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THE GREENHOUSE EFFECT

THIS SUMMER WAS MERELY A WARM-UP

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SPECIAL REPORT

ENDLESS SUMMER: LIVING WITH THE GREENHOUSE EFFECT

Global warming has begun, and we had better start preparing for the dramatic changes to come.

BY ANDREW C. REVKIN

On June 23 the United States sizzled as thermometers topped 100 degrees in 45 cities from coast to coast: 102 in Sacramento; 103 in Lincoln, Nebraska; 101 in Richmond, Virginia. In the nation's heartland the searing heat was accompanied by a ruinous drought that ravaged crops and prompted talk of a dust bowl to rival that of the 1930s. Heat waves and droughts are nothing new, of course. But on that stifling June day a top atmospheric scientist testifying on Capitol Hill had a disturbing message for his senatorial audience: Get used to it.

This wasn't just a bad year, James Hansen of the NASA Goddard Institute for Space Studies told the Senate committee, or even the start of a bad decade. Rather, he could state with "99 percent confidence" that a recent, persistent rise in global temperature was a climatic signal he and his colleagues had long been expecting. Others were still hedging their bets, arguing there was room for doubt. But Hansen was willing to say what no one had dared say before. "The greenhouse effect," he claimed, "has been detected and is changing our climate now."

Until this year, despite dire warnings from climatologists, the greenhouse effect has seemed somehow academic and far off. The idea behind it is simple:

PHOTOGRAPH COURTESY TECHNOLOGY APPLICATION CENTER/NASA

Man-made gases that trap solar energy are building in the atmosphere and warming Earth.


THE GLOBAL GREENHOUSE
Incoming sunlight
Escaping infrared energy
Trapped infrared energy
Greenhouse gases
Reflected sunlight
Deforestation
Ice
Rice paddies

ILLUSTRATION BY IAN WORPOLE

gases accumulating in the atmosphere as by-products of human industry and agriculture—carbon dioxide, mostly, but also methane, nitrous oxide, ozone, and chlorofluorocarbons—let in the sun's warming rays but don't let excess heat escape. As a result, mean global temperature has probably been rising for decades. But the rise has been so gradual that it has been masked by the much greater, and ordinary, year-to-year swings in world temperature.

Not anymore, said Hansen. The 1980s have already seen the four hottest years on record, and 1988 is almost certain to be hotter still. Moreover, the seasonal, regional, and atmospheric patterns of rising temperatures—greater warming in winters than summers, greater warming at high latitudes than near the equator, and a cooling in the stratosphere while the lower atmosphere is warmer—jibe with what computer models predict should happen with greenhouse heating. And the warming comes at a time when, by rights, Earth should actually be cooler than normal. The sun's radiance has dropped slightly since the 1970s, and dust thrown up by recent volcanic eruptions, especially that of Mexico's El Chichon in 1982, should be keeping some sunlight from reaching the planet.

Even though most climatologists think Hansen's claims are premature, they agree that warming is on the way. Carbon dioxide levels are 25 percent higher now than they were in 1860, and the atmosphere's burden of greenhouse gases is expected to keep growing. By the middle of the next century the resulting warming could boost global mean temperatures from three to nine degrees Fahrenheit. That doesn't sound like much, but it equals the temperature rise since the end of the last ice age, and the consequences could be devastating. Weather patterns could shift, bringing drought to once fertile areas and heavy rains to fragile deserts that cannot handle them. As runoff from melting glaciers increases and warming seawater expands, sea level could rise as much as six feet, inundating low-lying coastal areas and islands. There would be dramatic disruptions of agriculture, water resources, fisheries, coastal activity, and energy use.

"Average climate will certainly get warmer," says Roger Revelle, an oceanographer and climatologist at the University of California at San Diego. "But what's more serious is how many more hurricanes we'll have, how many more droughts we'll have, how many days above one hundred degrees." By Hansen's reckoning, where Washington now averages one day a year over 100 degrees, it will average 12 such scorchers annually by the middle of the next century.

Comparable climate shifts have happened before, but over tens of centuries, not tens of years. The unprecedented rapid change could accelerate the already high rate of species extinction as plants and animals fail to adapt quickly enough. For the first time in history humans are affecting the ecological balance of not just a region but the entire world, all at once. "We're altering the environment far faster than we can possibly predict the consequences," says Stephen Schneider, a climate modeler at the National Center for Atmospheric Research in Boulder, Colorado. "This is bound to lead to some surprises."

Schneider has been trying to generate interest in the greenhouse effect since the early 1970s, although largely unsuccessfully. Frightening as the greenhouse effect is, the task of curbing it is so daunting that no one has been willing to take the necessary steps as long as there was even a tiny chance that the effect might not be real. Since greenhouse gases are chiefly the result of human industry and agriculture, it is not an exaggeration to say that civilization itself is the ultimate cause of global warming. That doesn't mean nothing can be done; only that delaying the effects of global warming by cutting down on greenhouse-gas emissions will be tremendously difficult, both technically and politically. Part of the problem is that predicting exactly what will happen to the local climate, region by region, is a task that's still beyond the power of even the most sophisticated computer model.

Some parts of the world could actually benefit from climate change, while others could suffer tremendously. But for the foreseeable future the effects will be uncertain. No nation can *plan* on benefiting, and so, says

Sunlight warms the planet, which radiates heat as infrared energy. Some light is reflected by clouds and ice; some heat is trapped by clouds. For millennia the net effect has been a fairly stable global temperature. Now CO_2 and other gases produced by industry, deforestation, and farming are trapping more infrared energy, turning up Earth's thermostat.

Schneider, we must all "hedge our global bets," by reducing emissions of greenhouse gases. "The longer we wait to take action," he says, "and the weaker the action, the larger the effect and the more likely that it will be negative." Says meteorologist Howard Ferguson, assistant deputy minister of the Canadian Atmospheric Environment Service, "All the greenhouse scenarios are consistent. These numbers are real. We have to start behaving as if this is going to happen. Those who advocate a program consisting only of additional research are missing the boat."

While the greenhouse effect threatens to make life on Earth miserable, it is also part of the reason life is livable in the first place. For at least the last 100,000 years atmospheric carbon dioxide, naturally generated and consumed by animals and plants, was in rough equilibrium, at a couple of hundred parts per million. Without this minute but critical trace to hold in heat, the globe's mean temperature would be in the forties instead of a comfortable 59 degrees. The amount of carbon dioxide has risen and fallen a bit, coinciding with the spread and retreat of glaciers as ice ages have come and gone. But until the Industrial Revolution, atmospheric carbon dioxide levels never rose above a manageable 280 parts per million.

Then, beginning early in the nineteenth century, the burning of fossil fuels, especially coal, took off. By 1900, carbon dioxide levels in the atmosphere had begun to rise steadily, reaching 340 parts per million last year.

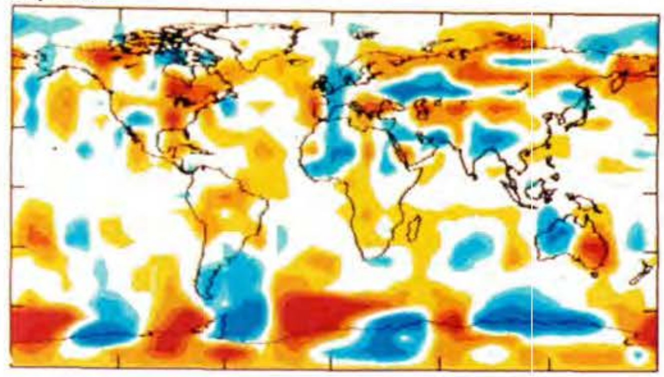
Levels of the other greenhouse gases have also risen. Methane, for example, is generated primarily by bacterial decomposition of organic matter—particularly in such places as landfills, flooded rice paddies, and the guts of cattle and termites—and by the burning of wood. Methane concentration in the atmosphere has grown steadily as Earth's human population has grown, rising one percent a year over the last decade. Levels of chlorofluorocarbons, which are used as refrigerants, as cleaning solvents, and as raw materials for making plastic foam, have climbed 5 percent annually.

The amount of nitrous oxide in the atmosphere has quickly increased as well, with about a third of the total added by human activity—much of that emitted by nitrogen-based fertilizers, and half of *that* from just three nations: China, the Soviet Union, and the United States. This gas is also released by the burning of coal and other fossil fuels, including gasoline. And ozone, which forms a beneficial shield against ultraviolet radiation when high in the stratosphere, is an efficient greenhouse gas when it appears at airliner altitudes—as it increasingly does, since it too is a by-product of fossil fuel burning.

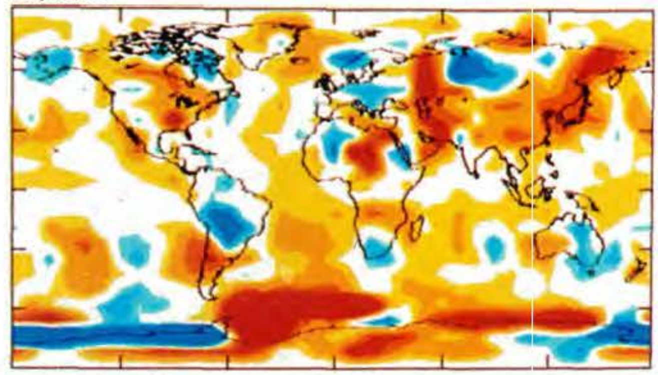
All these gases are far more efficient at absorbing infrared energy (the invisible radiation that ordinarily carries Earth's excess heat into space) than is carbon dioxide. Indeed, atmospheric chemists have estimated that the combined warming effect of these trace gases will soon equal or exceed the effect from carbon dioxide. And even as growth has slowed in the industrialized nations, the Third World is rushing full tilt into development. All told, billions of tons of greenhouse gases enter the atmosphere each year.

CHANGING CLIMES

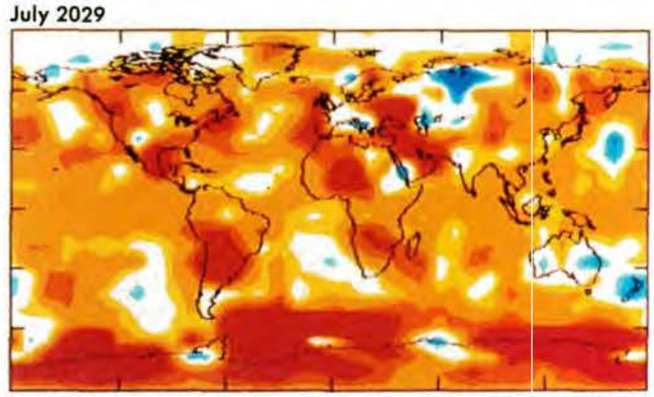
July 1987



July 2000



July 2029



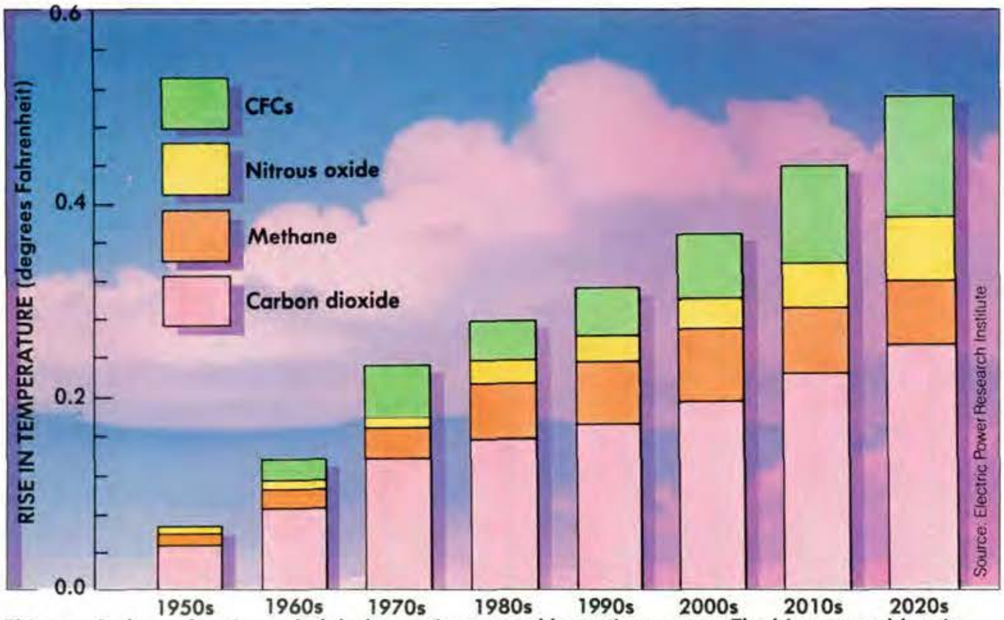
A computer projects changes in July temperatures through 2029. White means no change. Blue shows cooling; yellow, orange, and red show increasing heat—from two to nine degrees.

COMPUTER GRAPHICS COURTESY GODDARD INSTITUTE FOR SPACE STUDIES/NASA; GRAPH BY IAN WORPOLE

The big question is, given the inexorable buildup of these gases—a growth that even the most spirited optimists concede can only be slowed, not stopped—what will the specific effects be? It's hard to say, because the relationship between worldwide climate and local weather is such a complex phenomenon to begin with. The chaotic patterns of jet streams and vortices and ocean currents swirling around the globe and governing the weather still confound meteorologists; in fact, weather more than two weeks in the future is thought by some to be inherently unpredictable.

So far, the best answers have come from computer models that simulate the workings of the atmosphere. Most divide the atmosphere into hundreds of boxes, each of which is represented by mathematical equations for wind, temperature, mois-

THE GREENHOUSE GASES



This graph shows fractions of global warming caused by various gases. The biggest problem is now CO_2, but CFCs, methane, and nitrous oxide may cause just as much warming by 2010.

ture, incoming radiation, outgoing radiation, and the like. Each mathematical box is linked to its neighbors, so it can respond to changing conditions with appropriate changes of its own. Thus, the model behaves the way the world does—albeit at a very rough scale. A typical model divides the atmosphere vertically into nine layers and horizontally into boxes that are several hundred miles on a side.

Climate modelers can play with "what if" scenarios to see how the world would respond to an arbitrary set of conditions. Several years ago, for example, computer models were used to bolster the theory of nuclear winter, which concluded that smoke and dust lofted into the atmosphere in a nuclear war would block sunlight and dangerously chill the planet. To study the greenhouse effect, climatologists first used models to simulate current conditions, then instantly doubled the amount of carbon dioxide in the atmosphere. The computer was allowed to run until conditions stabilized at a new equilibrium, and a map could be drawn showing changes in temperature, precipitation, and other factors.

But Hansen's latest simulations—the ones he used in his startling congressional testimony—are more sophisticated. In them he added carbon dioxide to the atmosphere stepwise, just as is happening in the real world. The simulations, begun in 1983, took so much computer time that they were not completed and published until this summer.

Even the best climate model, however, has to oversimplify the enormous complexity of the real atmosphere. One problem is the size of the boxes. The model used at the National Center for Atmospheric Research, for example, typically uses boxes 4.5 degrees of latitude by 7 degrees of longitude—about the size of the center's home state of Colorado—and treats them as uniform masses of air. While that's inherently inaccurate—the real Colorado contains such fundamentally different features as the Rocky Mountains and the Great Plains—using smaller boxes would take too much computing power.

Another problem is that modelers must estimate the influence of vegetation, ice and snow, soil moisture, terrain, and especially clouds, which reflect lots of sunlight back into space and also hold in surface heat. "Clouds are an important factor about which little is known," says Schneider. "When I first started looking at this in 1972, we didn't know much about the feedback from clouds. We don't know any more now than we did then."

So it is not surprising that while the more than a dozen major global climate models in use around the world tend to agree on the broadest phenomena, they differ wildly when it comes to regional effects. And, says Robert Cess, a climate modeler at the State University of New York at Stony Brook, "The smaller the scale, the bigger the disagreement."

That makes it extremely hard to get national and local governments to take action. Says Stephen Leatherman, director of the Laboratory for Coastal Research at the University of Maryland, "Unless you can put something down on paper and show the effects on actual locations—even actual buildings—then it's just pie in the sky."

There are, however, some consequences of a warming Earth that will be universal. Perhaps the most obvious is a rise in sea level. "If we went all out to slow the warming trend, we might stall sea level rise at three to six feet," says Robert Buddemeier of Lawrence Livermore National Laboratory, who is studying the impact of sea-level rise on coral reefs. "But that's the very best you could hope for." And a six-foot rise, Buddemeier predicts, would be devastating.

It would, for one thing, render almost all low coral islands uninhabitable. "Eventually," Buddemeier says, "a lot of this real estate is going to go underwater." For places like the Marshall Islands in the Pacific, the Maldives off the west coast of India, and some Caribbean nations, this could mean nothing less than national extinction. "You're really looking at a potential refugee problem of unprecedented dimensions," says Buddemeier. "In the past, people have run away from famine or oppression. But they've never been physically displaced from a country because a large part of it has disappeared."

Coastal regions of continents or larger islands will also be in harm's way, particularly towns or cities built on barrier islands and the fertile flat plains that typically surround river deltas. Bangladesh, dominated by the Ganges-Brahmaputra-Meghna Delta, is the classic case, says Buddemeier. "It's massively populated, achingly poor, and something like a sixth of the country is going to go away."

Egypt will be in similar

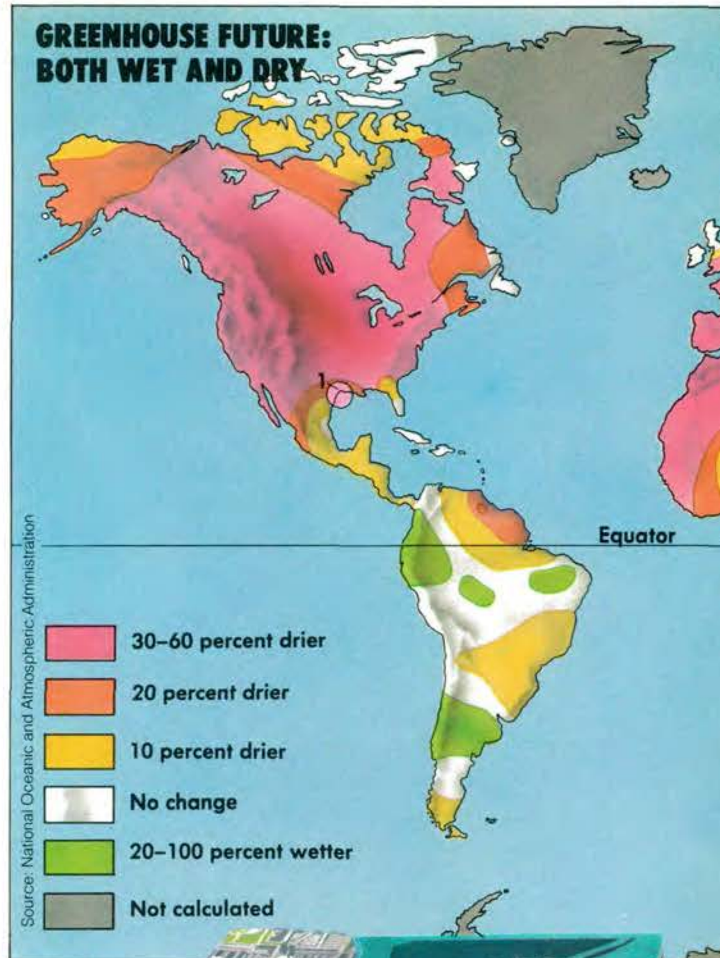
trouble, according to a study by economist James Broadus and several colleagues at Woods Hole Oceanographic Institution. Like the Ganges-Brahmaputra-Meghna, the soft sediments of the Nile Delta are subsiding. Given even an intermediate scenario for sea-level rise by the year 2050, Egypt could lose 15 percent of its arable land, land that currently houses 14 percent of its population and produces 14 percent of its gross domestic product.

One mitigating factor for some coastal nations that are still developing, such as Belize and Indonesia, is that they generally have committed fewer resources to the coastline than their developed counterparts—Australia, for example, or the United States, with such vulnerable cities as Galveston and Miami. "Developed countries have billions invested in a very precarious, no-win situation," Buddemeier says. "The less developed countries will have an easier time adapting."

Indeed, the impact on coastal cities in developed countries may be enormous. The Urban Institute, a nonpartisan think tank, is completing a study for the Environmental Protection Agency on what a three-foot sea level rise would do to Miami. Miami is particularly vulnerable. Not only is it a coastal city, but it is nearly surrounded by water, with the Atlantic to the east, the Everglades to the west, and porous limestone beneath—"one of the most permeable aquifers in the world," says William Hyman, a senior research associate at the institute. "The aquifer in Miami is so porous that you'd actually have to build a dike down one hundred fifty feet beneath the surface to keep water from welling up." In an unusually severe storm nearby Miami Beach would be swept by a wall of water up to 16 feet above the current sea level.

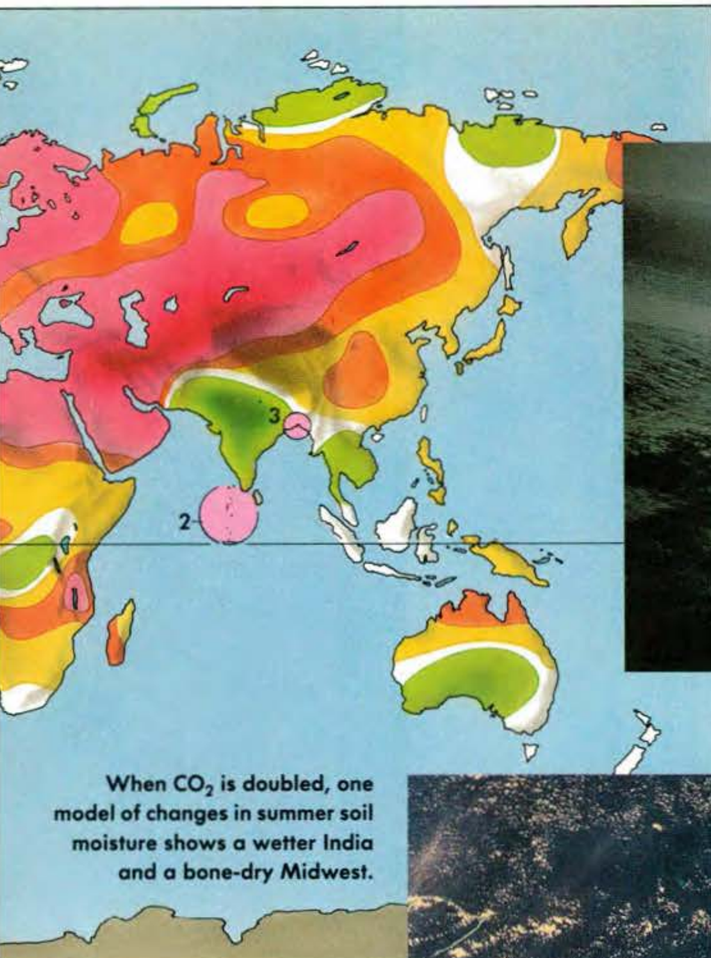
Storms are an even greater danger to Galveston, which Leatherman has studied extensively. Given just a couple of feet in sea-level rise, a moderately bad hurricane, of the type that occurs about once every ten years, would have the destructive impact of the type of storm that occurs once a century. And Galveston is typical of a whole range of resort areas on the eastern and Gulf coasts, such as Atlantic City, New Jersey ("almost the whole New Jersey coast, really," says Leatherman); Ocean City, Maryland; and Myrtle Beach, South Carolina. "The point is, all these cities have been built on low-lying sandy barrier islands, mostly with elevations no higher than ten feet above sea level," Leatherman says. "Just a small rise in sea level will result in a lot of complications."

Even as cities become more vulnerable to moderate storms, the intensity of hurricanes may increase dramatically, says Kerry Emanuel, a meteorologist at MIT. Hurricane intensity is linked to the temperature of the sea surface, Emanuel explains. According to his models, if the sea warms to predicted levels, the most intense hur-



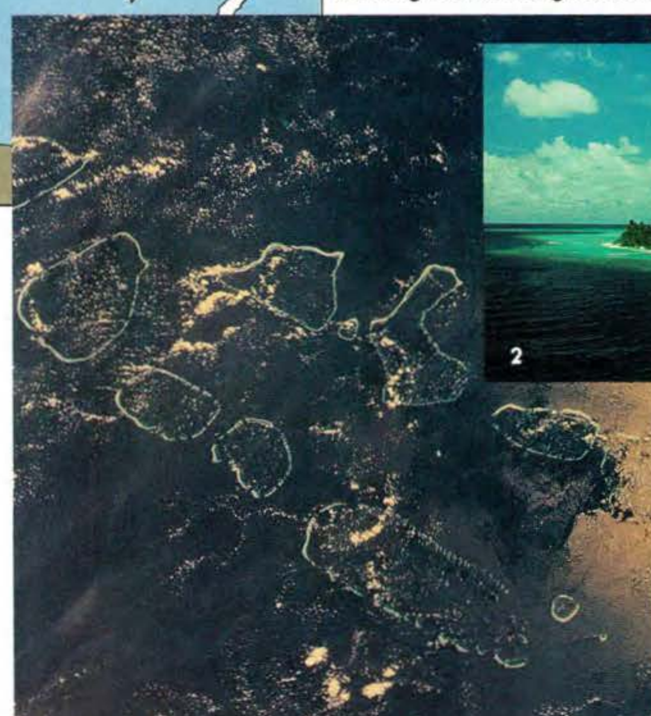
MAP AND ILLUSTRATION BY IAN WORPOLE; PHOTOGRAPH COURTESY U.S. ARMY CORPS OF ENGINEERS

A projected sea-level rise of just a few feet would cause even a small hurricane to inundate low-lying coastal cities such as Galveston and Texas City (illustration). Galveston will experience much more serious flooding than that caused by Hurricane Alicia in 1983 (photo).



When CO_2 is doubled, one model of changes in summer soil moisture shows a wetter India and a bone-dry Midwest.

Bangladesh, already plagued by floods like this one in 1987 (above), would lose one sixth of its land area if greenhouse warming of seas and glaciers raises sea level by three feet.



The Maldives would be swamped by a rising sea.

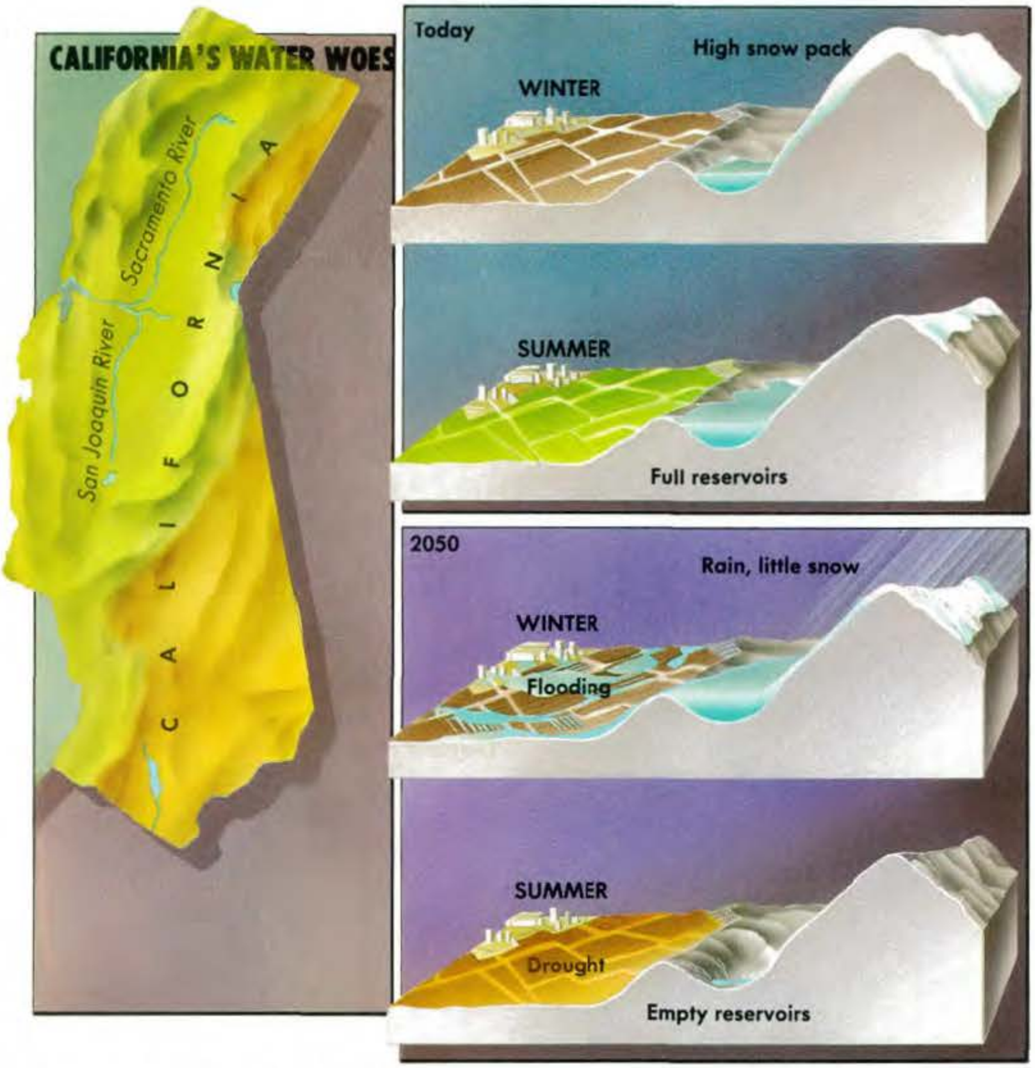
PHOTOGRAPHS: TOP BY ANTHONY SUAU/BLACK STAR CENTER BY ANDREW C. REVKIN; BOTTOM BY PHOTRI

ricanes will be 40 to 50 percent more severe than the most intense hurricanes of the past 50 years.

James Titus, director of the Environmental Protection Agency's Sea Level Rise Project, says communities will have two choices: build walls or get out of the way. For cities such as New York or Boston the answer may well be to build walls. But for most other coastal regions, picking up and moving may work out better. One of the first examples of a regional government making a regulation based on the greenhouse effect took place in Maine last year. The state approved regulations allowing coastal development with the understanding that if sea level rises enough to inundate a property, the property will revert to nature, with the owner footing the bill for dismantling or moving structures.

Another worldwide consequence of global warming is increased precipitation: warmer air will mean more evaporation of ocean water, more clouds, and an overall rise in rain and snow of between 5 and 7 percent. But it won't be evenly distributed. One climate model at Princeton University's Geophysical Fluid Dynamics Laboratory predicts that central India will have doubled precipitation, while the centers of continents at middle latitudes—the midwestern United States, for example—will actually have much drier summers than they have now (this summer's drought could, in other words, be a foretaste). Some arid areas, including southern California and Morocco, will have drier winters; and winters are when such areas get most of their precipitation. Moreover, the effect may be self-perpetuating: drier soil, says Syukuro Manabe, the climatologist who developed the model, leads to even hotter air.

The changes could be political dynamite for nations that already argue over water resources. A prime example is Egypt and Sudan, both of which draw their lifeblood from the north-flowing Nile. Sudan has been trying to divert a bigger share of the river's water; but downstream, Egypt is experiencing one of Africa's



If atmospheric carbon dioxide levels double, the mountain snow that supplies much of California's water will dwindle, creating winter floods and summer droughts.

fastest population explosions and will need every drop of water it can get. A string of droughts in the Sudan could make the conflict far worse. The same situation occurs in many other parts of the world.

Not all the tensions will be international. Within nations, local effects of global warming will cause internecine fights for increasingly scarce water. In the United States, for example, western states have long argued over who owns what fraction of the water in such rivers as the Colorado. In California 42 percent of the water comes from the Sacramento and San Joaquin river basins, which are fed by runoff from the Sierra Nevada and other mountain ranges. Most of the water falls as snow in the winter, which melts in the spring to feed the rivers, reservoirs, and subterranean aquifers. The state's normal strategy for water management calls for keeping the reservoirs low in winter, to provide protection against floods, and keeping them as high as possible in summer, to ensure an adequate supply for the giant farming operations in the Central Valley (one of the most productive agricultural regions in the world) and for arid southern California.

Peter Gleick of the Pacific Institute for Studies in Development, Environment and Security, in Berkeley, California, has devised a widely praised model that predicts a dramatic disruption of the state's water supply in the event of global warming, even if total precipitation remains unchanged. It focuses on the Sacramento River basin, which alone provides 30 percent of the state's water and almost all the water for agriculture in the Central Valley.

According to the model, higher temperatures will mean that what falls in winter will increasingly be rain, not snow, and that more of it will run off right away. California may get the same amount of total annual runoff, but the water-distribution system won't be able to deal with it. "California will get the worst of all possible worlds—more flooding in the winter, less available water in the summer," Gleick says. "This will reverberate throughout the state." San Francisco Bay will feel a secondary effect. As freshwater supplies shrink in the summer, seawater, which has already infiltrated freshwater aquifers beneath the low-lying Sacramento Delta, will continue its push inland. Rising sea level will just compound the effect.

Food is another crucial resource that will be affected by the global greenhouse. Taken by itself, a rise in atmospheric carbon dioxide might not be so bad. For many crops more carbon dioxide means a rise in the rate of photosynthesis and, therefore, in growth; and with increased carbon dioxide some plants' use of water is more efficient, according to studies done in conventional glass greenhouses. Also, as the planet gets warmer, crops might be cultivated farther north. But as usual, things are not so simple. A temperature rise of only 3.5 degrees in the tropics could reduce rice production by more than 10 percent.

In temperate regions also, the picture is mixed. Cynthia Rosenzweig, a researcher based at Goddard, has been using crop-growth computer models to predict effects of carbon dioxide buildup and climate change on wheat, the most widely cultivated crop in the world. Plugging in temperature changes derived from the Goddard climate model, Rosenzweig tested a world with doubled carbon dioxide levels. Because the Goddard model is bad at predicting precipitation, she did separate runs for normal and dry condi-

ILLUSTRATION BY IAN WORPOLE

tions. She found that in normal years the wheat grew better, thanks to the extra carbon dioxide. But in dry years there was a marked increase in crop failures, because of excessive heat. Given the likelihood that heat waves and droughts are increasing, she says, no one should count on better yields in years to come.

The nations most likely to reap the benefits of warmer climate are Canada and the Soviet Union, much of whose vast land area is too cold for large-scale crop cultivation. There has even been speculation that these countries might go slowly on controlling the greenhouse effect, or even oppose such control; anyone who has spent the winter in Moscow or Saskatoon would be sorely tempted by the prospect of better weather.

But again, atmospheric scientists stress that no nation can count on benefits. "The models suggest that ecological zones will shift northward," says planetary scientist Michael McElroy of Harvard. "The southwestern desert to the Grain Belt; the Grain Belt to Canada. There might be winners and losers if this shift occurs slowly. But suppose it shifts so fast that ecosystems are unable to keep up?" For example, he says, there is a limit to the distance that a forest can propagate in a year. "If it is unable to propagate fast enough, then either we have to come in and plant trees, or else we'll see total devastation and the collapse of the ecosystem."

According to Irving Mintzer, a senior associate with the Energy and Climate Project of the World Resources Institute in Washington, there is another reason to be leery of projections for regional agricultural benefits. Just because climatic conditions conducive to grain cultivation move north, that doesn't mean that other conditions necessary for agricultural superpowerdom will be present. Much of Canada, for example, does not have the optimum type of soil for growing wheat and corn.

"California will get the worst of all possible worlds—flooding in winter, less water in summer."

Wildlife will suffer, too. In much of the world, wilderness areas are increasingly hemmed in by development, and when climate shifts, these fragile ecosystems won't be able to shift with it. Plants will suddenly be unable to propagate their seeds, and animals will have no place to go. Species in the Arctic, such as caribou, may lose vital migratory routes as ice bridges between islands melt.

In the United States the greatest impact will likely be on coastal wetlands: the salt marshes, swamps, and bayous that are among the world's most diverse and productive natural habitats. James Titus of the Environmental Protection Agency estimates that a five-foot rise in sea level—not even the worst-case scenario—would destroy between 50 and 90 percent of America's wetlands. Under natural conditions marshes would slowly shift inland. But with levees, condominiums, and other man-made structures in the way, they can't. The situation is worst in Louisiana, says Titus, which has 40 percent of U.S. wetlands (excluding those in Alaska); much of the verdant Mississippi River delta may well vanish.

A satellite image of West Africa shows many fires (white spots). Five percent of Earth's surface burns each year.

PHOTOGRAPH BY DMSP, NATIONAL SNOW AND ICE DATA CENTER

In many parts of the tropics, low forests of mangrove trees thrive in the shallow waters along coastlines. Their dense networks of roots and runners are natural island-building systems, trapping sediment and cushioning the damaging effects of tropical storms. But rising sea levels will flood the mangroves; the natural response would be for them to shift with the tide, spreading their roots farther inland. But in places where development has encroached on the shore, the mangrove forests will feel the same squeeze that will threaten marshes.

The only way to eliminate the greenhouse problem completely would be to return the world to its preindustrial state. No one proposes that. But researchers agree that there is plenty that can be done to at least slow down the warming. Energy conservation comes first: using less coal, finding more efficient ways to use cleaner-burning fossil fuels, and taking a new look at nonfossil alternatives, everything from solar and geothermal energy to—yes, even some environmentalists are admitting it—nuclear power.

Getting the world's fractious nations to agree to a program of remedial measures sounds extremely difficult, but Stephen Schneider sees signs that it may not be

The only way to eliminate the problem would be to return the world to its preindustrial state.

impossible. Schneider was one of more than 300 delegates from 48 countries who attended the International Conference on the Changing Atmosphere, which took place in Toronto, coincidentally, just a week after Hansen's congressional testimony. It was, says Schneider, the "Woodstock of CO_2" (an obvious reference to the "Woodstock of Physics" meeting held last year, during which news of the high-temperature superconductors exploded into the public consciousness).

The meeting was the first large-scale attempt to bridge the gap between scientists and policymakers on a wide range of atmospheric problems, including not just the greenhouse effect but also acid rain and the depletion of the protective layer of ozone in the stratosphere. Four days of floor debates, panel discussions, and closed-door sessions produced an ambitious manifesto calling for, among other things, the following:

• A 20 percent reduction in carbon dioxide emissions by industrialized nations by the year 2005, using a combination of conservation efforts and reduced consumption of fossil fuels. A 50 percent cut would eventually be needed to stabilize atmospheric carbon dioxide.

• A switch from coal or oil to other fuels. Burning natural gas, for example, produces half as much carbon dioxide per unit of energy as burning coal.

• Much more funding for development of solar power, wind power, geothermal power, and the like, and efforts to develop safe nuclear power.

• Drastic reductions in deforestation, and encouragement of forest replanting and restoration.

• The labeling of products whose manufacture does not harm the environment.

• Nearly complete elimination of the use of chlorofluorocarbons, or CFCs, by the year 2000.

Of all the anti-greenhouse measures, the last should prove easiest to achieve. Although CFCs are extremely persistent, remaining in the upper atmosphere for decades, and although they are 10,000 times more efficient than carbon dioxide at trapping heat, the process of controlling them has been under way for years, for reasons having nothing to do with the greenhouse effect. Since the early 1970s atmospheric scientists have known that CFCs could have destructive effects on ozone. CFCs were banned from spray cans in the United States and Canada in the late 1970s, and the appearance of a "hole" in the ozone layer over Antarctica in the early 1980s created an international consensus that CFCs must go. Last year 53 nations crafted an agreement that will cut CFC production by 50 percent over the next decade; the chemicals may well be banned altogether by the turn of the century.

CFCs are a special case, however. Since they are entirely man-made, and since substitutes are available or under development, control is straightforward. "There are only thirty-eight companies worldwide that produce CFCs," says Pieter Winsemius, former minister of the environment of the Netherlands. "You can put them all in one room; you can talk to them. But you can't do that with the producers of carbon dioxide—all the world's utilities and industries."

Also, there is a lack of basic information on the flow of carbon dioxide and the other greenhouse gases into and out of the atmosphere and biosphere. Just as one example, there is no good estimate of how much carbon dioxide, methane, and nitrous oxide are produced by fires, both man-made and naturally occurring. "We need to better assess global biomass burning as a source of greenhouse gases," says Joel Levine of the NASA Langley Research Center in Hampton, Virginia. "We have to understand what we're actually doing when we burn tropical forests and when we burn agricultural stubble after harvest. We don't know on a global basis what the contribution is."

Remarkably, the conference spurred some specific promises from political leaders rather than just vague platitudes. Standing before a 40-foot-wide photorealist painting of a cloud-studded skyscape, prime ministers Brian Mulroney of Canada and Gro Harlem Brundtland of Norway pledged that their countries will slow fossil fuel use and forgive some Third World debt, allowing developing countries to grow in a sustainable way. Says Schneider, "In the fifteen years that I've been trying to convince people of the seriousness of the greenhouse effect, this is the first time I've seen a broad consensus: First, there is a consensus that action is *not* premature. Second, that solutions have to occur on a global as well as a national scale."

In the end, the greatest obstacle facing those who are trying to slow the output of greenhouse gases is the fundamental and pervasive nature of the human activities that are causing the problem: deforestation, industrialization, energy production. As populations boom, productivity must keep up. And even as the developed nations of the world cut back on fossil fuel use, there will be no justifiable way to prevent the Third World from expanding its use of coal and oil. How can the developed countries expect that China, for example, which has plans to double its coal production in the next 15 years in order to spur development, will be willing or even able to change course?

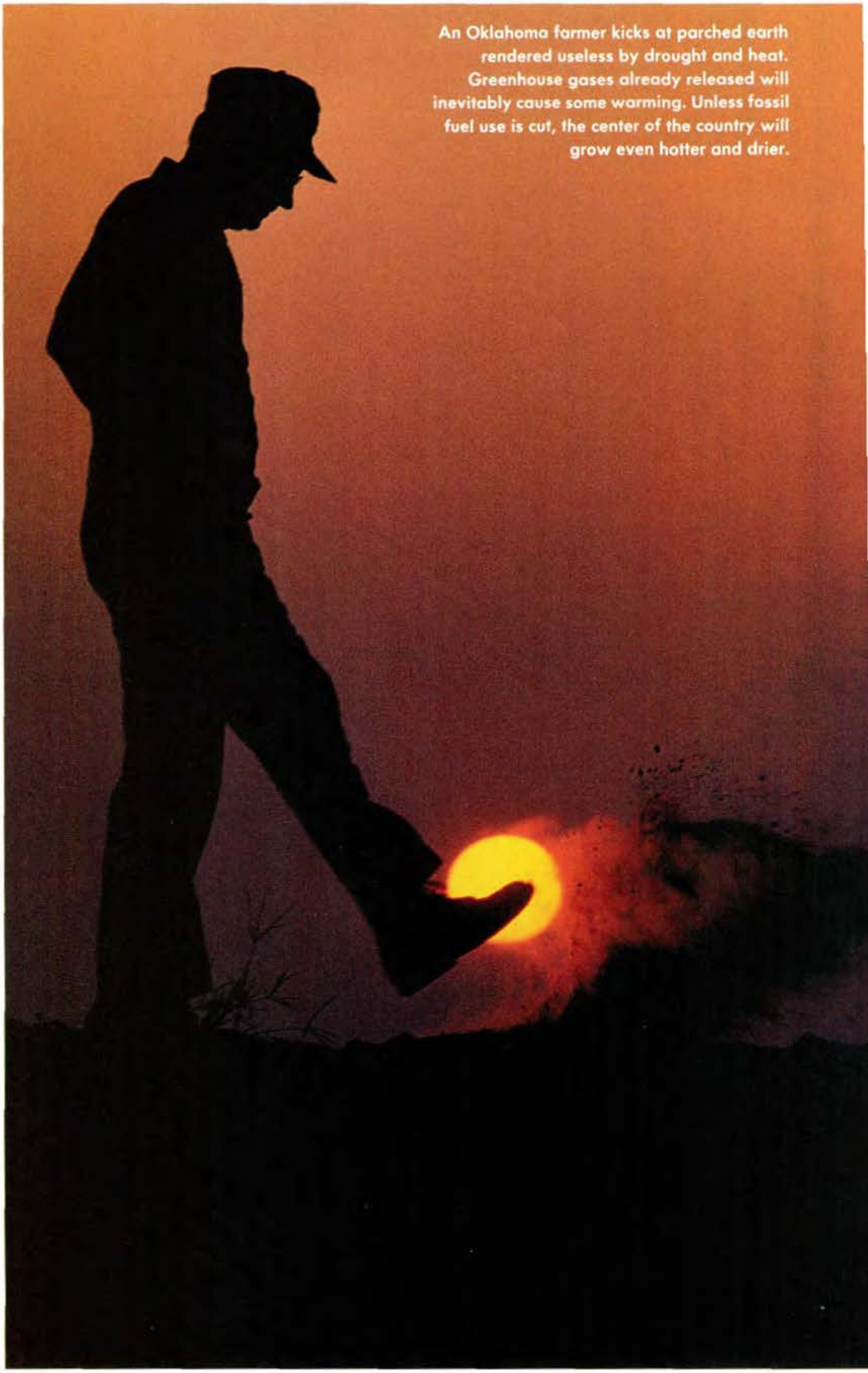
And then there is poverty, which contributes to the greenhouse effect by encouraging destruction of forests. "Approximately seventy-five percent of the deforestation occurring in the world today is accounted for by landless people in a desperate search for food," says José Lutzenberger, director of the Gaia Foundation, an influential Brazilian environmental group. Commercial logging accounts for just 15 percent of tropical forest loss worldwide. Unfortunately for the atmosphere and the forests themselves, working out an agreement with the tropical timber industry will be far easier than eliminating rural poverty.

Industrialized nations, which created most of the greenhouse problem, should lead the way to finding solutions, says State Department official Richard Benedick, who represented the United States during negotiations for cuts in CFCs and who was a conference attendee. The first priority, he says, should be strong conservation efforts—an area in which the United States lags far behind such countries as Japan. The effect of such measures, Benedick feels, can only be positive and the cost is not great. "Certain things make sense on their own merits," he says. Technology can be transferred to developing countries. In some Third World nations a partial solution can be as simple as modernizing energy production and distribution. Upgrading India's electric-power distribution system, Benedick says, could double the effective energy output of existing coal-fired power plants.

Addressing the conference, Canadian minister of energy Marcel Masse noted that there is cause for optimism. One need look no further than the energy crisis of a decade ago. From 1979 to 1985, thanks primarily to conservation, substantial cuts were made in the use of fossil fuels by industrialized nations. Only since 1986 and the current oil glut, said Masse, has there been a resurgence in oil use and coal burning.

Michael McElroy concluded, "If we choose to take on this challenge, it appears that we can slow the rate of change substantially, giving us time to develop mechanisms so that the cost to society and the damage to ecosystems can be minimized. We could alternatively close our eyes, hope for the best, and pay the cost when the bill comes due." ❑

Senior Editor Andrew C. Revkin wrote about the Florida alligator wars in last month's issue.



An Oklahoma farmer kicks at parched earth rendered useless by drought and heat. Greenhouse gases already released will inevitably cause some warming. Unless fossil fuel use is cut, the center of the country will grow even hotter and drier.

PHOTOGRAPH BY HERMAN KOKOJAN/BLACK STAR

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