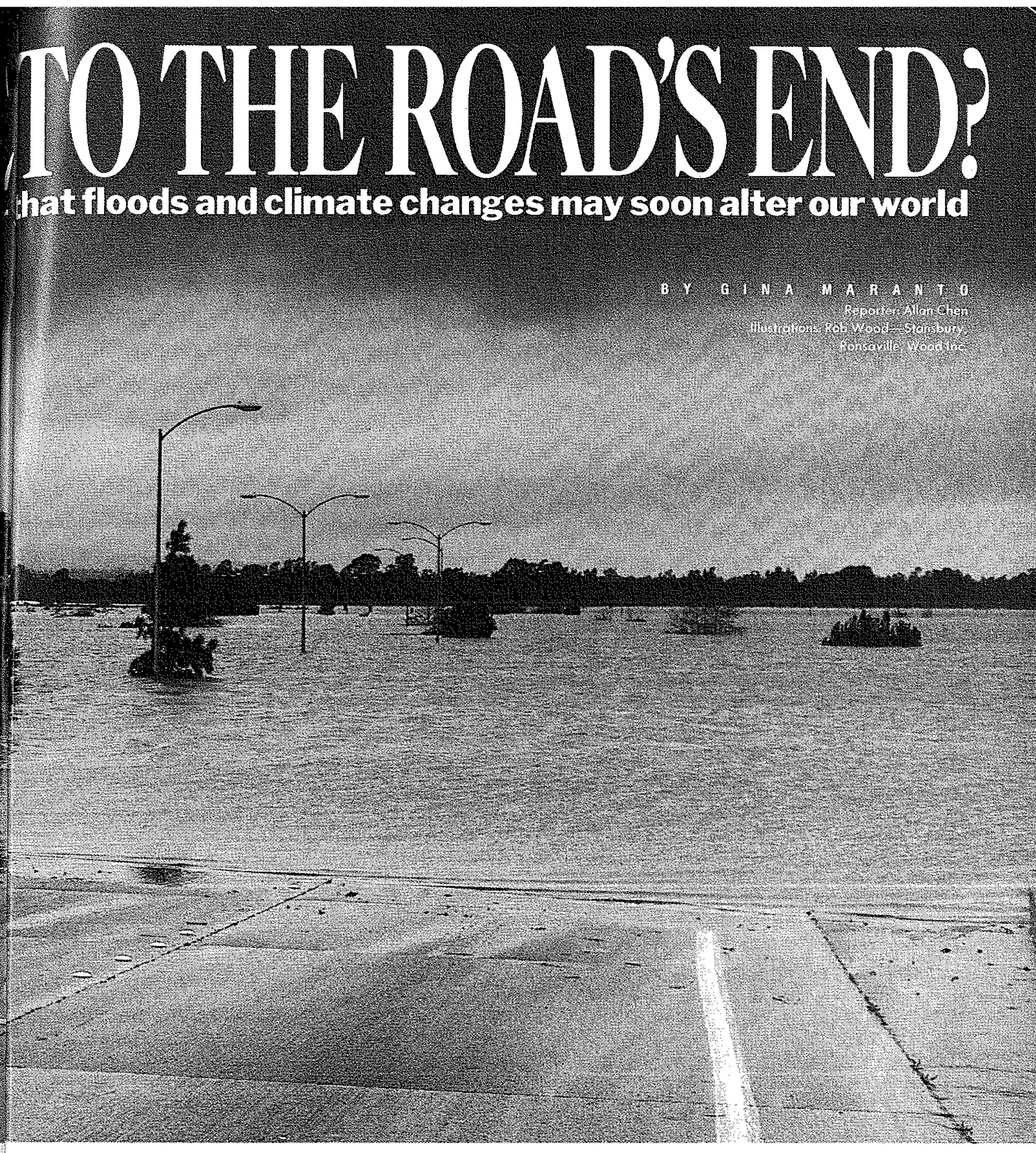
A perfect day in Boulder, Colo. It's too early in the year for the smog to drift over from Denver, and cumulo-nimbus clouds tower over the rust-red Flatirons, which are backlit by the late afternoon sun. From the wide grassland that slopes down from the National Center for Atmospheric Research (NCAR, commonly called en-car), magpies take off in flashes of black and white, while a single mule deer grazes. A perfect day, and I'm pondering the end of the world.

Actually, next to English garden design, the end of the world happens to be one of my favorite subjects. I spend a lot

TO THE ROAD'S END?

hat floods and climate changes may soon alter our world

BY GINA MARANTO
Reporter: Allan Chen
Illustrations: Rob Wood—Stansbury, Ronsaville, Wood Inc.



BILL ROSS—WEST LIGHT/WOODFIN CAMP

of time wondering whether it's going to come as T. S. Eliot said it would (not with a bang but a whimper) or on the wings of 10,000 megatons. Maybe I've read too much Edmund Burke. You know: "Whatever is in any sort terrible is a source of the sublime." And: "At certain distances and with certain modifications, [pain and danger] are delightful."

I'm not delighted, though. I've just spent two days talking to half a dozen scientists about a grand "experiment," the outcome of which is still pending. It began early in the nineteenth century without a lead agency or a principal investigator. Like a lot of human endeavors, it started under a shroud of ignorance, but now that it's really up and running, to use the technician's jargon, a whole bunch of scientists are keeping watch on it. It could usher in changes the likes of which haven't been experienced for 125,000 years.

The laboratory where this experiment is being carried out is the earth and its atmosphere. The experiment is simple in conception: load the atmosphere with as much carbon dioxide (CO_2) as you can, add a few other gases for good measure, and see what happens.

For nearly a century, scientists have been debating what will occur; it has only been in the past few years that they've devised this projection: if we continue to burn one to two per cent more fossil fuel a year and to cut down forests at the present rate, the carbon dioxide content of the atmosphere will double from its pre-industrial level of about 280 parts per million sometime between the years 2050 and 2100.

The consequences of such a doubling were discussed in 1896 by a Swedish chemist, Svante Arrhenius, who calculated that the "evaporation" of the world's coal reserves in the furnaces of industry might be releasing enough carbon dioxide to alter the composition of the thin blanket of gases that makes the earth habitable. The planet, he warned, could warm up as a result of a phenomenon that has come to be called the greenhouse effect. Scientists now know that other gases—chlorofluorocarbons used in refrigeration and spray cans, for example, and methane produced by rice paddies and flatulent cattle (yes, that's right)—act like carbon dioxide, trapping heat radiated from the earth's surface and re-radiating it downward.

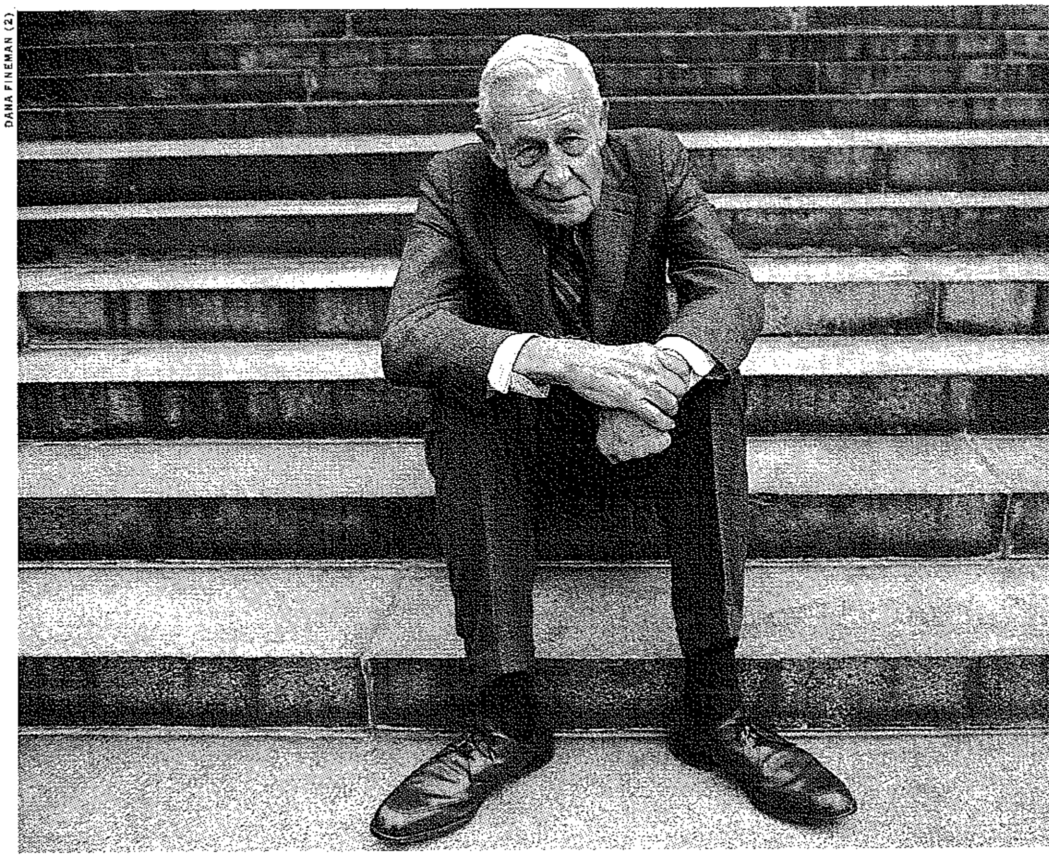
What will the consequence of this warming be? Maybe nothing of note. Or maybe there's an overriding and little appreciated force at work here, and the world will slip into another ice age, as a few researchers claim it's doing. However, the cooling trend that took place from the 1940s to '70s has stopped. Not only that, what seems almost certain to happen, given what scientists have divined about the complicated way the planet's life-support systems work, is that the annual worldwide mean surface temperature will increase by anywhere from 3° to 10° F. by the end of the next century.

As a consequence, climate—which is determined by heat from the sun and by chemical and physical interactions among the atmosphere, the oceans, the land masses, and the polar ice sheets—will probably change, maybe significantly. In the past, naturally occurring climate swings have brought down societies—the Anasazi Indians of the American Southwest, for instance, from decreased rainfall—and perhaps even led to mass extinctions of flora and fauna. Now modern societies and modern agriculture must prepare to deal with a similar, albeit man-made, swing.

This preparation is necessary because it seems clear that the CO_2 build-up can't be stopped or even slowed. In 1983 the avowedly conservative Carbon Dioxide Assessment Committee of the National Academy of Sciences prefaced a report this way: "There is a broad class of problems that have no 'solution' in the sense of an agreed course of action that would be expected to make the problem go away. Increasing atmospheric CO_2 and its climatic consequences constitute such a problem."

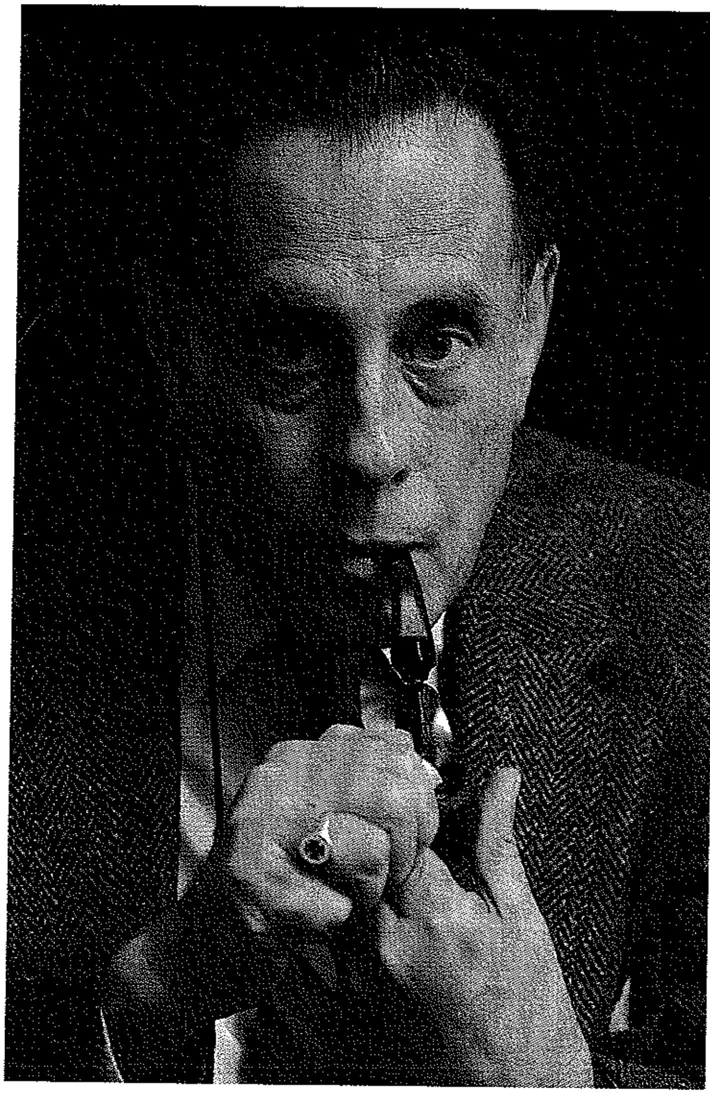
As far as public policy goes, that leaves two choices. Governments can begin now to take steps that might make them able to adapt speedily and with a minimum of fuss if the anticipated warming takes place. Or they can take an easier and cheaper path: they can do nothing. They can wait and see what turns up. Except that by then it may be too late.

When it comes to details—what global warming will mean to the people of Pittsburgh or Bangkok or Sydney—climatologists, geographers, and resource economists have little to offer. Climatologists only recently began to feel confident about the reliability of their global computer models; creating scenarios of how climate might change on a regional scale is still slightly beyond them. And money is rarely

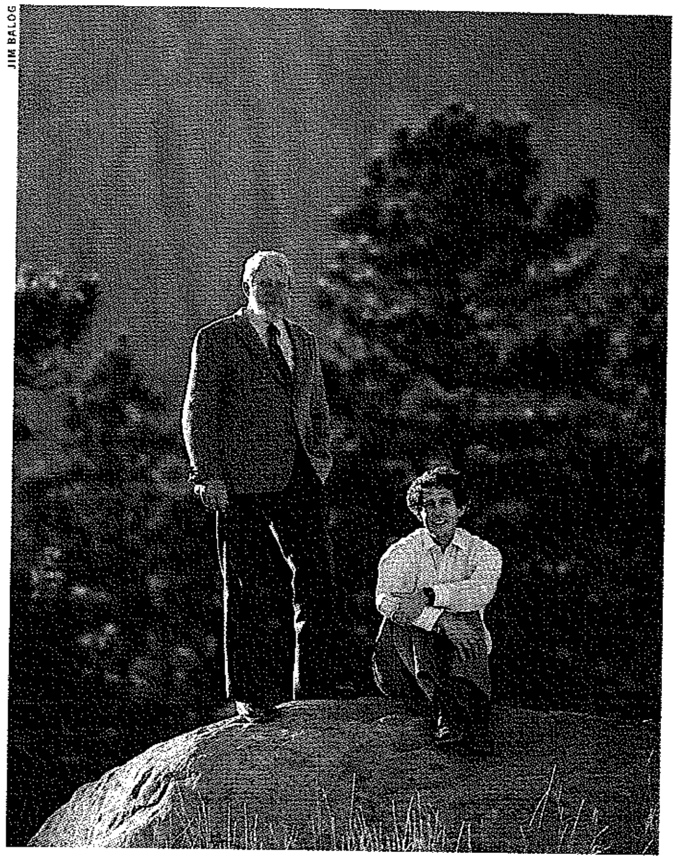


DANA FINEMAN (2)

Revelle calls the burning of fossil fuels man's "great geophysical experiment."



JIM BALOG



At NCAR, Kellogg *(left)* looked back to find more CO_2 made temperate climes drier; Schneider looked ahead to dire days for coastal cities.

Koomanoff thinks those who link global warming to CO_2 build-up are blowing smoke.

made available for assessments of the agricultural, economic, and social impacts of climate change, studies that might provide general guidelines for policy makers.

But quite a few researchers have made preliminary calculations and modeling runs, and will hazard some guesses—though they nearly always issue one caveat: living in a high-carbon-dioxide world need not be all bad. The northernmost reaches of the earth's land masses, including parts of Canada, Alaska, Iceland, Scandinavia, the Soviet Union, and Japan, may benefit from warming. For example, an increase in Iceland's grazing land could result in a doubling of its sheep production. That said, the researchers will tell you about the less encouraging aspects of their investigations.

The one most widely bruited by the press is that the sea level will rise from the melting of the polar ice caps. Figures thrown around have ranged from one to 25 feet; the differences that these two numbers represent are unresolvable, given the present state of knowledge. A middling rise would put virtually all the world's ports under water, as well as vast tracts of farmland in the Netherlands, Bangladesh, Thailand, Kampuchea, Vietnam, and China.

Steve Schneider and Robert Chen, climatologists at NCAR, redrew the coastline of the U.S. based on a rise of 15 to 25 feet, which they concede is probably centuries away. But they wanted to examine the economic effects of environmental changes. They found that half of Florida and Louisiana would be covered by the sea, as would more than one tenth of Virginia, Delaware, and New York. Across the country, nearly 16 million people would be displaced. Cities like Charleston and Galveston would be completely flooded; Miami, Baltimore, New York, Boston, San Francisco, and many others would lose major chunks of real estate. And congressmen would arrive by boat at Capitol Hill, which would be waterfront on the swollen Potomac. Of course, they could always move the capital to Omaha or Albuquerque.

But glaciologists, on the whole a rather persnickety bunch, argue that such forecasts, though not impossible, are far-fetched. At a polar workshop sponsored by the National Research Council (NRC) in Seattle in late 1984, scientists gathered to determine what a warmer world might do to glaciers, ice sheets, and sea level. They concluded that before they could attack larger questions like what the total sea-level rise will be, they needed to find out more about, in no particular order, the currents, temperature, and salinity of the water around the huge Antarctic ice sheet; about the floating sea ice in the polar regions; about clouds; about the shrinking of glaciers in mountain ranges in Central Asia, Patagonia, and Alaska.

A major fear has been that the West Antarctic ice sheet might collapse. This sheet, consisting of about two million cubic kilometers of ice, rests on underwater bedrock, and the ice flow is impeded by two partly floating ice shelves. If warmer ocean water, heated by air above the pole, begins to melt the shelves, the ice sheet could begin to melt as well. As it thinned it would begin to float, and ice from behind might push it into the sea. Adding this volume of ice to the ocean would cause its level to jump 16 to 19 feet.

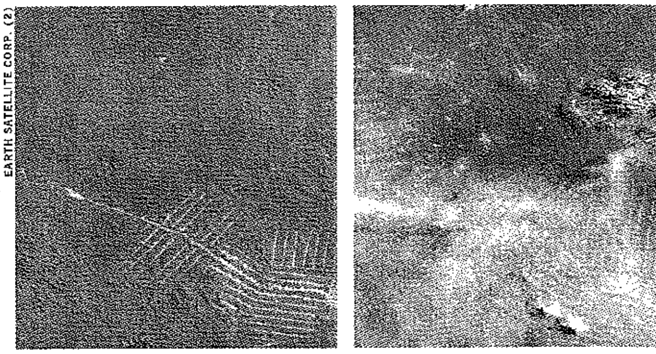
The NRC committee held this to be a highly unlikely event. It also played down warming's impact on glaciers. They would probably waste so slowly that the runoff would be inappreciable, and although floating ice would melt in warmer oceans, the water level wouldn't rise. (The analogy glaciologists like to use is of ice cubes in a drink; when they melt, the glass doesn't brim over.) In all, the committee concluded, the sea level rise by the year 2100 would probably be about 18 inches.

Roger Revelle, not a glaciologist but an oceanographer, who helped put CO_2 warming on the map, has surveyed the literature. He sets the figure at two feet over the next century, with one foot the result of glacial runoff, the other of a thermal expansion (when sea water warms it takes up more space). Still, a couple of feet isn't going to do wonders for your Padre Island or Daytona Beach. And even a minor rise could considerably boost the potency of coastal storms. With tides lapping closer to coastal condos and the like, the kind of damage that now occurs from surges only once every hundred years might be expected once every 50 to 25 years.

Then there are consequences that don't immediately come to mind—for instance, changes in the circulation patterns of the oceans, which are vital to life both in and beside the water. The Gulf Stream and other currents could weaken. Bill Jenkins, an oceanographer at Woods Hole (Mass.) Oceanographic Institution, explains why this might come to pass: circulation is driven by the thermal contrast between the poles and the Equator, with the ocean functioning as a pump that redistributes solar heat. "If the earth warms," says Jenkins, "the poles get hotter, reducing the thermal contrast and reducing the strength of the pump." Circulation would become less vigorous. At least one researcher has speculated that some places would become colder. Great Britain, for example, owes its temperate clime to the Gulf Stream. If the stream slowed, winters there could get chillier,

> A small change in the mean temperature may generate a large one in the frequency of extreme events like drought, freezes, floods, and hurricanes

EARTH SATELLITE CORP. (2)



Forests *(rust)* consume CO_2, but as satellite photographs of Brazi[l] in 1976 and '81 show, vast tracts are being clear-cut *(blue)*.

like those of places at similar latitudes, say the Aleutians.

Other regions might experience more hot days—and the hottest days would be hotter than they are now. Climatologist Jim Hansen of NASA's Goddard Institute for Space Studies in New York and his student Paul Ashcroft have calculated what the impact might be for two U.S. cities. Whereas the temperature in Washington, D.C. now exceeds 100° one day a year on the average, it would do so twelve days a year when CO_2 doubled. Eighty-seven days would have temperatures of more than 90°, as opposed to 36 days now. In Omaha, temperatures would soar above 100° about three weeks a year instead of three days, and above 90° on 86 days instead of on 37.

Richard Warrick, an atmospheric scientist at the Climatic Research Unit at the University of East Anglia in Norwich, England, points out that a small change in the mean temperature may generate a large one in the frequency of such extreme events as droughts, freezes, floods, and hurricanes. With high CO_2 the probability of having a sequence of back-to-back years of severe heat waves in the Great Plains might be higher. The number of hurricanes forming in the Caribbean might increase—or even decrease. Some researchers suggest that the shift of oce-

anic currents, along with th[e] increased temperature in th[e] lower atmosphere, could dis[-] rupt rainfall patterns and pos[-] sibly alter the cycles of majo[r] events like annual monsoons i[n] southern Asia.

Rejiggered rainfall pattern[s] represent the most worrisom[e] aspect of climate change. A de[-] crease in yearly rainfall o[n] the world's prime agricultura[l] belts, compounded by othe[r] losses of water from river[s,] plants, and soil (under highe[r] temperatures, evapotranspira[-] tion is hastened), could sub[-] stantially reduce the produc[-] tivity of some of the most fer[-] tile acres on earth.

At Princeton's Geophysica[l] Fluid Dynamics Laborator[y] Syukuro Manabe, an atmo[-] spheric scientist, has been us[-] ing a Cyber 205 supercom[-] puter to create models of fu[-] ture climates. From a thick fil[e] he pulls out computer-genera[t-] ed temperature and soil mois[-] ture maps of a world with dou[-] ble the present concentratio[n] of CO_2. Then he pulls out map[s] of the U.S. during the 1930[s.] When the two are placed sid[e] by side, it's obvious even to th[e] untrained eye that the pattern[s] resemble one another. "What [I] am saying is that the kind [of] drought we get from our mode[l] calculations may be similar t[o] the drought of the Dust Bow[l] period," he says.

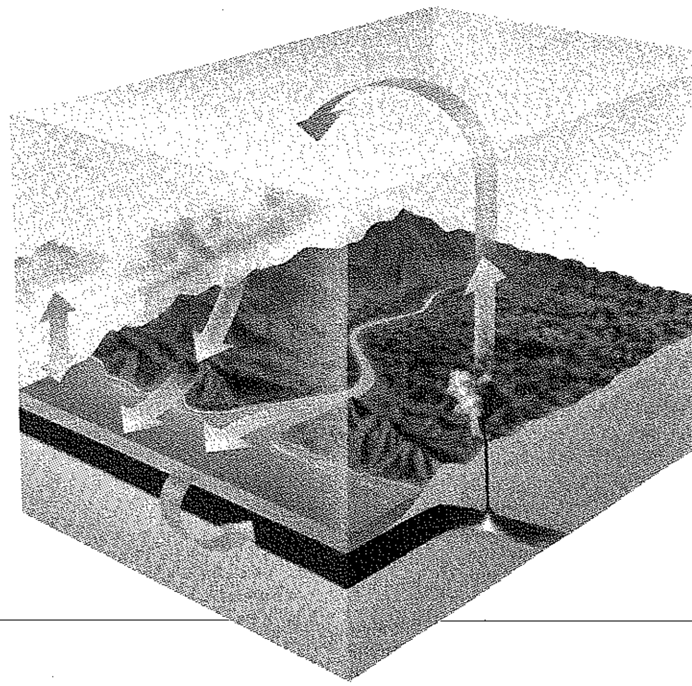
When Manabe first go[t] these results, the research com[-] munity was skeptical. But the computers of other researchers are beginning to kick out similar figures. In a high CO_2 world, it seems, soil moisture in the mid-continental U.S. and Europe might be reduced substantially.

Studies of warmer periods in the earth's history (even those not attributable to CO_2) lend credence to this conclusion. A reconstruction by NCAR's William Kellogg indicates that during the Altithermal period, 5,000 to 9,000 years ago, the highlands of Mexico, the Saudi Arabian peninsula, the northwestern part of the Indian subcontinent, western Australia, and most of north and east Africa were wetter, whereas the central plains of North America were drier. Hermann Flohn, a climatologist at the University of Bonn, conducted a similar survey of warmer climates in the Northern Hemisphere as far back as the Late Tertiary, twelve million years ago. From his study one can infer that in a climate 7° F. warmer, northern forests would advance almost to the northernmost points of the lands encircling the pole, the world's major deserts would become less arid because of greater rainfall, and temperate areas in the middle latitudes would become drier.

In the U.S. the loss of water could be worsened by a northward shift of the rain belts. Revelle and Paul Waggoner, director of the Connecticut Agricultural Experiment Station, have calculated what increased loss of moisture from soils and plants brought on by higher temperatures, coupled with a relatively small drop in precipitation, would do to water supplies in the West. A 3.5° rise in temperature and a ten per cent decrease in precipitation could cut the flow of the Colorado River by 40 per cent and leave

THE ROCK CYCLE KEEPS ON ROLLING

In a natural process millions of years long, volcanoes and hot springs spew CO_2 into the air. Some rains back to earth and becomes a component of rocks. These are eroded by rivers, which carry the carbon to the sea, where it sinks. The plates on the ocean floor transport the carbon to the hot mantle at the edge of continents. There it can again be borne upward by volcanoes.



THE ANSWER MAY LIE IN THE ICE

There are places in Greenland where the ice is more than a mile thick. For four years in the 1960s the U.S. Army maintained a research station called Camp Century atop the ice pack, and during that time a team of engineers and ice specialists cut a core out of it four inches in diameter. It gave them, in the form of ice rods, each five feet long, a slender column of time extending back more than 100,000 years.

It took a decade and then some to decipher the story locked into the Greenland ice. That occurred at the University of Bern, where physicist Hans Oeschger melted tiny samples of the Camp Century ice and collected the gases trapped in air bubbles. In the section formed during the last ice age, 20,000 years ago, the carbon dioxide content of the atmosphere measured between 180 and 200 parts per million. In samples taken after the ice age, the CO_2 level was between 260 and 300 parts per million.

Oeschger's team and a group in France repeated the measurements on cores from Antarctica and the great continental glaciers. Each time they found the same thing: during ice ages, the earth's atmosphere contains less carbon dioxide than it does in warmer times.

Scientists had long known that CO_2 in the atmosphere trapped heat—the greenhouse effect—and that since man began burning coal and oil in large quantities, the amount of CO_2 in the atmosphere had been rising. But most had assumed that before the Industrial Revolution the CO_2 level was fairly constant. Oeschger's finding destroyed that assumption.

His discovery also posed this question directly: Were fluctuations in th amount of carbon dioxide in the atmosphere responsible for the beginnir and end of ice ages? And this one indirectly: Does the flow of CO_2 in anc out of the atmosphere mold the long, slow warmings and coolings that dominate the earth's climate over periods of tens of millions of years?

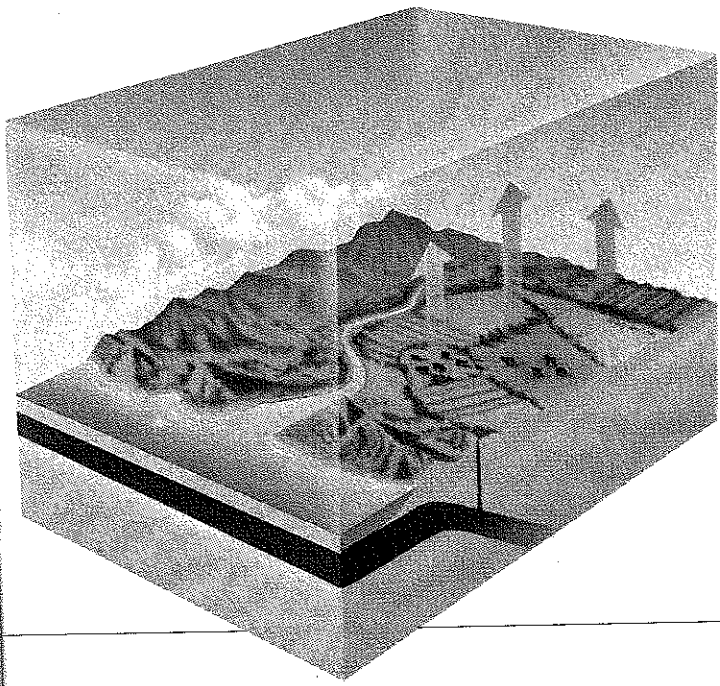
To confront these questions, one must understand the non-biological processes that control the amount of carbon dioxide in the atmosphere. How much CO_2 is in the air—and hence how warm or cold the earth gets- depends on how much CO_2 the earth releases into the atmosphere in a geological process called the rock cycle.

The earth stores carbon in rock. Below the surface it heats carbonate and other carbon-bearing rocks continuously. As the rocks warm, they de-gas, i.e., give off some of their carbon as carbon dioxide. Volcanic eruptions release some gas to the surface and thence into the air, and, ir what one scientist calls the Perrier effect, CO_2 also bubbles up through carbonated springs. Some of the carbon then returns to the earth dissolved in rain.

Now the other half of the rock cycle begins. As continental rocks weather, they bind with carbon dioxide from the atmosphere to release carbon-bearing ions that are eventually carried off in river water. The rivers flow to the sea, and the ions they bear react with calcium in sea wate to form calcium carbonate, largely in the form of skeletal remains of ma-

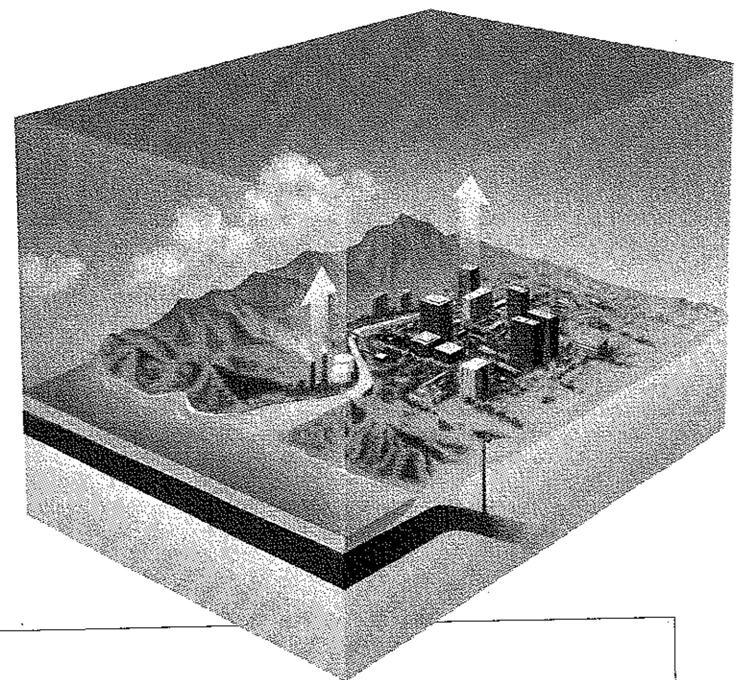
HOW PRE-INDUSTRIAL MAN CHANGED THE FLOW OF CO_2

The cutting of a mature forest puts carbon dioxide into the atmosphere. Felled trees release carbon—slowly if left to decompose, rapidly if burned—as do conventionally plowed fields. The fewer the trees to re-absorb CO_2 by photosynthesis, the greater the amount in the air. Livestock give off CO_2 as they breathe, and methane when they're flatulent.



A LEGACY OF THE INDUSTRIAL REVOLUTION

The concentration of population in cities and the wide use of fossil fuels in manufacturing and transportation has disrupted the carbon cycle and, it seems probable, raised global temperatures. In a century or so, man has burned a large part of the earth's carbon reserves; in 1984 alone, combustion of coal, oil, and natural gas released five billion tons of carbon into the air.



rine organisms that consumed the ions. The new compounds settle slowly to the bottom of the oceans, and there, over time, the sediment forms into rock. Finally, the movement of the earth's crust carries the new rock deep enough into the earth to begin the cycle anew.

The process is extraordinarily slow—a single carbon atom could take as many as 200 million years to complete the cycle—but its effects are dramatic. Says Yale geochemist Robert Berner, "The rock cycle provides the long-term background upon which all the shorter-term climatic fluctuations are superimposed."

To test that assertion, Berner, with geochemists Antonio Lasaga of Yale and Robert Garrels of the University of South Florida, developed a model to describe the changes in the amount of carbon dioxide over the past 100 million years. The Cretaceous period, which ended 65 million years ago (the last time dinosaurs thrived) was virtually ice free—which, according to other researchers, means it has to have been at least 9° F. warmer than today. To produce a greenhouse effect intense enough to warm the earth that much, the atmosphere would have had to contain five times as much CO_2 as it does today. That, says Berner, doesn't prove that carbon dioxide was more plentiful 100 million years ago, but it does provide circumstantial evidence that CO_2 caused a prehistoric greenhouse effect.

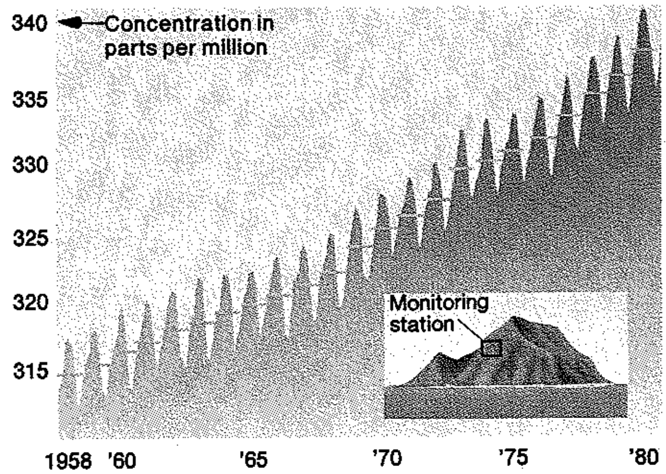
But while this and other research indicated that carbon dioxide can cause large shifts in climate, it didn't come to grips with another phenomenon apparent in the ice cores: at the end of the last ice age CO_2 levels changed blindingly quickly by geological standards—in a few thousand years. This compelled climate modelers to ask if the CO_2 changes triggered the beginning and end of ice ages, and if they did, what natural process could account for the rapid fluctuations in atmospheric CO_2?

The largest expansions and contractions in ice sheets have followed a 100,000-year cycle, but quicker fluctuations also seem to have taken place. Before the ice core bubbles confused the picture, geologists had devised an explanation for some of the more rapid shifts. As the earth moves around the sun it's tilted slightly, and spins around its axis like a top. That spin has a couple of wobbles in it, and the angle of the axis changes in a pattern that requires 41,000 years to complete. As the world wobbles and dips, the amount of energy each hemisphere receives from the sun changes, one gaining and the other losing warmth. In the 1920s and '30s, a Serbian mathematician, Milutin Milankovitch, calculated how big the increases and decreases in warmth would be, and concluded that the wobbles and tilts could cool a hemisphere enough to cause the ice to expand. In 1976 a study of ocean floor sediment demonstrated the validity of his computations.

That seemed to be that—the connection between sunlight and ice was clear, and it made sense. Then ice core bubbles burst onto the ➻

PROOF OF THE CARBON DIOXIDE BUILD-UP

Since Charles Keeling of Scripps Institution first sampled CO_2 on Mauna Loa, the mean concentration has risen from 315 parts per million to 338. (The seasonal fluctuation is caused by plants, which absorb more CO_2 in summer.)



most western states without enough water. Supplies in the Rio Grande basin, the hardest hit, would fall 75 per cent.

American farmers are fairly flexible, says Waggoner. They readily till new land and cultivate different crops in response to changing market prices and natural pressures such as plant diseases. So a drier climate on the southern periphery of the Grain Belt wouldn't cripple American agriculture. The growing season in northern states would be lengthened in a high-CO_2 world, and, given adequate soils, those areas could pick up the slack. In countries where there's nowhere to move to, however, or where agriculture subsists on dry, marginal land, changing conditions could—and do—lead to many years of hardship, or worse.

The key to a society's survival would be its ability to make adjustments to minimize disruptions. In the U.S. no coherent plan—say, building dikes to protect low-lying areas—has yet been discussed at the federal level. Representative George Brown (D-Calif.), one of the first legislators to recognize the seriousness of CO_2 build-up, suggests that it may be prudent for the government to plan for climate change the way it planned in the past for civil defense—but better. "There's no good answer to when you should start taking some action on warming," he says. "In ten to fifteen years scientists should be able to say with reasonable confidence that, for every *x* per cent increase in CO_2, you'll get *x* per cent temperature rise. Can we save New York or Charleston then? I say no, the process is irreversible. We have to begin preparing either to protect or to move these cities."

When geophysicists in Calgary, Canada were told at a conference not too long ago that the world might grow several degrees warmer, they broke into wild applause—because all they could think of was frigid winters on the Canadian plains. As long as you view such climate changes as hypothetical or merely local, they don't sound so awful.

But changes in climate can be disastrous for economies on the margin. In *A Distant Mirror*, Barbara Tuchman wrote: "In 1315, after rains so incessant that they were compared

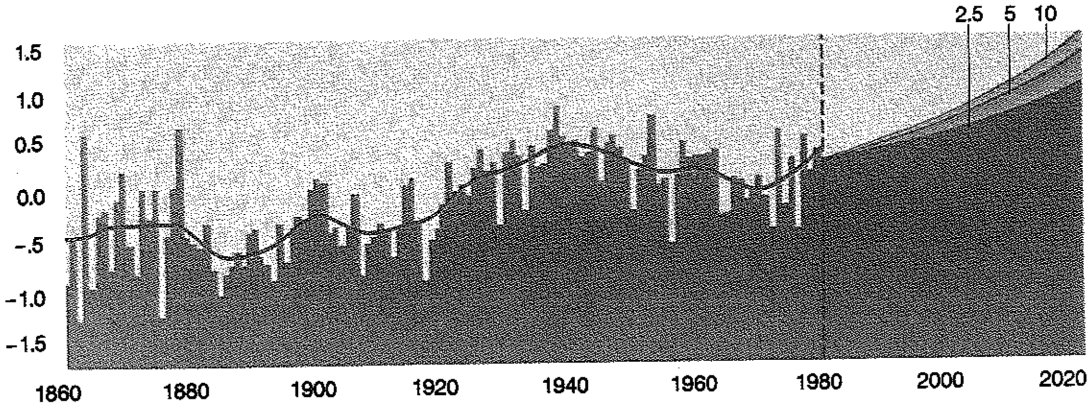
scientific stage. The first bubble research showed only that something strange had happened at the end of the last ice age—the data covered just the past 40,000 years, far less than the 100,000-year ice age cycle. This led Cambridge University's Nicholas Shackleton and Oregon State oceanographer Niklas Pisias to prospect through sediments on the ocean floor in search of traces of great climate changes over the past 340,000 years. They discovered that alterations in carbon dioxide levels occurred a few thousand years before ice ages began and ended. Most important, says Pisias, "the sedimentary evidence for atmospheric CO_2 shows big changes at the end of each of the past two hundred-thousand-year intervals—and then the record rapidly gets back to normal."

The issue isn't settled—sediment cores contain only indirect evidence about atmospheric carbon dioxide—but there's enough evidence, Pisias says, to conclude that carbon dioxide acts as a transmitter or an amplifier of the coolings and warmings that result from the earth's wobbling. But while "we can say that CO_2 forces climate change," Pisias asks, "what causes the change in CO_2?"

Wallace Broecker, a geochemist at Columbia University's Lamont Doherty Geological Observatory, confronted that question. He focused on the fact that, compared to rock cycle events, ice ages are quick climate shifts. The rock cycle is a geological phenomenon. It depends on heating, cooling, and weathering—all processes that would go on continuously whether or not the planet was inhabited. Fast changes implied only one thing to Broecker: living things had to be playing a role, because only life can grow or die swiftly enough to change conditions on earth dramatica in a few thousand years.

Broecker first tried to find out how living things in the ocean could increase the amount of carbon dioxide in the air to produce a natural gree house effect. Some CO_2 enters the sea from the atmosphere simply by dissolving in the surface waters. Plants growing in the ocean consume carbon, creating more "room" for carbon dioxide to dissolve into the se An increased number of plants in the ocean, Broecker reasoned, would consume more carbon, which would mean that more CO_2 would be able to move from the atmosphere to the ocean, which would mean that less carbon dioxide would remain in the air, which would mean that the worlc would cool and ice sheets would get bigger. Decrease the number of plants, and the process would be reversed.

To explain the rapid end of ice ages, Broecker hypothesized that life earth could amplify an orbital effect that had already begun to melt the glaciers. If some ice melted, sea levels would rise. When sea levels g up, parts of the continental shelf get covered, and some nutrients, especially phosphorus, could get trapped in the sediments that would come rest there. Then, Broecker theorized, the plants at the ocean's surface would behave like any underfertilized crop: they would be fewer in numb and would grow more slowly, and thus consume less carbon. In turn, the ocean would absorb less CO_2 from the atmosphere—and the warming a ready under way would intensify as the build-up of atmospheric CO_2 trapped more and more heat from the sun.



IT SEEMS WE'RE HEADED FOR SOME HOT TIMES

Researchers plotted temperatures over Northern Hemisphere land masses from 1860 to 1980, and found the average (as it varied from a mean) rose by 1° F. If CO_2 caused it, the pace should quicken, with the increase being as high as 10° by 2020.

to the Biblical flood, crops failed all over Europe, and famine, the dark horseman of the Apocalypse, became familiar to all. The previous rise in population had already exceeded agricultural production, leaving people undernourished and more vulnerable to hunger and disease. Reports spread of people eating their own children, of the poor in Poland feeding on hanged bodies . . ."

What will the headlines be in 2035? GREAT PLAINS DROUGHT IN EIGHTH YEAR; GLOBAL FOOD CRISIS DEEPENS . . . WORLD HEALTH ORGANIZATION STUDY SHOWS TROPICAL DISEASES SPREADING IN SOUTHERN U.S . . . EGYPT, LIBYA AT WAR OVER PRIME GRAZING LAND . . . ?

Thirteen million Bangladeshis live on ground that's less than ten feet above sea level. When the flooding starts, do you suppose they'll simply pack up in an orderly fashion and be politely allowed to file into India and Burma?

Roger Mudd, the NBC newsman, is driving NCAR secretaries crazy. It's June, and Mudd and his crew have commandeered a room in NCAR's headquarters and begun summoning scientists. One reason for this media attention is a paper published in the *Journal of Geophysical Research*, which concludes that trace gases being released into the atmosphere could amplify the greenhouse effect. Three of the four authors, all atmospheric specialists, are in Boulder: Veerabhadran Ramanathan, Ralph Cicerone, and Jeff Kiehl. The fourth, Hanwant Singh, is at SRI International in Menlo Park, Calif.

Ask Ram (everyone calls Ramanathan that) how mere molecules of gases can warm up the earth, and he replies, "Ah, that's a question of physics," jumps from his chair, and begins vibrating to show how a molecule would act. Ask him about the implications of the trace-gases paper, and eventually—after he lists a bunch

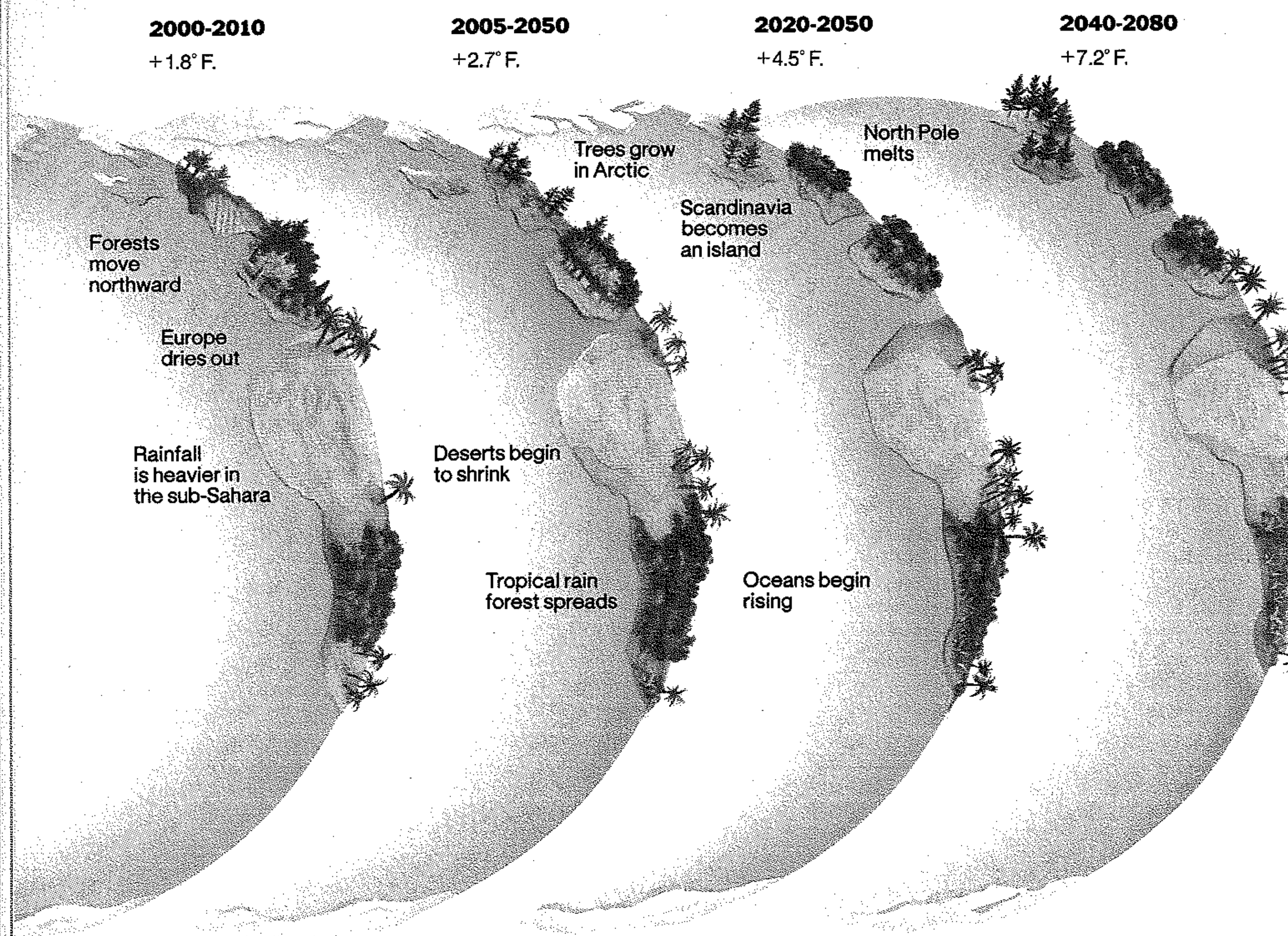
The most recent evidence indicates that Broecker's idea can explain a portion of the difference in CO_2 levels during an ice age and those during a warm period. Still missing is a mechanism that could account for the rest of the change, as well as explain the reverse greenhouse effect—the cooling that comes with a drop in CO_2 levels—that could bring about an ice age. To that end, Harvard atmospheric scientist Michael McElroy has taken Broecker's central theme—that it's life that makes the difference—and come up with a theory to explain both the onset of ice ages and the existence of the 100,000-year ice age cycle.

McElroy argues that the plants in certain parts of the ocean would thrive whenever changes in the earth's orbit increased the amount of sunlight they received. When they grew well, they would use more CO_2, drawing it out of the atmosphere. That would cool the earth every time the rhythm of its orbit created the ideal conditions for this kind of plant growth. As an extra twist, McElroy thinks that eventually the plants would overpopulate their range and deplete the ocean of the oxygen they need to survive. Thus, every hundred thousand years or so, the plants would suddenly die off, and with the plants dead, the ocean would stop sucking CO_2 out of the atmosphere. It would build up in the air, and the earth would warm quickly. McElroy's hypothesis includes the idea that circulation patterns that move nutrients around the oceans changed during ice ages.

Broecker's team and two other groups came up with similar ideas. All these theories have one big flaw: the sediments don't show the changes in the oceans' nutrient content that each of the models says should be there. Part of the difficulty is that the sediment samples cover 500,000 years and information about CO_2 levels only 100,000 years. Comparisons may soon make much more sense: a group of French scientists is now analyzing the oldest ice core yet found. "The Russians are drilling a core at Vostok station in Antarctica that goes back five hundred thousand years," Broecker says. "They just stack the ice like logs, and the French go get it. The ultimate evidence we need will come out of that core."

Even before those answers emerge, this much is clear: the climate changes that give birth to and kill off ice ages are complex processes. The physics of the earth's orbit, the chemistry of gas exchange between the atmosphere and the ocean, the geological effects that come with the spreading of ice—all these interact with life to create the changes.

In the normal course of geological events, the earth now should be within one or two thousand years of the start of another long cooling trend. Since the last ice age, however, a different form of life has begun to reshape the earth's climate. The CO_2 that pours into the atmosphere as man burns coal, gas, and oil rearranges the composition of the atmosphere. It's a change, says Berner, "that reproduced in a couple of centuries an effect that ordinarily takes millions of years." Certainly this extra carbon dioxide will provide important new information about how CO_2 affects climate. In a sense, the entire human race is inadvertently conducting a geophysical research project. "It's a great experiment," Broecker says, "but it's a dangerous one. We are experimenting with the whole world, and we don't know what will happen." —*Thomas Levenson*



A CLIMATE RIPE FOR CHANGE

As the planet warms, climates will shift. Rainfall, for example, may drop in northwest Europe, and increase in east Africa and Asia. Diminished precipitation plus greater evaporation will leave some now productive farms parched, while some marginal lands, receiving more water, will become arable.

of polysyllabic organics, describes their chemical fates in the troposphere, and rattles off estimates of current and future concentrations of the various chemicals—he'll let slip that the paper is "ominous." Because if trace gas emissions continue at roughly the present rate, they alone could warm the planet by 1.5° to 3° F. Add this to CO_2-driven warming, and what climatologists call THE SIGNAL (they always say it as if it were written in capital letters) will show up sooner rather than later, in, say, ten to 15 years. The signal is a rise in the average global temperature that can be pinned unequivocally on man. Says Ram, "It's not a problem now, but if trace gases increase by a factor of ten, we should see a significant warming. If this happens, it will be a much larger jump than any in the last thousand years."

Now ask Ram whether he thinks the government ought to take steps to cut trace gas emissions, and he replies, "There's no cause for panic. I'm not going to go to congressmen and pound the table for regulatory action." What he would like to see is comprehensive monitoring programs for trace gases, particularly over the oceans. "For this, yes, I feel a sense of urgency," he says. "We should shift our emphasis. It's time that we seriously discuss whether we're spying on the atmosphere the way we should."

Walk down the hall to Cicerone's office for another opinion. Cicerone is suffering from a bad case of hay fever but won't take any antihistamine. He's expecting the call from Mudd any minute, but sits back in his chair, relaxed and unhurried. "For several years," he says, "the writing was on the wall that the trace gases were growing, and it was only a matter of time before they surpassed CO_2. It's a huge scientific and political question that wasn't getting the attention of politicians."

Cicerone is leaping into a zone that most scientists avoid: "We could see the answers, how they'd come out. And we knew we had to produce a scholarly report that went through peer review and could withstand attacks. The last thing you want to do is alienate your fellow scientists."

In admitting that the team tailored its paper to be persuasive, Cicerone has left science and gone into the murky territory of public policy, as have a surprising number of scientists concentrating on the carbon dioxide question. Oh, there have been the usual bitter fights over CO_2, salvos fired in the pages of journals with circulations of around a thousand. Factions have been formed and dissolved, reputations made and broken. But in the past two years or so, the scientists have begun to present a unified front on the global effects of CO_2. They're pulling together on the science end and backbiting less. Increasingly, acrimony is reserved for another question (and a corollary of it): What should the government's policy response to CO_2 be (and what sort of research in this area needs the greatest financial backing)?

On the main issue, scientists can be divided roughly into two camps. One group holds that you can't make any costly decisions unless you know more about the essence of the problem. The loudest proponent of this view isn't a scientist but a federal bureaucrat named Fred Koomanoff, head of the Department of Energy's CO_2 unit, which dispenses a significant part of the money that goes toward carbon dioxide research in the U.S. ($13.3 million in 1985) as well as a portion of what's spent abroad.

He'll tell you that before we can begin to speculate on what the effects on climate will be and offer advice to politicians, we've got to 1) learn more about the carbon cycle, the process whereby carbon shifts around among the oceans, the soil, the atmosphere, and the biosphere *(see box, page 34)*; 2) refine computer models of global climate; and 3) sort out the signal from the noise—that is, show beyond a reasonable doubt that the rise in average annual temperature is caused by carbon dioxide, not solar flux or volcanoes or something no one has thought of.

In his offices in Germantown, Md., he hauls out a huge flow chart to display how little is yet known. At the left is the carbon cycle. Far to the right, at the end of a seemingly unnavigable maze of boxes and feedback arrows, are what the department euphemistically terms indirect effects.

Koomanoff has a deep intellectual attachment to flow charts—"Unless you know where you're going," he says, "it's going to be pretty hard to get there"—and adamantly resists any suggestion that one or another of the charted steps might be skipped. To those who would argue that policymakers should begin to devise a strategy to deal with global warming, he says bluntly, "If we don't know what, where, and when, it's difficult to recognize what to do. I show a view graph when I give talks. It's got a mallard duck flying across it, with a shotgun blast ahead and a shotgun blast behind. The caption reads, 'By the law of averages, this duck is dead.' Averages are no good. Use averages to make policies, and the policies will be bad."

Those in agreement with Koomanoff argue that, considering the uncertainties about warming, it doesn't pay to do anything yet. After all, the projected temperature rise may not even materialize. Thomas Schelling, a professor of political economy and a public policy specialist at Harvard's John F. Kennedy School of Government, has two reasons for being cautious: "One is a good one. It's that our grandchildren may have such advanced technologies that carbon dioxide build-up may not be a problem for them. The other is persuasive, but not so good. It's that solving the problem now will take a level of global cooperation that's utterly unlikely."

The other school, by far the larger among the thirty or so scientists interviewed in preparing for this piece, holds that if we wait until the signal shows up, it'll be too late. "If we believed that uncertainty was a ground for no action," says NCAR's Schneider, one of the most articulate and outspoken members of this camp, "then we would have no insurance companies and no armies." More compelling is this aspect of the activists' argument: if it's possible that the consequences of not acting will be horrendous, then we can't afford not to act.

Scientists have begun to present a unified front on the effects of CO2. They're asking what government's response to the problem should be

But what about other, more pressing problems? Schneider says, "[Sociologist] Elise Boulding and I were chairing a panel that came up with the tie-in strategy in Annapolis in 1979. We were at a conference, and a lot of people were saying 'With war and poverty, why should we care about carbon dioxide?' So over a couple of bottles of wine, our group worked out the best defense. It's that most things you do to prepare for global warming [such as developing hardier crops, encouraging energy conservation and better water management, and stressing population control] make good sense anyway." Joseph Smagorinsky, former director of Princeton's Geophysical Fluid Dynamics Lab, concurs: "A lot of things you can do now would be useful even if carbon dioxide weren't in the picture. If CO_2 turns out to be a non-problem, then learning how to cope with it will have essentially been the same as learning how to cope with a rapidly growing world population."

If climate changes are brought about by warming, they'll start occurring during the lifetimes of about half of the people alive today. But a date like 2035 has a certain unreality to it; it's something Stanley Kubrick, not scientists or policymakers, should be concerned with. Even something closer at hand—say, the possibility that the monsoons will come late to India in 1995—commands less attention than the dollar's robustness in the international money market this month or rioting in South Africa. Lawmakers, especially in the U.S., seem unable to think ahead more than a couple of years. Says Senator Albert Gore Jr. (D-Tenn.), "Congress has a bias against solving long-term problems. The next election, the next budget cycle, the next redistricting: these are the sorts of concerns that command the most attention. An issue like global warming requires Congress to look decades ahead."

It's not that congressmen are unfamiliar with CO_2 build-up. Consider the following important events in the recent history of the carbon dioxide issue. They are set in Senate and House hearing rooms in the Dirksen and Rayburn buildings in Washington, D.C.

Mini drama No. 1 takes place in July 1979, shortly after the Carter administration begins pushing for a massive synthetic fuels program that's supposed to make the U.S. less dependent on foreign oil. The Committee on Governmental Affairs, headed by Senator Abraham Ribicoff (D-Conn.), gathers some expert witnesses to talk about carbon dioxide. Among those testifying are Wallace Broecker, an irascible, widely respected geochemist at Columbia University's Lamont-Doherty Geological Observatory; Revelle, who in 1957 issued the first heeded warning on the deleterious effects of burning fossil fuels—what he called man's "great geophysical experiment"—and instituted a long-term program for measuring carbon dioxide in the atmosphere; George Woodwell, former director of the Ecosystems Center, Marine Biological Laboratory at Woods Hole, who's best known for his work on pesticides and nuclear winter; Smagorinsky; and Schneider, whom Revelle calls "the smartest guy in the climate modeling field."

Also present is David Slade, director of the Department of Energy's CO_2 unit and an enthusiastic supporter of research into the possible agricultural, economic, and social consequences of global warming. He's given to saying things like "We're dealing with an issue that involves the functioning of the total physical global system, the total biological global system, and the total societal system." Slade doesn't know that this predilection is going to get him into trouble.

These are big scientific guns, some of whom have been at the center of the action for a quarter of a century. They're men who by and large prefer to discuss the carbon dioxide *question*, rather than the carbon dioxide *problem*, because their studies have by no means persuaded them that the consequences of CO_2 build-up will be disastrous—or even all bad. Yet during the hearing the scientists urge that the synfuels program not be allowed to upstage conservation and development of renewable sources of energy, because burning any amount of synfuel puts 50 per cent more carbon dioxide into the atmosphere than burning the same amount of coal, the worst fossil fuel in this regard. Moreover, they agree that immediate steps should be taken to reduce carbon dioxide emissions through conservation and the development of alternative energy sources, including solar and nuclear.

Woodwell speaks for the consensus when he proposes several actions: "One of them is that we limit the total amount of fossil fuel, including coal, that we're going to use. Another is that we remove sulphur from the coal before it is burned, because we have a very serious problem with the acidification of rain over large areas of North America and Europe."

Toward the end of the session, Ribicoff says, "Are we not dealing with a serious problem to the earth and mankind? We all agree on that. So we all agree that, if we have a sense of responsibility, we can't afford to be stampeded into a [synfuels] program without doing whatever we can to put into place as many safeguards as we can, as many brakes as we can." Four months later, the responsible gentlemen in the Senate vote $20 billion for the establishment of the Synthetic Fuels Corporation. Ribicoff comes out in favor of the final Senate bill. The next June the compromise version passes both houses of Congress.

> No one's very hopeful about staving off the inevitable. If industrial nations forswore fossil fuels, it would take fifty years to complete the switch to a new energy source

Mini drama No. 2. In April 1980, the Senate Committee on Energy and Natural Resources holds carbon dioxide hearings chaired by Paul Tsongas (D-Mass.). CO_2 has become typecast as an "energy problem." Woodwell and Slade are there, as well as a couple of veteran environmental scientists, Kellogg and Gordon MacDonald.

Except for two bureaucrats, who beat around the bush, everyone argues for—guess what?—reducing CO_2 emissions through conservation and the encouragement of alternative technologies. No one's terribly hopeful that anything can actually be done to stave off the inevitable. If industrial nations forswore fossil fuels, it would take fifty years or so to complete the switch to a new energy source. And Third World countries aren't keen on curtailing emissions; after all, fossil fuels and trace gases like chlorofluorocarbons play key roles in industrialization.

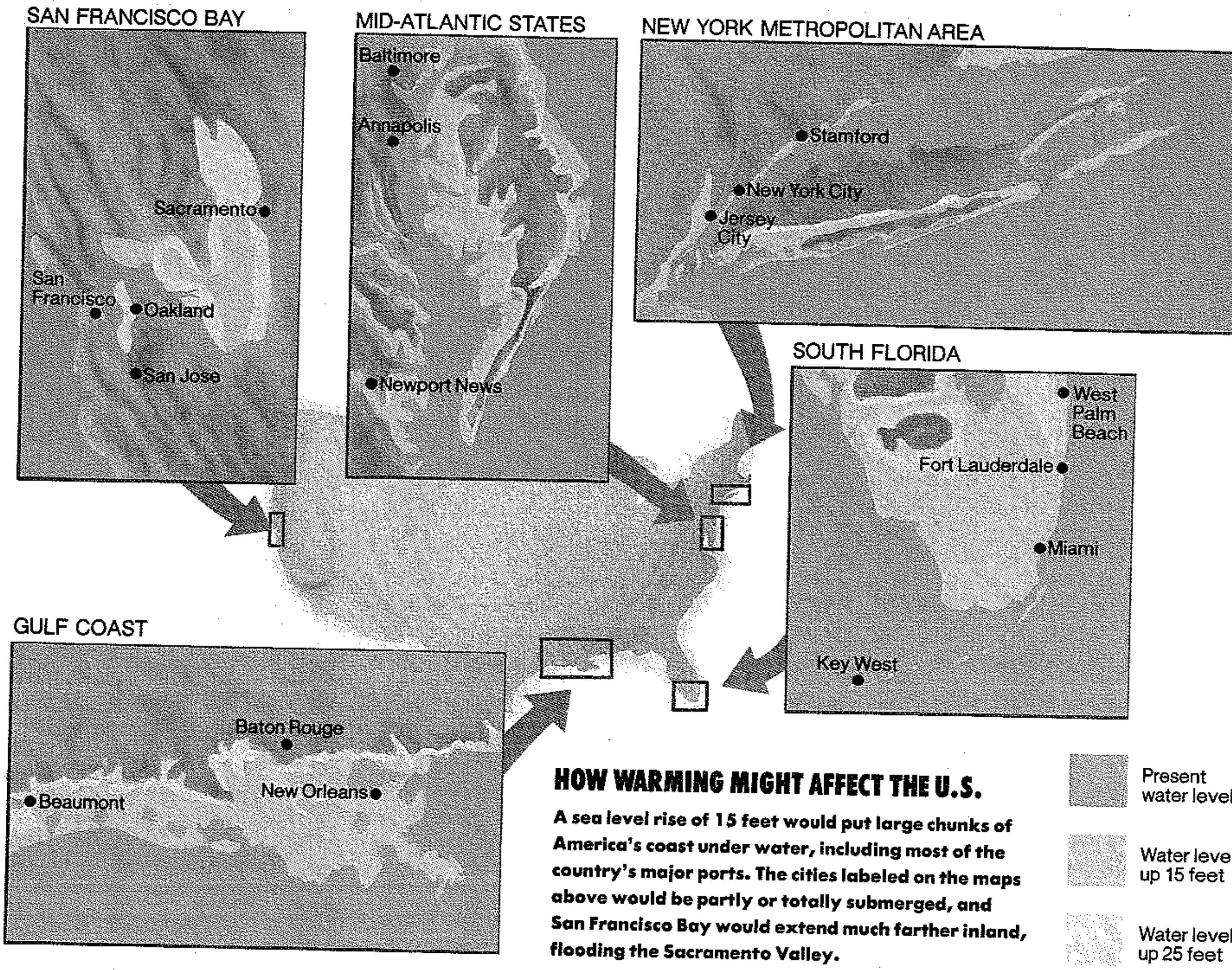
Woodwell argues that differences among scientists about the details of the CO_2 build-up "cannot be taken as a reason for ignoring, neglecting, or failing to act on the central issues." Kellogg recommends that the government undertake contingency planning for public action and pay for research into the impact of possible climate changes.

Not too long afterward, Slade is fired from his job. The story around Washington is that Energy Secretary James Edwards, a former dentist, can't understand why an energy agency is giving money to social scientists. "The DOE unit under Slade," laments one researcher, "was a model of how a bureaucracy could do something good."

Mini drama No. 3. March 1982. A trio of Senate committees with names too long to repeat holds hearings on carbon dioxide. Koomanoff, Slade's replacement, is there. His division has just slashed its budget from the $12 million appropriated to $8 million. A piqued James Scheuer (D-N.Y.) assails the cuts: "How can you possibly justify the kind of reductions in funding for this program that your agency is asking us for?" Koomanoff defends the move by saying "There are certain phases of the work that are coming in and out. In the future we may be coming back and asking you for some more money. We're not always going to have a monotonic curve on budgets."

Scheuer: "You're not going to have what?"

In his drab, book-laden office over Tom's Restaurant on upper Broadway in Manhattan, Jim Hansen explains a recent calculation. He and his colleagues have used a computer model to simulate the global climate under rising CO_2 and trace gases, as well as



HOW WARMING MIGHT AFFECT THE U.S.

A sea level rise of 15 feet would put large chunks of America's coast under water, including most of the country's major ports. The cities labeled on the maps above would be partly or totally submerged, and San Francisco Bay would extend much farther inland, flooding the Sacramento Valley.

aerosols thrown up by volcanoes, which would offset the greenhouse effect. The resulting graph projects how much of the warming would show up at specific times beginning in 1958 and ending in 2000. At first the curve tracks a shallow course across the page with a net warming of .4° F. by 1985. In this period two unusually large volcanic eruptions—Mount Agung in 1963 and El Chichón in 1982—cooled the planet. But after 1985 the temperature shoots upward, reaching 1° F. in the early 1990s and almost 2° by 2000. If the model is correct, ten to fifteen years from now the earth will be warmer than it has been for thousands of years.

We may not have to wait fifteen years: the greenhouse signal may already have been picked up. Researchers at East Anglia, using data gathered from land-based weather stations from 1851 to 1984, have plotted the number of degrees the annual surface temperature in the Northern Hemisphere has varied from the mean *(see graph, page 39)*. The line dips here and there, but since 1851 the annual surface temperature has registered a net increase of about 1° F.

This 1° F. warming is just about what Hansen's calculations say one should expect to see as a result of CO_2.

But other climatic factors must come into play to explain the dips and peaks of the observed temperature curve. In 1981, using a computer climate model to simulate global temperature trends, Hansen and some colleagues generated three model curves *(also in diagram, page 39)*. The first took into account only the rise in CO_2 concentrations. The computer-generated temperature trend didn't come close to resembling the actual trend (the "fit" was bad, in the parlance). Several volcanic eruptions since 1880 have thrown enough debris into the upper atmosphere to cool the planet down at various times, so they factored this in and generated a second line. The fit wasn't bad. When they factored in proposed fluctuations in the sun's output, the fit was very good indeed.

When these results were published in *Science* in August 1981, Hansen took a lot of flak, but after ten years of modeling, he's fairly confident that within the next ten to 15 years, Arrhenius's conjecture will have been proved. "The only way we could be wrong," he says, "is if the negative feedbacks are larger than we anticipate."

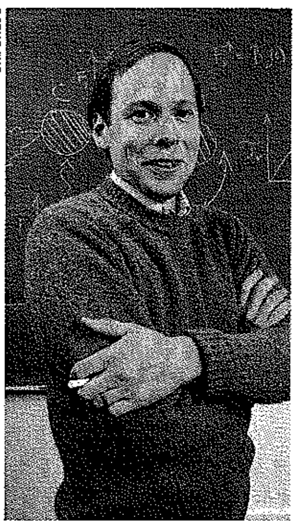
Lately, climatologists have been thinking a lot about feedbacks, natural processes that might temper or amplify the greenhouse effect, and thus mitigate or worsen climate effects. They've come up with some ideas, a few of which sound outlandish. ➻

BLOCKING THE WINDOW: HOW THE GREENHOUSE EFFECT WORKS

In the 1960s, sculptor Sheldon Machlin made stabiles by attaching heavy metal balls to the ends of stiff springs, and then anchoring the other ends of the springs in solid bases, like chunks of steel. Machlin invited audience participation, and when you walked into one of his shows, the gallery would be abob with jigging balls and pulsing springs. What you saw was a fair visual analogy to what goes on invisibly in the atmosphere when molecules and infrared energy meet.

Short-wave radiation from the sun slips easily through the atmosphere and strikes the earth's surface. But much of the long-wave infrared energy that radiates back from the heated planet is prevented from escaping to space by gases in the atmosphere. "Certain gases have tremendous absorptive features, with each one absorbing only particular wave lengths," says Veerabhadran Ramanathan, an atmospheric scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colo.

JIM BALOG

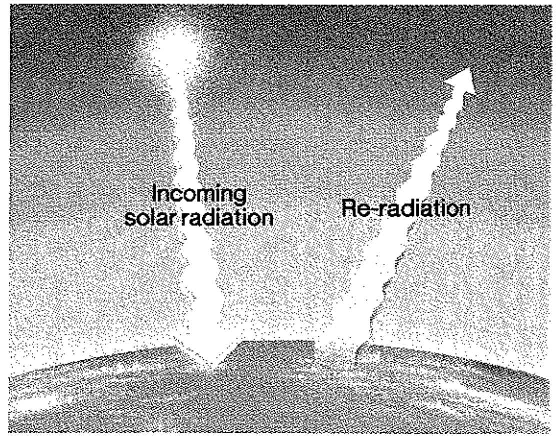


Kiehl: finder of rogue gases

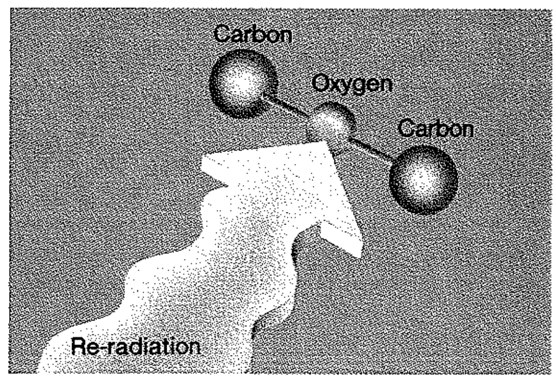
When hit by infrared radiation, a carbon dioxide molecule, which consists of a carbon atom sandwiched between two oxygen atoms, turns the energy into motion; it accordions back and forth, rotates, or vibrates. Other molecules, with more complex configurations, have even more elaborate choreographies. But no matter how complex the molecule is, it re-radiates a portion of the energy it absorbs groundward.

Carbon dioxide absorbs radiation at 15 microns, blocking most of it. Hence the analogy of the glass of a greenhouse, which allows sunlight to pass through and warm the interior, but prevents heated air from escaping. The greenhouse effect isn't limited to earth; in recent decades space probes and fly-bys have provided evidence that it operates on other planets as well. Mars, with its thin atmosphere, spins icy and lifeless because the greenhouse effect is minimal, while Venus, with a stew of an atmosphere, is a hothouse.

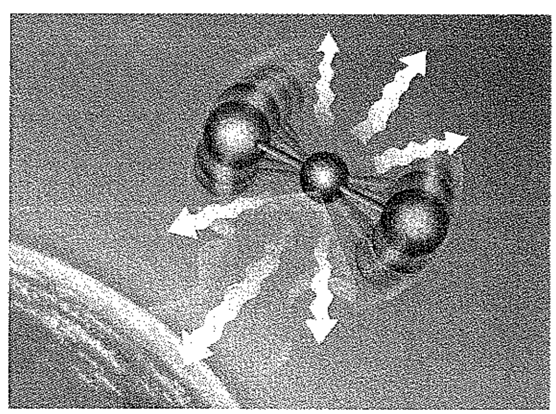
But what about radiation below 15 microns, in the range of eight to twelve microns, which accounts for most of the earth's surface heat? How is it trapped? Recently, Jeff Kiehl, an atmospheric scientist at NCAR, meticulously reviewed the characteristics of a lengthy list of known infrared absorbers. After throwing out 30 or 40 gases, he produced a rogues' gallery of about a dozen that are long-lived—that is, stay in the atmosphere for 100 to 500 years before breaking down—and that absorb in the eight-to-twelve-micron window. Most of the gases are man-made, and putting them into the atmosphere with carbon dioxide is guaranteed to increase the amount of energy emitted back to earth. Says NCAR atmospheric scientist Ralph Cicerone, "If you were Lex Luthor [a villain in *Superman*] and you wanted to destroy the earth, blocking the window wouldn't be a bad way to go."



Radiation emitted from the sun hits the earth, heating it up. The earth then sends those waves of infrared lengths back out toward space.



Some of that reflected infrared radiation hits molecules of carbon dioxide, which are made up of one carbon atom and two oxygen atoms.



Absorbing the radiation sets the molecules vibrating, spinning, and waggling. Some energy is re-radiated back to earth, causing the greenhouse effect.

Here are positive feedbacks, i.e., ones that would increase warming:

- Ocean warming could cause mud on the sea floor to release millions of tons of methane trapped within frozen water molecules.
- Deep water formation (the process whereby cold, dense water north of 50 degrees in the Atlantic sinks and makes a 500- to 1,000-year journey around the globe, flowing southward to Cape Horn, then around the Horn, and west and north into the Pacific and Indian oceans) could stall, along with surface currents. The sinking waters carry CO_2 out of the atmosphere, depositing it in sediments on the sea floor. If they did so less vigorously, the greenhouse effect could be exacerbated.
- With higher mean temperatures in the troposphere, greater volumes of sea water would evaporate. Water vapor is an even more efficient absorber of infrared energy (heat) than carbon dioxide, so it, too, could exacerbate the warming.

But more water vapor could also mean thicker cloud cover, and clouds reflect sunlight back to space before it reaches the ground, so more evaporation might actually curtail warming. Nobody knows.

Then there are trees. They eat up carbon dioxide, so couldn't they help limit CO_2 build-up? After working through a series of complicated equations for the uptake and outflow of carbon by ecosystems on land and in the sea, Woodwell concludes: yes and no. Forests at the peak of photosynthetic efficiency use more CO_2 than they release as waste. But virtually any disturbance (e.g., fires, clear-cutting), Woodwell says, "tends to result in transfer of carbon into the atmosphere." Just to begin to reduce the amounts of CO_2 being pumped into the atmosphere by man would require reforestation on an enormous scale, which seems unlikely considering that deforestation and the clearing of land for agriculture may each year be releasing, for a variety of reasons, a billion or so additional tons of carbon into the atmosphere.

At this juncture, there seems to be no easy way to prevent CO_2 build-up. There have been a few wild suggestions, like scrubbing the gas from smokestack emissions. But if you burn coal, for example, the process of removing the CO_2 would eat up about half the energy the coal produces. Researchers have suggested periodic seeding of the stratosphere with sulphur dioxide. Sulphuric acid droplets would form and shield the planet from solar rays and cool it down. But sulphur dioxide also contributes to acid rain, and no one could say whether the seeded SO_2 would drift into the lower atmosphere and contribute to that problem.

At the least, researchers would like to see more money spent on studies of "indirect effects": computer simulations of regional climates and on finer-grained scenario studies. Since 1978 only five per cent of the DOE's \$53 million CO_2 budget has been spent on this category of research—the rest goes mainly for broader studies and staging conferences. And even the series of reports it's in the process of issuing includes a section on the consequences of the CO_2 that one peer reviewer called "unsalvageable and five years too late."

Broecker, one of the loudest voices calling for additional research, would like to see \$100 million to \$200 million spent over ten to twenty years to study the biological, geological, and chemical interactions that control climate. Although some of his colleagues expect to get the money, he's not hopeful. "A lot of us are discouraged. No one will get behind us," he says. "Exaggerations have given the environmental movement a bad name. But a basic research program shouldn't threaten anybody."

At the most, scientists are asking for a definite policy response. "We should be doing everything we can to try to understand the system," says Jenkins, "but not delaying policy decisions until some computer model is refined to higher degrees of precision. We have to rely on our human computers. Beware of alarmists, but beware of placaters, too."

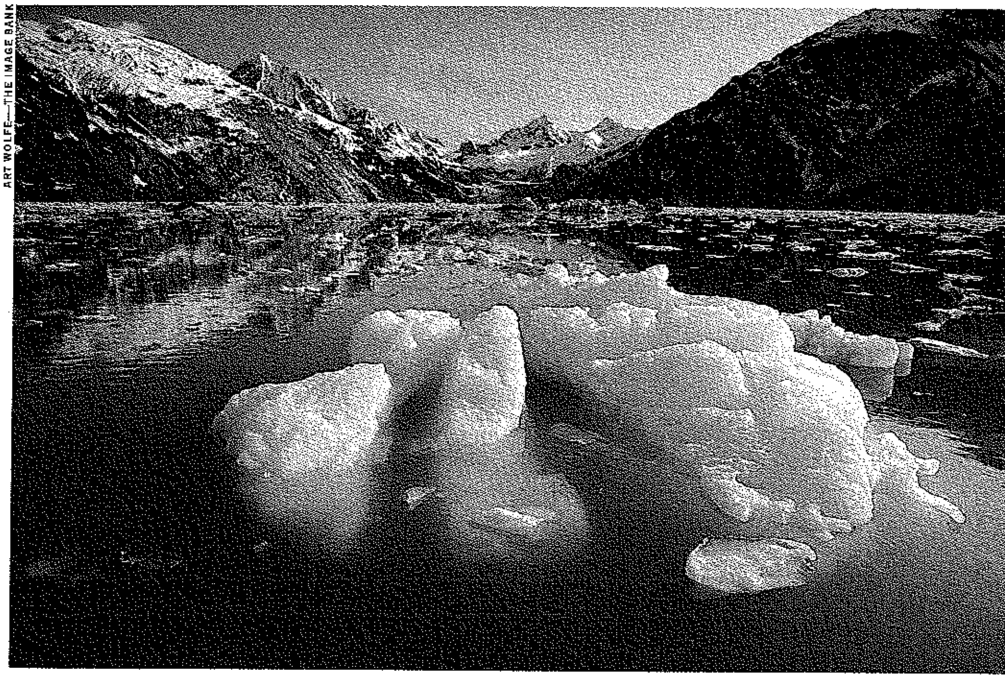
> For starters, many scientists urge, we should encourage conservation and the development of other energy sources, especially wind and solar

For starters, many scientists urge, industrialized nations should encourage, or continue to encourage, energy conservation and the development of other energy sources, especially wind and solar. Other in this case also includes nuclear. Although CO_2 researchers are fully aware of the dangers and shortcomings of fission, some have reluctantly conceded that it may be the only technology capable of satisfying the world's needs. At the same time, there should be a worldwide ban on non-essential uses of chlorofluorocarbons like deodorant spray cans.

To make agriculture more flexible, there should be more research into the climate dependence of various crops. Seed stocks should be diversified. Farmers should be encouraged to use water more efficiently. Irrigation projects and large-scale water supply systems should take into account possible future shifts in rainfall patterns. Climatologist Bo Doos of Stockholm University recommends radical reforestation programs, and an international effort to stop countries like Brazil and Malaysia from devastating their rain forests. If trees won't eliminate CO_2 build-up, they may at least slightly delay the onset of warming.

Steps should be taken to bring about international cooperation on these policies. International agencies should continue to work to improve the resilience of agriculture in hardscrabble areas of the world. And, says Doos, "we should try to foster free trade and good relations, because if there are major environmental changes, the world will be more dependent than ever on peace among nations."

That's a laudable sentiment, but considering that far simpler problems still cloud the international atmosphere, it's hard to imagine how a problem that's intertwined in the fiber of industrial economies will be easily solved. Witness Canada's inability to persuade the U.S. to regulate acid-rain-causing sulphur dioxide emissions from Midwestern power plants. "Not all the effects of carbon-dioxide-induced cli-



ART WOLFE—THE IMAGE BANK

Glaciers, like the one at the head of this bay in Alaska, could raise the world's water levels if, because of CO_2 build-up, they begin to melt faster and add more thawing ice to the oceans.

mate change will adversely affect human life," says Manabe, "and this is another obstacle to reaching agreements. Different countries may perceive differently the potential impact of carbon dioxide."

All these steps to reduce the impact of warming make good sense anyway, as the scientists are wont to say. But then, it makes good sense to stop smoking if you've had a heart attack, and people don't always do that. Some politicians concur with the scientists. Listen to Gore: "The greenhouse effect has moved from the fringes of science into the mainstream. We now have a scientific consensus that the problem is not only real but also threatening. As a result, we should take stronger action to confront the issue. We should speed up efforts to eliminate the remaining areas of uncertainty and confusion. We should overcome the refusal of federal agencies to look at the role of trace gases in the greenhouse effect. We should be aggressive in forging international scientific alliances to address the research agenda thoroughly." And to Representative Brown: "The CO_2 problem is helping us to engage in long-term social and economic thinking that's bound to facilitate the adaptability of the human species. As you can easily perceive, I take the global outlook. I'm for anything that facilitates the adaptability of the human species."

But listen to the political dissenters, too. "Even if the worst of the predicted climate changes show up," says policy specialist Schelling, "carbon dioxide isn't going to be on my list of the half-dozen things we need to worry about."

In fact, what we do or don't do may finally have little bearing. Says Woodwell, "The series of problems associated with carbon dioxide build-up will become major issues in the next century, whether we address them now or not. They'll press themselves upon us."

After spending a morning in July talking about the difficulties of spotting the signal in the record of global mean temperature, climatologist Mick Kelly and I stroll across the East Anglia campus in Norwich to lunch in the Fainsbury Centre for Visual Arts, an aluminum-sheathed building set in a vast lawn beside the River Yare. The building is equipped to regulate its own internal environment, but, says Kelly, "it can get awfully muggy in here in the summer." We push our trays through the cafeteria line, and then sit beside a three-story glass wall at one end of the building. There has been trouble with kingfishers, which, perhaps mistaking the expanse of window for open space, fly into the glass. There's a solution, says Kelly—putting hawk decals on the windows—but no one has done it yet.

We ask Hubert Lamb to join us. Lamb, who's now retired, essentially founded the field of historical climatology, introducing scholarly rigor into the analysis of the sporadic and sometimes unreliable weather records dating back several centuries. Our conversation starts out on a hopeful, philosophical note: we agree that one benefit that has come from interest in the CO_2 question is a consciousness-raising: it has forced scientists to pay attention to the notion that resources are finite, and to see the earth's biological, geological, and chemical systems as interconnected and interdependent. A heartening number of researchers engaged in studying CO_2 lean toward an integrative, interdisciplinary approach. Holistic even. This sort of global awareness can't be bad.

We end, however, on a glum note. Kelly, like every scientist I've talked to about global warming, has been careful to emphasize the uncertainties surrounding the subject, but now he admits to a concrete and specific worry. "If the recent run of droughts in Africa and the eastern U.S. is typical of what we're going to see with CO_2-driven warming," he says, "then there's going to be unprecedented pressure on the globe. Then we're looking at death on an enormous scale. If that's so, then CO_2 build-up is a problem not of academic concern alone. It's not just environmentalist claptrap."

Lamb takes the high road. Maybe things will work out despite us. Maybe nature will somehow thwart our best efforts to make a mess of the planet, or we'll modify our technology and muddle through.

Leaving the campus, marveling at a grouping of floribunda rose bushes covered with salmon- and cream-colored blooms the size of teacups, and at the benign climate of this northern land, I can't rid myself of the troubling image of kingfishers dead at the foot of the glass. ■