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THE CLIMATE OF MAN—I

by ELIZABETH KOLBERT

Disappearing islands, thawing permafrost, melting polar ice. How the earth is changing.

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The Alaskan village of Shishmaref sits on an island known as Sarichef, five miles off the coast of the Seward Peninsula. Sarichef is a small island—no more than a quarter of a mile across and two and a half miles long—and Shishmaref is basically the only thing on it. To the north is the Chukchi Sea, and in every other direction lies the Bering Land Bridge National Preserve, which probably ranks as one of the least visited national parks in the country. During the last ice age, the land bridge—exposed by a drop in sea levels of more than three hundred feet—grew to be nearly a thousand miles wide. The preserve occupies that part of it which, after more than ten thousand years of warmth, still remains above water.

Shishmaref (pop. 591) is an Inupiat village, and it has been inhabited, at least on a seasonal basis, for several centuries. As in many native villages in Alaska, life there combines—often disconcertingly—the very ancient and the totally modern. Almost everyone in Shishmaref still lives off subsistence hunting, primarily for bearded seals but also for walrus, moose, rabbit, and migrating birds. When I visited the village one day last April, the spring thaw was under way, and the seal-hunting season was about to begin. (Wandering around, I almost tripped over the remnants of the previous year's catch emerging from storage under the snow.) At noon, the village's transportation planner, Tony Weyiouanna, invited me to his house for lunch. In the living room, an enormous television set tuned to the local public-access station was playing a rock soundtrack. Messages like "Happy Birthday to the following elders . . ." kept scrolling across the screen.

Traditionally, the men in Shishmaref hunted for seals by driving out over the sea ice with dogsleds or, more recently, on snowmobiles. After they hauled the seals back to the village, the women would skin and cure them, a process that takes several weeks. In the early nineteen-nineties, the hunters began to notice that the sea ice was changing. (Although the claim that the Eskimos have hundreds of words for snow is an exaggeration, the Inupiat make distinctions among many different types of ice, including sikuliaq, "young ice," sarri, "pack ice," and tuvaq, "landlocked ice.") The ice was starting to form later in the fall, and also to break up earlier in the spring. Once, it had been possible to drive out twenty miles; now, by the time the seals arrived, the ice was mushy half that distance from shore. Weyiouanna described it as having the consistency of a "slush puppy." When you encounter it, he said, "your hair starts sticking up. Your eyes are wide open. You can't even blink." It became too dangerous to hunt using snowmobiles, and the men switched to boats.

Soon, the changes in the sea ice brought other problems. At its highest point, Shishmaref is only twenty-two feet above sea level, and the houses, many built by the U.S. government, are small, boxy, and not particularly sturdy-looking. When the Chukchi Sea froze early, the layer of ice protected the village, the way a tarp prevents a swimming pool from getting roiled by the wind. When the sea started to freeze later, Shishmaref became more vulnerable to storm surges. A storm in October, 1997, scoured away a hundred-and-twenty-five-foot-wide strip from the town's northern edge; several houses were destroyed, and more than a dozen had to be relocated. During another storm, in October, 2001, the village was threatened by twelve-foot waves. In the summer of 2002, residents of Shishmaref voted, a hundred and sixty-one to twenty, to move the entire village to the mainland. Last year, the federal government completed a survey of possible sites for a new village. Most of the spots that are being considered are in areas nearly as remote as Sarichef, with no roads or nearby cities, or even settlements. It is estimated that a full relocation will cost at least a hundred and eighty million dollars.

People I spoke to in Shishmaref expressed divided emotions about the proposed move. Some worried that, by leaving the tiny island, they would give up their connection to the sea and become lost. "It makes me feel lonely," one woman said. Others seemed excited by the prospect of gaining certain conveniences, like running water, that Shishmaref lacks. Everyone seemed to agree, though, that the village's situation, already dire, was likely only to get worse.

Morris Kiyutelluk, who is sixty-five, has lived in Shishmaref almost all his life. (His last name, he told me, means "without a wooden spoon.") I spoke to him while I was hanging around the basement of the village church, which also serves as the unofficial headquarters for a group called the Shishmaref Erosion and Relocation Coalition. "The first time I heard about global warming, I thought, I don't believe those Japanese," Kiyutelluk told me. "Well, they had some good scientists, and it's become true."

The National Academy of Sciences undertook its first rigorous study of global warming in 1979. At that point, climate modelling was still in its infancy, and only a few groups, one led by Syukuro Manabe, at the National Oceanic and Atmospheric Administration, and another by James Hansen, at nasa's Goddard Institute for Space Studies, had considered in any detail the effects of adding carbon dioxide to the atmosphere. Still, the results of their work were alarming enough that President Jimmy Carter called on the academy to investigate. A nine-member panel was appointed, led by the distinguished meteorologist Jule Charney, of M.I.T.

The Ad Hoc Study Group on Carbon Dioxide and Climate, or the Charney panel, as it became known, met for five days at the National Academy of Sciences' summer study center, in Woods Hole, Massachusetts. Its conclusions were unequivocal. Panel members had looked for flaws in the modellers' work but had been unable to find any. "If carbon dioxide continues to increase, the study group finds no reason to doubt that climate changes will result and no reason to believe that these changes will be negligible," the scientists wrote. For a doubling of CO2 from pre-industrial levels, they put the likely global temperature rise at between two and a half and eight degrees Fahrenheit. The panel members weren't sure how long it would take for changes already set in motion to become manifest, mainly because the climate system has a built-in time delay. It could take "several decades," they noted. For this reason, what might seem like the most conservative approach—waiting for evidence of warming in order to assess the models' accuracy—actually amounted to the riskiest possible strategy: "We may not be given a warning until the CO2 loading is such that an appreciable climate change is inevitable."

It is now twenty-five years since the Charney panel issued its report, and, in that period, Americans have been alerted to the dangers of global warming so many times that volumes have been written just on the history of efforts to draw attention to the problem. (The National Academy of Sciences alone has issued nearly two hundred reports on global warming; the most recent, "Radiative Forcing of Climate Change," was published just last month.) During this same period, worldwide carbon-dioxide emissions have continued to increase, from five billion billion metric tons a year to seven billion, and the earth's temperature, much as predicted by Manabe's and Hansen's models, has steadily risen. The year 1990 was the warmest year on record until 1991, which was equally hot. Almost every subsequent year has been warmer still. The year 1998 ranks as the hottest year since the instrumental temperature record began, but it is closely followed by 2002 and 2003, which are tied for second; 2001, which is third; and 2004, which is fourth. Since climate is innately changeable, it's difficult to say when, exactly, in this sequence natural variation could be ruled out as the sole cause. The American Geophysical Union, one of the nation's largest and most respected scientific organizations, decided in 2003 that the matter had been settled. At the group's annual meeting that year, it issued a consensus statement declaring, "Natural influences cannot explain the rapid increase in global near-surface temperatures." As best as can be determined, the world is now warmer than it has been at any point in the last two millennia, and, if current trends continue, by the end of the century it will likely be hotter than at any point in the last two million years.

In the same way that global warming has gradually ceased to be merely a theory, so, too, its impacts are no longer just hypothetical. Nearly every major glacier in the world is shrinking; those in Glacier National Park are retreating so quickly it has been estimated that they will vanish entirely by 2030. The oceans are becoming not just warmer but more acidic; the difference between day and nighttime temperatures is diminishing; animals are shifting their ranges poleward; and plants are blooming days, and in some cases weeks, earlier than they used to. These are the warning signs that the Charney panel cautioned against waiting for, and while in many parts of the globe they are still subtle enough to be overlooked, in others they can no longer be ignored. As it happens, the most dramatic changes are occurring in those places, like Shishmaref, where the fewest people tend to live. This disproportionate effect of global warming in the far north was also predicted by early climate models, which forecast, in column after column of fortran-generated figures, what today can be measured and observed directly: the Arctic is melting.

Most of the land in the Arctic, and nearly a quarter of all the land in the Northern Hemisphere—some five and a half billion acres—is underlaid by zones of permafrost. A few months after I visited Shishmaref, I took a trip through the interior of Alaska with Vladimir Romanovsky, a geophysicist and permafrost expert at the University of Alaska. I flew into Fairbanks, where Romanovsky lives, and when I arrived the whole city was enveloped in a dense haze that looked like fog but smelled like burning rubber. People kept telling me that I was lucky I hadn't come a couple of weeks earlier, when it had been much worse. "Even the dogs were wearing masks," one woman I met said. I must have smiled. "I am not joking," she told me.

Fairbanks, Alaska's second-largest city, is surrounded on all sides by forest, and virtually every summer lightning sets off fires in these forests, which fill the air with smoke for a few days or, in bad years, weeks. This past summer, the fires started early, in June, and were still burning two and a half months later; by the time of my visit, in late August, a record 6.3 million acres—an area roughly the size of New Hampshire—had been incinerated. The severity of the fires was clearly linked to the weather, which had been exceptionally hot and dry; the average summertime temperature in Fairbanks was the highest on record, and the amount of rainfall was the third lowest.

On my second day in Fairbanks, Romanovsky picked me up at my hotel for an underground tour of the city. Like most permafrost experts, he is from Russia. (The Soviets more or less invented the study of permafrost when they decided to build their gulags in Siberia.) A broad man with shaggy brown hair and a square jaw, Romanovsky as a student had had to choose between playing professional hockey and becoming a geophysicist. He had opted for the latter, he told me, because "I was little bit better scientist than hockey player." He went on to earn two master's degrees and two Ph.D.s. Romanovsky came to get me at 10 a.m.; owing to all the smoke, it looked like dawn.

Any piece of ground that has remained frozen for at least two years is, by definition, permafrost. In some places, like eastern Siberia, permafrost runs nearly a mile deep; in Alaska, it varies from a couple of hundred feet to a couple of thousand feet deep. Fairbanks, which is just below the Arctic Circle, is situated in a region of discontinuous permafrost, meaning that the city is freckled with regions of frozen ground. One of the first stops on Romanovsky's tour was a hole that had opened up in a patch of permafrost not far from his house. It was about six feet wide and five feet deep. Nearby were the outlines of other, even bigger holes, which, Romanovsky told me, had been filled with gravel by the local public-works department. The holes, known as thermokarsts, had appeared suddenly when the permafrost gave way, like a rotting floorboard. (The technical term for thawed permafrost is talik, from a Russian word meaning "not frozen.") Across the road, Romanovsky pointed out a long trench running into the woods. The trench, he explained, had been formed when a wedge of underground ice had melted. The spruce trees that had been growing next to it, or perhaps on top of it, were now listing at odd angles, as if in a gale. Locally, such trees are called "drunken." A few of the spruces had fallen over. "These are very drunk," Romanovsky said.

In Alaska, the ground is riddled with ice wedges that were created during the last glaciation, when the cold earth cracked and the cracks filled with water. The wedges, which can be dozens or even hundreds of feet deep, tended to form in networks, so that when they melt they leave behind connecting diamond- or hexagonal-shaped depressions. A few blocks beyond the drunken forest, we came to a house where the front yard showed clear signs of ice-wedge melt-off. The owner, trying to make the best of things, had turned the yard into a miniature-golf course. Around the corner, Romanovsky pointed out a house—no longer occupied—that had basically split in two; the main part was leaning to the right and the garage toward the left. The house had been built in the sixties or early seventies; it had survived until almost a decade ago, when the permafrost under it started to degrade. Romanovsky's mother-in-law used to own two houses on the same block. He had urged her to sell them both. He pointed out one, now under new ownership; its roof had developed an ominous-looking ripple. (When Romanovsky went to buy his own house, he looked only in permafrost-free areas.)

"Ten years ago, nobody cared about permafrost," he told me. "Now everybody wants to know." Measurements that Romanovsky and his colleagues at the University of Alaska have made around Fairbanks show that the temperature of the permafrost has risen to the point where, in many places, it is now less than one degree below freezing. In places where permafrost has been disturbed, by roads or houses or lawns, much of it is already thawing. Romanovsky has also been monitoring the permafrost on the North Slope and has found that there, too, are regions where the permafrost is very nearly thirty-two degrees Fahrenheit. While the age of permafrost is difficult to determine, Romanovsky estimates that most of it in Alaska probably dates back to the beginning of the last glacial cycle. This means that if it thaws it will be doing so for the first time in more than a hundred and twenty thousand years. "It's really a very interesting time," he said.

The next morning, Romanovsky picked me up at seven. We were going to drive from Fairbanks nearly five hundred miles north to the town of Deadhorse, on Prudhoe Bay, to collect data from electronic monitoring stations that Romanovsky had set up. Since the road was largely unpaved, he had rented a truck for the occasion. Its windshield was cracked in several places. When I suggested this could be a problem, Romanovsky assured me that it was "typical Alaska." For provisions, he had brought along an oversized bag of Tostitos.

The road that we were travelling on had been built for Alaskan oil, and the pipeline followed it, sometimes to the left, sometimes to the right. (Because of the permafrost, the pipeline runs mostly aboveground, on pilings.) Trucks kept passing us, some with severed caribou heads strapped to their roofs, others advertising the Alyeska Pipeline Service Company. About two hours outside Fairbanks, we started to pass through tracts of forest that had recently burned, then tracts that were still smoldering, and, finally, tracts that were still, intermittently, in flames. The scene was part Dante, part "Apocalypse Now." We crawled along through the smoke. Beyond the town of Coldfoot—really just a gas station—we passed the tree line. An evergreen was marked with a plaque that read "Farthest North Spruce Tree on the Alaska Pipeline: Do Not Cut." Predictably, someone had taken a knife to it. A deep gouge around the trunk was bound with duct tape. "I think it will die," Romanovsky said.

Finally, at around five in the afternoon, we reached the turnoff for the first monitoring station. Because one of Romanovsky's colleagues had nursed dreams—never realized—of travelling to it by plane, it was near a small airstrip, on the far side of a river. We pulled on rubber boots and forded the river, which, owing to the lack of rain, was running low. The site consisted of a few posts sunk into the tundra; a solar panel; a two-hundred-foot-deep borehole with heavy-gauge wire sticking out of it; and a white container, resembling an ice chest, that held computer equipment. The solar panel, which the previous summer had been mounted a few feet off the ground, was now resting on the scrub. At first, Romanovsky speculated that this was a result of vandalism, but after inspecting things more closely he decided that it was the work of a bear. While he hooked up a laptop computer to one of the monitors inside the white container, my job was to keep an eye out for wildlife.

For the same reason that it is sweaty in a coal mine—heat flux from the center of the earth—permafrost gets warmer the farther down you go. Under equilibrium conditions—which is to say, when the climate is stable—the very warmest temperatures in a borehole will be found at the bottom and they will decrease steadily as you go higher. In these circumstances, the lowest temperature will be found at the permafrost's surface, so that, plotted on a graph, the results will be a tilted line. In recent decades, though, the temperature profile of Alaska's permafrost has drooped. Now, instead of a straight line, what you get is shaped more like a sickle. The permafrost is still warmest at the very bottom, but instead of being coldest at the top it is coldest somewhere in the middle, and warmer again toward the surface. This is an unambiguous sign that the climate is heating up.

"It's very difficult to look at trends in air temperature, because it's so variable," Romanovsky explained after we were back in the truck, bouncing along toward Deadhorse. It turned out that he had brought the Tostitos to stave off not hunger but fatigue—the crunching, he said, kept him awake—and by now the bag was more than half empty. "So one year you have around Fairbanks a mean annual temperature of zero"—thirty-two degrees Fahrenheit—"and you say, 'Oh yeah, it's warming,' and other years you have a mean annual temperature of minus six"—twenty-one degrees Fahrenheit—"and everybody says, 'Where? Where is your global warming?' In the air temperature, the signal is very small compared to noise. What permafrost does is it works as a low-pass filter. That's why we can see trends much easier in permafrost temperatures than we can see them in atmosphere." In most parts of Alaska, the permafrost has warmed by three degrees since the early nineteen-eighties. In some parts of the state, it has warmed by nearly six degrees.

When you walk around in the Arctic, you are stepping not on permafrost but on something called the "active layer." The active layer, which can be anywhere from a few inches to a few feet deep, freezes in the winter but thaws over the summer, and it is what supports the growth of plants—large spruce trees in places where conditions are favorable enough and, where they aren't, shrubs and, finally, just lichen. Life in the active layer proceeds much as it does in more temperate regions, with one critical difference. Temperatures are so low that when trees and grasses die they do not fully decompose. New plants grow out of the half-rotted old ones, and when these plants die the same thing happens all over again. Eventually, through a process known as cryoturbation, organic matter is pushed down beneath the active layer into the permafrost, where it can sit for thousands of years in a botanical version of suspended animation. (In Fairbanks, grass that is still green has been found in permafrost dating back to the middle of the last ice age.) In this way, much like a peat bog or, for that matter, a coal deposit, permafrost acts as a storage unit for accumulated carbon.

One of the risks of rising temperatures is that this storage process can start to run in reverse. Under the right conditions, organic material that has been frozen for millennia will break down, giving off carbon dioxide or methane, which is an even more powerful greenhouse gas. In parts of the Arctic, this is already happening. Researchers in Sweden, for example, have been measuring the methane output of a bog known as the Stordalen mire, near the town of Abisko, for almost thirty-five years. As the permafrost in the area has warmed, methane releases have increased, in some spots by up to sixty per cent. Thawing permafrost could make the active layer more hospitable to plants, which are a sink for carbon. Even this, though, probably wouldn't offset the release of greenhouse gases. No one knows exactly how much carbon is stored in the world's permafrost, but estimates run as high as four hundred and fifty billion metric tons.

"It's like ready-use mix—just a little heat, and it will start cooking," Romanovsky told me. It was the day after we had arrived in Deadhorse, and we were driving through a steady drizzle out to another monitoring site. "I think it's just a time bomb, just waiting for a little warmer conditions." Romanovsky was wearing a rain suit over his canvas work clothes. I put on a rain suit that he had brought along for me. He pulled a tarp out of the back of the truck.

Whenever he has had funding, Romanovsky has added new monitoring sites to his network. There are now sixty of them, and while we were on the North Slope he spent all day and also part of the night—it stayed light until nearly eleven—rushing from one to the next. At each site, the routine was more or less the same. First, Romanovsky would hook up his computer to the data logger, which had been recording permafrost temperatures on an hourly basis since the previous summer. (When it was raining, he would perform this step hunched under the tarp.) Then he would take out a metal probe shaped like a "T" and poke it into the ground at regular intervals, measuring the depth of the active layer. The probe was a metre long, which, it turned out, was no longer quite long enough. The summer had been so warm that almost everywhere the active layer had grown deeper, in some spots by just a few centimetres, in other spots by more than that; in places where the active layer was particularly deep, Romanovsky had had to work out a new way of measuring it using the probe and a wooden ruler. Eventually, he explained, the heat that had gone into increasing the depth of the active layer would work its way downward, bringing the permafrost that much closer to the thawing point. "Come back next year," he advised me.

On the last day I spent on the North Slope, a friend of Romanovsky's, Nicolai Panikov, a microbiologist at the Stevens Institute of Technology, in New Jersey, arrived. Panikov had come to collect cold-loving microörganisms known as psychrophiles. He was planning to study these organisms in order to determine whether they could have functioned in the sort of conditions that, it is believed, were once found on Mars. Panikov told me that he was quite convinced that Martian life existed—or, at least, had existed. Romanovsky expressed his opinion on this by rolling his eyes; nevertheless, he had agreed to help Panikov dig up some permafrost.

That day, I also flew with Romanovsky by helicopter to a small island in the Arctic Ocean, where he had set up yet another monitoring site. The island, just north of the seventieth parallel, was a bleak expanse of mud dotted with little clumps of yellowing vegetation. It was filled with ice wedges that were starting to melt, creating a network of polygonal depressions. The weather was cold and wet, so while Romanovsky hunched under his tarp I stayed in the helicopter and chatted with the pilot. He had lived in Alaska since 1967. “It’s definitely gotten warmer since I’ve been here,” he told me. “I have really noticed that.”

When Romanovsky emerged, we took a walk around the island. Apparently, in the spring it had been a nesting site for birds, because everywhere we went there were bits of eggshell and piles of droppings. The island was only about ten feet above sea level, and at the edges it dropped off sharply into the water. Romanovsky pointed out a spot along the shore where the previous summer a series of ice wedges had been exposed. They had since melted, and the ground behind them had given way in a cascade of black mud. In a few years, he said, he expected more ice wedges would be exposed, and then these would melt, causing further erosion. Although the process was different in its mechanics from what was going on in Shishmaref, it had much the same cause and, according to Romanovsky, was likely to have the same result. “Another disappearing island,” he said, gesturing toward some freshly exposed bluffs. “It’s moving very, very fast.”

On September 18, 1997, the Des Groseilliers, a three-hundred-and-eighteen-foot-long icebreaker with a bright-red hull, set out from the town of Tuktoyaktuk, on the Beaufort Sea, and headed north under overcast skies. Normally, the Des Groseilliers, which is based in Québec City, is used by the Canadian Coast Guard, but for this particular journey it was carrying a group of American geophysicists, who were planning to jam it into an ice floe. The scientists were hoping to conduct a series of experiments as they and the ship and the ice floe all drifted, as one, around the Arctic Ocean. The expedition had taken several years to prepare for, and during the planning phase its organizers had carefully consulted the findings of a previous Arctic expedition, which took place back in 1975. Based on those findings, they had decided to look for a floe averaging nine feet thick. But when they reached the area where they planned to overwinter—at seventy-five degrees north latitude—they found that not only were there no floes nine feet thick but there were barely any that reached six feet. One of the scientists on board recalled the reaction on the Des Groseilliers this way: “It was like ‘Here we are, all dressed up and nowhere to go.’ We imagined calling the sponsors at the National Science Foundation and saying, ‘Well, you know, we can’t find any ice.’ ”

Sea ice in the Arctic comes in two varieties. There is seasonal ice, which forms in the winter and then melts in the summer, and perennial ice, which persists year-round. To the untrained eye, all sea ice looks pretty much the same, but by licking it you can get a good idea of how long a particular piece has been floating around. When ice begins to form in seawater, it forces out the salt, which has no place in the crystal structure. As the ice gets thicker, the rejected salt collects in tiny pockets of brine too highly concentrated to freeze. If you suck on a piece of first-year ice, it will taste salty. Eventually, if the ice survives, these pockets of brine drain out through fine, vein-like channels, and the ice becomes fresher. Multiyear ice is so fresh that if you melt it you can drink it.

The most precise measurements of Arctic sea ice have been made by nasa, using satellites equipped with microwave sensors. In 1979, the satellite data show, perennial sea ice covered 1.7 billion acres, or an area nearly the size of the continental United States. The ice’s extent varies from year to year, but since then the over-all trend has been strongly downward. The losses have been particularly great in the Beaufort and Chukchi Seas, and also considerable in the Siberian and Laptev Seas. During this same period, an atmospheric circulation pattern known as the Arctic Oscillation has mostly been in what climatologists call a “positive” mode. The positive Arctic Oscillation is marked by low pressure over the Arctic Ocean, and it tends to produce strong winds and higher temperatures in the far north. No one really knows whether the recent behavior of the Arctic Oscillation is independent of global warming or a product of it. By now, though, the perennial sea ice has shrunk by roughly two hundred and fifty million acres, an area the size of New York, Georgia, and Texas combined. According to mathematical models, even the extended period of a positive Arctic Oscillation can account for only part of this loss.

The researchers aboard the Des Groseilliers knew that the Arctic sea ice was retreating; that was, in fact, why they were there. At the time, however, there wasn’t much data on trends in sea-ice depth. (Since then, a limited amount of information on this topic—gathered, for rather different purposes, by nuclear submarines—has been declassified.) Eventually, the researchers decided to settle for the best ice floe they could find. They picked one that stretched over some thirty square miles and in some spots was six feet thick, in some spots three. Tents were set up on the floe to house experiments, and a safety protocol was established: anyone venturing out onto the ice had to travel with a buddy and a radio. (Many also carried a gun, in case of polar-bear problems.) Some of the scientists speculated that, since the ice was abnormally thin, it would grow during the expedition. The opposite turned out to be the case. The Des Groseilliers spent twelve months frozen into the floe, and, during that time, it drifted some three hundred miles north. Nevertheless, at the end of the year, the average thickness of the ice had declined, in some spots by as much as a third. By August, 1998, so many of the scientists had fallen through that a new requirement was added to the protocol: anyone who set foot off the ship had to wear a life jacket.

Donald Perovich has studied sea ice for thirty years, and on a rainy day last fall I went to visit him at his office in Hanover, New Hampshire. Perovich works for the Cold Regions Research and Engineering Laboratory, or crrel (pronounced “crell”), a division of the U.S. Army established in 1961 in anticipation of a very cold war. (The assumption was that if the Soviets invaded they would probably do so from the north.) He is a tall man with black hair, very black eyebrows, and an earnest manner. His office is decorated with photographs from the Des Groseilliers expedition, for which he served as the lead scientist; there are shots of the ship, the tents, and, if you look closely enough, the bears. One grainy-looking photo shows someone dressed up as Santa Claus, celebrating Christmas out on the ice. “The most fun you could ever have” was how Perovich described the expedition to me.

Perovich’s particular area of expertise, in the words of his crrel biography, is “the interaction of solar radiation with sea ice.” During the Des Groseilliers expedition, he spent most of his time monitoring conditions on the floe using a device known as a spectroradiometer. Facing toward the sun, a spectroradiometer measures incident light, and facing toward earth it measures reflected light. If you divide the latter by the former, you get a quantity known as albedo. (The term comes from the Latin word for “whiteness.”) During April and May, when conditions on the floe were relatively stable, Perovich took measurements with his spectroradiometer once a week, and during June, July, and August, when they were changing more rapidly, he took measurements every other day. The arrangement allowed him to plot exactly how the albedo varied as the snow on top of the ice turned to slush, and then the slush became puddles, and, finally, some of the puddles melted through to the water below.

An ideal white surface, which reflected all the light that shone on it, would have an albedo of one, and an ideal black surface, which absorbed all the light, would have an albedo of zero. The albedo of the earth, in aggregate, is 0.3, meaning that a little less than a third of the sunlight that hits it gets reflected back out. Anything that changes the earth’s albedo changes how much energy the planet absorbs, with potentially dramatic consequences. “I like it because it deals with simple concepts, but it’s important,” Perovich told me.

At one point, Perovich asked me to imagine that we were looking down at the earth from a spaceship above the North Pole. “It’s springtime, and the ice is covered with snow, and it’s really bright and white,” he said. “It reflects over eighty per cent of the incident sunlight. The albedo’s around 0.8, 0.9. Now, let’s suppose that we melt that ice away and we’re left with the ocean. The albedo of the ocean is less than 0.1; it’s like 0.07.

“Not only is the albedo of the snow-covered ice high; it’s the highest of anything we find on earth,” he went on. “And not only is the albedo of water low; it’s pretty much as low as anything you can find on earth. So what you’re doing is you’re replacing the best reflector with the worst reflector.” The more open water that’s exposed, the more solar energy goes into heating the ocean. The result is a positive feedback, similar to the one between thawing permafrost and carbon releases, only more direct. This so-called ice-albedo feedback is believed to be a major reason that the Arctic is warming so rapidly.

“As we melt that ice back, we can put more heat into the system, which means we can melt the ice back even more, which means we can put more heat into it, and, you see, it just kind of builds on itself,” Perovich said. “It takes a small nudge to the climate system and amplifies it into a big change.”

A few dozen miles to the east of crrel, not far from the Maine-New Hampshire border, is a small park called the Madison Boulder Natural Area. The park’s major—indeed, only—attraction is a block of granite the size of a two-story house. The Madison Boulder is thirty-seven feet wide and eighty-three feet long and weighs about ten million pounds. It was plucked out of the White Mountains and deposited in its current location eleven thousand years ago, and it illustrates how relatively minor changes to the climate system have, when amplified, yielded cataclysmic results.

Geologically speaking, we are now living in a warm period after an ice age. Over the past two million years, huge ice sheets have advanced across the Northern Hemisphere and retreated again more than twenty times. (Each major glaciation tended, for obvious reasons, to destroy the evidence of its predecessors.) The most recent advance, called the Wisconsin, began roughly a hundred and twenty thousand years ago, when ice began to creep outward from centers in Scandinavia, Siberia, and the highlands near Hudson Bay. By the time the sheets had reached their maximum southern extent, most of New England and New York and a good part of the upper Midwest were buried under ice nearly a mile thick. The ice sheets were so heavy that they depressed the crust of the earth, pushing it down into the mantle. (In some places, the process of recovery, known as isostatic rebound, is still going on.) As the ice retreated, it deposited, among other landmarks, the terminal moraine called Long Island.

It is now known, or at least almost universally accepted, that glacial cycles are initiated by slight, periodic variations in the earth's orbit. These orbital variations alter the distribution of sunlight at different latitudes during different seasons according to a complex pattern that takes a hundred thousand years to complete. But orbital variations in themselves aren't nearly sufficient to produce the sort of massive ice sheet that moved the Madison Boulder.

The crushing size of that ice sheet, the Laurentide, which stretched over some five million square miles, was the result of feedbacks, more or less analogous to those now being studied in the Arctic, only operating in reverse. As ice built up, albedo increased, leading to less heat absorption and the growth of yet more ice. At the same time, for reasons that are not entirely understood, as the ice sheets advanced CO2 levels declined: during each of the most recent glaciations, carbon-dioxide levels dropped almost precisely in synch with falling temperatures. During each warm period, when the ice retreated, CO2 levels rose again. Ice cores from Antarctica contain a record of the atmosphere stretching back more than four glacial cycles—minute samples of air get trapped in tiny bubbles—and researchers who have studied these cores have concluded that fully half the temperature difference between cold periods and warm ones can be attributed to changes in the concentrations of greenhouse gases. Antarctic ice cores also show that carbon-dioxide levels today are significantly higher than they have been at any other point in the last four hundred and twenty thousand years.

While I was at crrel, Perovich took me to meet a colleague of his named John Weatherly. Posted on Weatherly's office door was a bumper sticker designed to be pasted—illicitly—on S.U.V.s. It said, "I'm Changing the Climate! Ask Me How!" For the last several years, Weatherly and Perovich have been working to translate the data gathered on the Des Groseilliers expedition into computer algorithms to be used in climate forecasting. Weatherly told me that some climate models—worldwide, there are about fifteen major ones in operation—predict that the perennial sea-ice cover in the Arctic will disappear entirely by the year 2080. At that point, although there would continue to be seasonal ice that forms in winter, in summer the Arctic Ocean would be completely ice-free. "That's not in our lifetime," he observed. "But it is in the lifetime of our kids."

Later, back in his office, Perovich and I talked about the long-term prospects for the Arctic. Perovich noted that the earth's climate system is so vast that it is not easily altered. "On the one hand, you think, It's the earth's climate system, it's big; it's robust. And, indeed, it has to be somewhat robust or else it would be changing all the time." On the other hand, the climate record shows that it would be a mistake to assume that change, when it comes, will come slowly. Perovich offered a comparison that he had heard from a glaciologist friend. The friend likened the climate system to a rowboat: "You can tip and then you'll just go back. You can tip it and just go back. And then you tip it and you get to the other stable state, which is upside down."

Perovich said that he also liked a regional analogy. "The way I've been thinking about it, riding my bike around here, is, You ride by all these pastures and they've got these big granite boulders in the middle of them. You've got a big boulder sitting there on this rolling hill. You can't just go by this boulder. You've got to try to push it. So you start rocking it, and you get a bunch of friends, and they start rocking it, and finally it starts moving. And then you realize, Maybe this wasn't the best idea. That's what we're doing as a society. This climate, if it starts rolling, we don't really know where it will stop."

As a cause for alarm, global warming could be said to be a nineteen-seventies idea; as pure science, however, it is much older than that. In 1859, a British physicist named John Tyndall, experimenting with a machine he had built—the world's first ratio spectrophotometer—set out to study the heat-trapping properties of various gases. Tyndall found that the most common elements in the air—oxygen and nitrogen—were transparent to both visible and infrared radiation. Gases like carbon dioxide, methane, and water vapor, by contrast, were not. Tyndall was quick to appreciate the implications of his discovery: the imperfectly transparent gases, he declared, were largely responsible for determining the earth's climate. He likened their impact to that of a dam built across a river: just as a dam "causes a local deepening of the stream, so our atmosphere, thrown as a barrier across the terrestrial rays, produces a local heightening of the temperature at the earth's surface."

The phenomenon that Tyndall identified is now referred to as the "natural greenhouse effect." It is not remotely controversial; indeed, it's an essential condition of life on earth as we know it. To understand how it works, it helps to imagine the planet without it. In that situation, the earth would constantly be receiving energy from the sun and, at the same time, constantly radiating energy back out to space. All hot bodies radiate, and the amount that they radiate is a function of their temperature. In order for the earth to be in equilibrium, the quantity of energy it sends into space must equal the quantity it is receiving. When, for whatever reason, equilibrium is disturbed, the planet will either warm up or cool down until the temperature is once again sufficient to make the two energy streams balance out.

If there were no greenhouse gases, energy radiating from the surface of the earth would flow away from it unimpeded. In that case, it would be comparatively easy to calculate how warm the planet would have to get to throw back into space the same amount of energy it absorbs from the sun. (This amount varies widely by location and time of year; averaged out, it comes to some two hundred and thirty-five watts per square metre, or roughly the energy of four household light bulbs.) The result of this calculation is a frigid zero degrees. To use Tyndall's Victorian language, if the heat-trapping gases were removed from the air for a single night "the warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost."

Greenhouse gases alter the situation because of their peculiar absorptive properties. The sun's radiation arrives mostly in the form of visible light, which greenhouse gases allow to pass freely. The earth's radiation, meanwhile, is emitted mostly in the infrared part of the spectrum. Greenhouse gases absorb infrared radiation and then reëmit it—some out toward space and some back toward earth. This process of absorption and reëmission has the effect of limiting the outward flow of energy; as a result, the earth's surface and lower atmosphere have to be that much warmer before the planet can radiate out the necessary two hundred and thirty-five watts per square metre. The presence of greenhouse gases is what largely accounts for the fact that the average global temperature, instead of zero, is actually a far more comfortable fifty-seven degrees.

By the end of the nineteenth century, Tyndall's work on the natural greenhouse effect had been extended to what would today be called the "enhanced greenhouse effect." In 1894, the Swedish chemist Svante Arrhenius became convinced that humans were altering the earth's energy balance. Much as Tyndall had tried to imagine what the world would be like in the absence of greenhouse gases, Arrhenius tried to imagine what it would be like in the presence of more of them. Starting on Christmas Eve, he set out to calculate what would happen to the earth's temperature if CO2 levels were doubled. Arrhenius described the calculations as some of the most tedious of his life. He routinely worked on them for fourteen hours a day, and was not finished for nearly a year. Finally, in December, 1895, he announced his results to the Royal Swedish Academy of Sciences.

Like the natural greenhouse effect, the enhanced greenhouse effect is—in theoretical terms, at least—uncontroversial. If greenhouse-gas levels in the atmosphere increase, all other things being equal, the earth's temperature will rise. The key uncertainties concern how this process will play out in practice, since in the real world all things rarely are equal. For several decades after Arrhenius completed his calculations, scientists were unsure to what extent mankind was even capable of affecting atmospheric carbon-dioxide levels; the general assumption was that the oceans would absorb just about everything humans could emit. Arrhenius himself predicted that it would take three thousand years of coal burning to double the CO2 in the air, a prediction, it is now known, that was off by roughly twenty-eight centuries.

Swiss Camp is a research station set up in 1990 on a platform drilled into the Greenland ice sheet. Because the ice sheet is moving—ice flows like water, only more slowly—the camp is always in motion: in fifteen years, it has migrated by more than a mile, generally in a westerly direction. Every summer, the whole place gets flooded, and every winter its contents solidify. The cumulative effect of all this is that almost nothing at Swiss Camp functions anymore the way it was supposed to. To get into it, you have to clamber up a snowdrift and descend through a trapdoor in the roof, as if entering a ship's hold or a space module. The living quarters are no longer habitable, so now the scientists at the camp sleep outside, in tents. (The one assigned to me was the same sort used by Robert Scott on his ill-fated expedition to the South Pole.) By the time I arrived at the camp, late last May, someone had jackhammered out the center of the workspace but had left the desks encased in three-foot-high blocks of ice. Inside them I could dimly make out a tangle of wires, a bulging plastic bag, and an old dustpan.

Konrad Steffen, a professor of geography at the University of Colorado, is the director of Swiss Camp. A native of Zurich, Steffen is tall and lanky, with pale-blue eyes, blondish hair, and a blondish-gray beard. He fell in love with the Arctic when, as a graduate student in 1975, he spent a summer on Axel Heiberg Island, four hundred miles northwest of the north magnetic pole. A few years later, for his doctoral dissertation, he lived for two winters on the sea ice off Baffin Island. (Steffen told me that for his honeymoon he had wanted to take his wife to Spitsbergen, an island five hundred miles north of Norway, but she demurred, and they had ended up driving across the Sahara instead.)

When Steffen planned Swiss Camp—he built much of the place himself—it was not with global warming in mind. Rather, he was interested in meteorological conditions on what is known as the ice sheet's "equilibrium line." Along this line, winter snow and summer melt are supposed to be precisely in balance. But, in recent years, "equilibrium" has become an increasingly elusive quality. In the summer of 2002, the ice sheet melted to an unprecedented extent. Satellite images taken by nasa showed that snow had melted up to an elevation of sixty-five hundred feet. In some of these spots, ice-core records revealed, liquid water had not been seen for hundreds, perhaps thousands, of years. The following winter, there was an unusually low snowfall, and in the summer of 2003 the melt was so great that, around Swiss Camp, five feet of ice were lost.

When I arrived at the camp, the 2004 melt season was already under way. This, to Steffen, was a matter of both intense scientific interest and serious practical concern. A few days earlier, one of his graduate students, Russell Huff, and a postdoc, Nicolas Cullen, had driven out on snowmobiles to service some weather stations closer to the coast. The snow there was melting so fast that they had had to work until five in the morning, and then take a long detour back, to avoid getting caught in the quickly forming rivers. Steffen wanted to get everything that needed to be done completed ahead of schedule, in case everyone had to pack up and leave early. My first day at Swiss Camp he spent fixing an antenna that had fallen over in the previous year's melt. It was bristling with equipment, like a high-tech Christmas tree. Even on a relatively warm day on the ice sheet, which this was, it never gets more than a few degrees above freezing, and I was walking around in a huge parka, two pairs of pants plus long underwear, and two pairs of gloves. Steffen, meanwhile, was tinkering with the antenna with his bare hands. He has spent fourteen summers at Swiss Camp, and I asked him what he had learned during that time. He answered with another question.

"Are we disintegrating part of the Greenland ice sheet over the longer term?" he asked. He was sorting through a tangle of wires that to me all looked the same but must have had some sort of distinguishing characteristics. "What the regional models tell us is that we will get more melt at the coast. It will continue to melt. But warmer air can hold more water vapor, and at the top of the ice sheet you'll get more precipitation. So we'll add more snow there. We'll get an imbalance of having more accumulation at the top, and more melt at the bottom. The key question now is: What is the dominant one, the more melt or the increase?"

Greenland's ice sheet is the second-largest on earth. (Antarctica's is the largest.) In its present form, the Greenland ice sheet is, quite literally, a relic of the last glaciation. The top layers consist of snow that fell recently. Beneath these layers is snow that fell centuries and then millennia ago, until, at the very bottom, there is snow that fell a hundred and thirty thousand years ago. Under current climate conditions, the ice sheet probably would not form, and it is only its enormous size that has sustained it for this long. In the middle of the island, the ice is so thick—nearly two miles—that it creates a kind of perpetual winter. Snow falls in central Greenland year-round and it never melts, although, over time, the snow gets compacted into ice and is pressed out toward the coast. There, eventually, it either calves off into icebergs or flows away. In summertime, lakes of a spectacular iridescent blue form at the ice sheet's lower elevations; these empty into vast rivers that fan out toward the sea. Near Swiss Camp—elevation 3,770 feet—there is a huge depression where one such lake forms each July, but by that point no one is around to see it: it would be far too dangerous.

Much of what is known about the earth's climate over the last hundred thousand years comes from ice cores drilled in central Greenland, along a line known as the ice divide. Owing to differences between summer and winter snow, each layer in a Greenland core can be individually dated, much like the rings of a tree. Then, by analyzing the isotopic composition of the ice, it is possible to determine how cold it was at the time each layer was formed. (Although ice cores from Antarctica contain a much longer climate record, it is not as detailed.) Over the last decade, three Greenland cores have been drilled to a depth of ten thousand feet, and these cores have prompted a rethinking of how the climate operates. Where once the system was thought to change, as it were, only glacially, now it is known to be capable of sudden and unpredictable reversals. One such reversal, called the Younger Dryas, after a small Arctic plant—Dryas octopetala—that suddenly reappeared in Scandinavia, took place roughly twelve thousand eight hundred years ago. At that point, the earth, which had been warming rapidly, was plunged back into glacial conditions. It remained frigid for twelve centuries and then warmed again, even more abruptly. In Greenland, average annual temperatures shot up by nearly twenty degrees in a single decade.

As a continuous temperature record, the Greenland ice cores stop providing reliable information right around the start of the last glacial cycle. Climate records pieced together from other sources indicate that the last interglacial, which is known as the Eemian, was somewhat warmer than the present one, the Holocene. They also show that sea levels during that time were at least fifteen feet higher than they are today. One theory attributes this to a collapse of the West Antarctic Ice Sheet. A second holds that meltwater from Greenland was responsible. (When sea ice melts, it does not affect sea level, because the ice, which was floating, was already displacing an equivalent volume of water.) All told, the Greenland ice sheet holds enough water to raise sea levels worldwide by twenty-three feet. Scientists at nasa have calculated that throughout the nineteen-nineties the ice sheet, despite some thickening at the center, was shrinking by twelve cubic miles per year.

Jay Zwally is a nasa scientist who works on a satellite project known as icesat. He is also a friend of Steffen's, and about ten years ago he got the idea of installing global-positioning-system receivers around Swiss Camp to study changes in the ice sheet's elevation. Zwally happened to be at the camp while I was there, and the second day of my visit we all got onto snowmobiles and headed out to a location known as jar 1 (for Jakobshavn Ablation Region) to reinstall a G.P.S. receiver. The trip was about ten miles. Midway through it, Zwally told me that he had once seen spy-satellite photos of the region we were crossing, and that they had shown that underneath the snow it was full of crevasses. Later, when I asked Steffen about this, he told me that he had had the whole area surveyed with bottom-seeking radar, and no crevasses of any note had been found. I was never sure which one of them to believe.

Reinstalling Zwally's G.P.S. receiver entailed putting up a series of poles, a process that, in turn, required drilling holes thirty feet down into the ice. The drilling was done not mechanically but thermally, using a steam drill that consisted of a propane burner, a steel tank to hold snow, and a long rubber hose. Everyone—Steffen, Zwally, the graduate students, me—took a turn. This meant holding onto the hose while it melted its way down, an activity reminiscent of ice fishing. Seventy-five years ago, not far from jar 1, Alfred Wegener, the German scientist who proposed the theory of continental drift, died while on a meteorological expedition. He was buried in the ice sheet, and there is a running joke at Swiss Camp about stumbling onto his body. “It’s Wegener!” one of the graduate students exclaimed, as the drill worked its way downward. The first hole was finished relatively quickly, at which point everyone decided—prematurely, as it turned out—that it was time for a midday snack. Unless a hole stays filled with water, it starts to close up again, and can’t be used. Apparently, there were fissures in the ice, because water kept draining out of the next few holes that were tried. The original plan had been for three holes, but, some six hours later, only two had been drilled, and it was decided that this would have to suffice.

Although Zwally had set out to look for changes in the ice sheet’s elevation, what he ended up measuring was, potentially, even more significant. His G.P.S. data showed that the more the ice sheet melted the faster it started to move. Thus in the summer of 1996, the ice around Swiss Camp moved at a rate of thirteen inches per day, but in 2001 it had sped up to twenty inches per day. The reason for this acceleration, it is believed, is that meltwater from the surface makes its way down to the bedrock below, where it acts as a lubricant. (In the process, it enlarges cracks and forms huge ice tunnels, known as moulins.) Zwally’s measurements also showed that, in the summer, the ice sheet rises by about six inches, indicating that it is floating on a cushion of water.

At the end of the last glaciation, the ice sheets that covered much of the Northern Hemisphere disappeared in a matter of a few thousand years—a surprisingly short time, considering how long it had taken them to build up. At one point, about fourteen thousand years ago, they were melting so fast that sea levels were rising at the rate of more than a foot a decade. Just how this happened is not entirely understood, but the acceleration of the Greenland ice sheet suggests yet another feedback mechanism: once an ice sheet begins to melt, it starts to flow faster, which means it also thins out faster, encouraging further melt. Not far from Swiss Camp, there is a huge river of ice known as the Jakobshavn Isbrae, which probably was the source of the iceberg that sank the Titanic. In 1992, the Jakobshavn Isbrae flowed at a rate of three and a half miles per hour; by 2003, its velocity had increased to 7.8 miles per hour. Similar findings were announced earlier this year by scientists measuring the flow of ice streams on the Antarctic Peninsula.

Over the last century, global sea levels have risen by about half a foot. The most recent report of the U.N.’s Intergovernmental Panel on Climate Change, issued in 2001, predicts that they will rise anywhere from four inches to three feet by the year 2100. This prediction includes almost no contribution from Greenland or Antarctica; it is based mostly on the physics of water, which, as it warms up, expands. Two climatologists at Pennsylvania State University, Richard Alley and Byron Parizek, recently issued new predictions that take into account the observed acceleration of the ice sheets; this effect in Greenland alone, they estimate, will cause up to two and half inches of additional sea-level rise over the coming century. James Hansen, the nasa official who directed one of the initial nineteen-seventies studies on the effects of carbon dioxide, has gone much further, arguing that if greenhouse-gas emissions are not controlled the total disintegration of the Greenland ice sheet could be set in motion in a matter of decades. Although the process would take hundreds, perhaps thousands, of years to fully play out, once begun it would become self-reinforcing, and hence virtually impossible to stop. In an article published earlier last year in the journal Climatic Change, Hansen, who is now the head of the Goddard Institute for Space Studies, wrote that he hoped he was wrong about the ice sheet, “but I doubt it.”

As it happened, I was at Swiss Camp just as last summer’s global-warming disaster movie, “The Day After Tomorrow,” was opening in theatres. One night, Steffen’s wife called on the camp’s satellite phone to say that she had just taken the couple’s two teen-age children to see it. Everyone had enjoyed the film, she reported, especially because of the family connection.

The fantastic conceit of “The Day After Tomorrow” is that global warming produces global freezing. At the start of the film, a chunk of Antarctic ice the size of Rhode Island suddenly melts. (Something very similar to this actually happened in March, 2002, when the Larsen B ice shelf collapsed.) Most of what follows—an instant ice age, cyclonic winds that descend from the upper atmosphere—is impossible as science but not as metaphor. The record preserved in the Greenland ice sheet shows that over the last hundred thousand years temperatures have often swung wildly—so often that it is our own relatively static experience of climate that has come to look exceptional. Nobody knows what caused the sudden climate shifts of the past; however, many climatologists suspect that they had something to do with changes in ocean-current patterns that are known as the thermohaline circulation.

“When you freeze sea ice, the salt is pushed out of the pores, so that the salty water actually drains,” Steffen explained to me one day when we were standing out on the ice, trying to talk above the howl of the wind. “And salty water’s actually heavier, so it starts to sink.” Meanwhile, owing both to evaporation and to heat loss, water from the tropics becomes denser as it drifts toward the Arctic, so that near Greenland a tremendous volume of seawater is constantly sinking toward the ocean floor. As a result of this process, still more warm water is drawn from the tropics toward the poles, setting up what is often referred to as a “conveyor belt” that moves heat around the globe.

“This is the energy engine for the world climate,” Steffen went on. “And it has one source: the water that sinks down. And if you just turn the knob here a little bit”—he made a motion of turning the water on in a bathtub—“we can expect significant temperature changes based on the redistribution of energy.” One way to turn the knob is to heat the oceans, which is already happening. Another is to pour more freshwater into the polar seas. This is also occurring. Not only is runoff from coastal Greenland increasing; the volume of river discharge into the Arctic Ocean has been rising. Oceanographers monitoring the North Atlantic have documented that in recent decades its waters have become significantly less salty. A total shutdown of the thermohaline circulation is considered extremely unlikely in the coming century. But, if the Greenland ice sheet started to disintegrate, the possibility of such a shutdown could not be ruled out. Wallace Broecker, a professor of geochemistry at Columbia University’s Lamont-Doherty Earth Observatory, has labelled the thermohaline circulation the “Achilles’ heel of the climate system.” Were it to halt, places like Britain, whose climate is heavily influenced by the Gulf Stream, could become much colder, even as the planet as a whole continued to warm up.

For the whole time I was at Swiss Camp, it was “polar day,” and so the sun never set. Dinner was generally served at 10 or 11 p.m., and afterward everyone sat around a makeshift table in the kitchen, talking and drinking coffee. (Because it is not—strictly speaking—necessary, alcohol was in short supply.) One night, I asked Steffen what he thought conditions at Swiss Camp would be like in the same season a decade hence. “In ten years, the signal should be much more distinct, because we will have added another ten years of greenhouse warming,” he said. Zwally interjected, “I predict that ten years from now we won’t be coming this time of year. We won’t be able to come this late. To put it nicely, we are heading into deep doo-doo.”

Either by disposition or by training, Steffen was reluctant to make specific predictions, whether about Greenland or, more generally, about the Arctic. Often, he prefaced his remarks by noting that there could be a change in atmospheric-circulation patterns that would dampen the rate of temperature increase or even—temporarily at least—reverse it entirely. But he was emphatic that “climate change is a real thing.

“It’s not something dramatic now—that’s why people don’t really react,” he told me. “But if you can convey the message that it will be dramatic for our children and our children’s children—the risk is too big not to care.”

The time, he added, “is already five past midnight.”

On the last night that I spent at Swiss Camp, Steffen took the data he had downloaded off his weather station and, after running them through various programs on his laptop, produced the mean temperature at the camp for the previous year. It was the highest of any year since the camp was built.

That night, dinner was unusually late. On the return trip of another pole-drilling expedition, one of the snowmobiles had caught on fire, and had to be towed back to camp. When I finally went out to my tent to go to bed, I found that the snow underneath it had started to melt, and there was a large puddle in the middle of the floor. I got some paper towels and tried to mop it up, but the puddle was too big, and eventually I gave up.

No nation takes a keener interest in climate change, at least on a per-capita basis, than Iceland. More than ten per cent of the country is covered by glaciers, the largest of which, Vatnajökull, stretches over thirty-two hundred square miles. During the so-called Little Ice Age, the advance of the glaciers caused widespread misery; it has been estimated that in the mid-eighteenth century nearly a third of the country’s population died of starvation or associated ills. For Icelanders, many of whom can trace their genealogy back a thousand years, this is considered to be almost recent history.

Oddur Sigurdsson heads up a group called the Icelandic Glaciological Society. One day last fall, I went to visit him in his office, at the headquarters of Iceland’s National Energy Authority, in Reykjavík. Little towheaded children kept wandering in to peer under his desk. Sigurdsson explained that Reykjavík’s public schoolteachers were on strike, and his colleagues had had to bring their children to work.

The Icelandic Glaciological Society is composed entirely of volunteers. Every fall, after the summer-melt season has ended, they survey the size of the country’s three hundred-odd glaciers and then file reports, which Sigurdsson collects in brightly colored binders. In the organization’s early years—it was founded in 1930—the volunteers were mostly farmers; they took measurements by building cairns and pacing off the distance to the glacier’s edge. These days, members come from all walks of life—one is a retired plastic surgeon—and they take more exacting surveys, using tape measures and iron poles. Some glaciers have been in the same family, so to speak, for generations. Sigurdsson became head of the society in 1987, at which point one volunteer told him that he thought he would like to relinquish his post.

“He was about ninety when I realized how old he was,” Sigurdsson recalled. “His father had done this at that place before and then his nephew took over for him.” Another volunteer has been monitoring his glacier, a section of Vatnajökull, since 1948. “He’s eighty," Sigurdsson said. "And if I have some questions that go beyond his age I just go and ask his mother. She's a hundred and seven."

In contrast to glaciers in North America, which have been shrinking steadily since the nineteen-sixties, Iceland's glaciers grew through the nineteen-seventies and eighties. Then, in the mid-nineteen-nineties, they, too, began to decline, at first slowly and then much more rapidly. Sigurdsson pulled out a notebook of glaciological reports, filled out on yellow forms, and turned to the section on a glacier called Sólheimajökull, a tongue-shaped spit of ice that sticks out from a much larger glacier, called My´rdalsjökull. In 1996, Sólheimajökull crept back by ten feet. In 1997, it receded by another thirty-three feet, and in 1998 by ninety-eight feet. Every year since then, it has retreated even more. In 2003, it shrank by three hundred and two feet and in 2004 by two hundred and eighty-five feet. All told, Sólheimajökull—the name means "sun-home glacier" and refers to a nearby farm—is now eleven hundred feet shorter than it was just a decade ago. Sigurdsson pulled out another notebook, which was filled with slides. He picked out some recent ones of Sólheimajökull. The glacier ended in a wide river. An enormous rock, which Sólheimajökull had deposited when it began its retreat, stuck out from the water, like the hull of an abandoned ship.

"You can tell by this glacier what the climate is doing," Sigurdsson said. "It is more sensitive than the most sensitive meteorological measurement." He introduced me to a colleague of his, Kristjana Eythórsdóttir, who, as it turned out, was the granddaughter of the founder of the Icelandic Glaciological Society. Eythórsdóttir keeps tabs on a glacier named Leidarjökull, which is a four-hour trek from the nearest road. I asked her how it was doing. "Oh, it's getting smaller and smaller, just like all the others," she said. Sigurdsson told me that climate models predicted that by the end of the next century Iceland would be virtually ice-free. "We will have small ice caps on the highest mountains, but the mass of the glaciers will have gone," he said. It is believed that there have been glaciers on Iceland for the last few million years. "Probably longer," Sigurdsson said.

In October, 2000, in a middle school in Barrow, Alaska, officials from the eight Arctic nations—the U.S., Russia, Canada, Denmark, Norway, Sweden, Finland, and Iceland—met to talk about global warming. The group announced plans for a three-part, two-million-dollar study of climate change in the region. This past fall, the first two parts of the study—a massive technical document and a hundred-and-forty-page summary—were presented at a symposium in Reykjavík.

The day after I went to talk to Sigurdsson, I attended the symposium's plenary session. In addition to nearly three hundred scientists, it drew a sizable contingent of native Arctic residents—reindeer herders, subsistence hunters, and representatives of groups like the Inuvialuit Game Council. In among the shirts and ties, I spotted two men dressed in the brightly colored tunics of the Sami and several others wearing sealskin vests. As the session went on, the subject kept changing—from hydrology and biodiversity to fisheries and on to forests. The message, however, stayed the same. Almost wherever you looked, temperatures in the Arctic were rising, and at a rate that surprised even those who had expected to find clear signs of climate change. Robert Corell, an American oceanographer and a former assistant director at the National Science Foundation, coördinated the study. In his opening remarks, he ran through its findings—shrinking sea ice, receding glaciers, thawing permafrost—and summed them up as follows: "The Arctic climate is warming rapidly now, with an emphasis on now." Particularly alarming, Corell said, were the most recent data from Greenland, which showed the ice sheet melting much faster "than we thought possible even a decade ago."

Global warming is routinely described as a matter of scientific debate—a theory whose validity has yet to be demonstrated. This characterization, or at least a variant of it, is offered most significantly by the Bush Administration, which maintains that there is still insufficient scientific understanding to justify mandatory action. The symposium's opening session lasted for more than nine hours. During that time, many speakers stressed the uncertainties that remain about global warming and its effects—on the thermohaline circulation, on the distribution of vegetation, on the survival of cold-loving species, on the frequency of forest fires. But this sort of questioning, which is so basic to scientific discourse, never extended to the relationship between carbon dioxide and rising temperatures. The study's executive summary stated, unequivocally, that human beings had become the "dominant factor" influencing the climate. During an afternoon coffee break, I caught up with Corell. "Let's say that there's three hundred people in this room," he told me. "I don't think you'll find five who would say that global warming is just a natural process."

The third part of the Arctic-climate study, which was still unfinished at the time of the symposium, was the so-called "policy document." This was supposed to outline practical steps to be taken in response to the scientific findings, including—presumably—reducing greenhouse-gas emissions. The policy document remained unfinished because American negotiators had rejected much of the language proposed by the seven other Arctic nations. (A few weeks later, the U.S. agreed to a vaguely worded statement calling for "effective"—but not obligatory—actions to combat the problem.) This recalcitrance left those Americans who had travelled to Reykjavík in an awkward position. A few tried—halfheartedly—to defend the Administration's stand to me; most, including many government employees, were critical of it. At one point, Corell observed that the loss of sea ice since the late nineteen-seventies was equal to "the size of Texas and Arizona combined. That analogy was made for obvious reasons."

That evening, at the hotel bar, I talked to an Inuit hunter named John Keogak, who lives on Banks Island, in Canada's Northwest Territories, some five hundred miles north of the Arctic Circle. He told me that he and his fellow-hunters had started to notice that the climate was changing in the mid-eighties. A few years ago, for the first time, people began to see robins, a bird for which the Inuit in his region have no word.

"We just thought, Oh, gee, it's warming up a little bit," he recalled. "It was good at the start—warmer winters, you know—but now everything is going so fast. The things that we saw coming in the early nineties, they've just multiplied.

"Of the people involved in global warming, I think we're on top of the list of who would be most affected," Keogak went on. "Our way of life, our traditions, maybe our families. Our children may not have a future. I mean, all young people, put it that way. It's just not happening in the Arctic. It's going to happen all over the world. The whole world is going too fast."

The symposium in Reykjavík lasted for four days. One morning, when the presentations on the agenda included "Char as a Model for Assessing Climate Change Impacts on Arctic Fishery Resources," I decided to rent a car and take a drive. In recent years, Reykjavík has been expanding almost on a daily basis, and the old port city is now surrounded by rings of identical, European-looking suburbs. Ten minutes from the car-rental place, these began to give out, and I found myself in a desolate landscape in which there were no trees or bushes or really even soil. The ground—fields of lava from some defunct, or perhaps just dormant, volcanoes—resembled macadam that had recently been bulldozed. I stopped to get a cup of coffee in the town of Hveragerdi, where roses are raised in greenhouses heated with steam that pours directly out of the earth. Farther on, I crossed into farm country; the landscape was still treeless, but now there was grass, and sheep eating it. Finally, I reached the sign for Sólheimajökull, the glacier whose retreat Oddur Sigurdsson had described to me. I turned off onto a dirt road. It ran alongside a brown river, between two crazily shaped ridges. After a few miles, the road ended, and the only option was to continue on foot.

By the time I got to the lookout over Sólheimajökull, it was raining. In the gloomy light, the glacier looked forlorn. Much of it was gray—covered in a film of dark grit. In its retreat, it had left behind ridged piles of silt. These were jet black and barren—not even the tough local grasses had had a chance to take root on them. I looked for the enormous boulder I had seen in the photos in Sigurdsson's office. It was such a long way from the edge of the glacier that for a moment I wondered if perhaps it had been carried along by the current. A raw wind came up, and I started to head down. Then I thought about what Sigurdsson had told me. If I returned in another decade, the glacier would probably no longer even be visible from the ridge where I was standing. I climbed back up to take a second look.
(This is the first part of a three-part article.)

THE CLIMATE OF MAN—II
by ELIZABETH KOLBERT
The curse of Akkad.
Issue of 2005-05-02

The world's first empire was established forty-three hundred years ago, between the Tigris and Euphrates Rivers. The details of its founding, by Sargon of Akkad, have come down to us in a form somewhere between history and myth. Sargon—Sharru-kin, in the language of Akkadian—means "true king"; almost certainly, though, he was a usurper. As a baby, Sargon was said to have been discovered, Moses-like, floating in a basket. Later, he became cupbearer to the ruler of Kish, one of ancient Babylonia's most powerful cities. Sargon dreamed that his master, Ur-Zababa, was about to be drowned by the goddess Inanna in a river of blood. Hearing about the dream, Ur-Zababa decided to have Sargon eliminated. How this plan failed is unknown; no text relating the end of the story has ever been found.

Until Sargon's reign, Babylonian cities like Kish, and also Ur and Uruk and Umma, functioned as independent city-states. Sometimes they formed brief alliances—cuneiform tablets attest to strategic marriages celebrated and diplomatic gifts exchanged—but mostly they seem to have been at war with one another. Sargon first subdued Babylonia's fractious cities, then went on to conquer, or at least sack, lands like Elam, in present-day Iran. He presided over his empire from the city of Akkad, the ruins of which are believed to lie south of Baghdad. It was written that "daily five thousand four hundred men ate at his presence," meaning, presumably, that he maintained a huge standing army. Eventually, Akkadian hegemony extended as far as the Khabur plains, in northeastern Syria, an area prized for its grain production. Sargon came to be known as "king of the world"; later, one of his descendants enlarged this title to "king of the four corners of the universe."

Akkadian rule was highly centralized, and in this way anticipated the administrative logic of empires to come. The Akkadians levied taxes, then used the proceeds to support a vast network of local bureaucrats. They introduced standardized weights and measures—the gur equalled roughly three hundred litres—and imposed a uniform dating system, under which each year was assigned the name of a major event that had recently occurred: for instance, "the year that Sargon destroyed the city of Mari." Such was the level of systematization that even the shape and the layout of accounting tablets were imperially prescribed. Akkad's wealth was reflected in, among other things, its art work, the refinement and naturalism of which were unprecedented.

Sargon ruled, supposedly, for fifty-six years. He was succeeded by his two sons, who reigned for a total of twenty-four years, and then by a grandson, Naram-sin, who declared himself a god. Naram-sin was, in turn, succeeded by his son. Then, suddenly, Akkad collapsed. During one three-year period, four men each, briefly, claimed the throne. “Who was king? Who was not king?” the register known as the Sumerian King List asks, in what may be the first recorded instance of political irony.

The lamentation “The Curse of Akkad” was written within a century of the empire’s fall. It attributes Akkad’s demise to an outrage against the gods. Angered by a pair of inauspicious oracles, Naram-sin plunders the temple of Enlil, the god of wind and storms, who, in retaliation, decides to destroy both him and his people:

For the first time since cities were built and founded,
The great agricultural tracts produced no grain,
The inundated tracts produced no fish,
The irrigated orchards produced neither syrup nor wine,
The gathered clouds did not rain, the masgurum did not grow.
At that time, one shekel’s worth of oil was only one-half quart,
One shekel’s worth of grain was only one-half quart. . . .
These sold at such prices in the markets of all the cities!
He who slept on the roof, died on the roof,
He who slept in the house, had no burial,
People were flailing at themselves from hunger.

For many years, the events described in “The Curse of Akkad” were thought, like the details of Sargon’s birth, to be purely fictional.

In 1978, after scanning a set of maps at Yale’s Sterling Memorial Library, a university archeologist named Harvey Weiss spotted a promising-looking mound at the confluence of two dry riverbeds in the Khabur plains, near the Iraqi border. He approached the Syrian government for permission to excavate the mound, and, somewhat to his surprise, it was almost immediately granted. Soon, he had uncovered a lost city, which in ancient times was known as Shekhna and today is called Tell Leilan.

Over the next ten years, Weiss, working with a team of students and local laborers, proceeded to uncover an acropolis, a crowded residential neighborhood reached by a paved road, and a large block of grain-storage rooms. He found that the residents of Tell Leilan had raised barley and several varieties of wheat, that they had used carts to transport their crops, and that in their writing they had imitated the style of their more sophisticated neighbors to the south. Like most cities in the region at the time, Tell Leilan had a rigidly organized, state-run economy: people received rations—so many litres of barley and so many of oil—based on how old they were and what kind of work they performed. From the time of the Akkadian empire, thousands of similar potsherds were discovered, indicating that residents had received their rations in mass-produced, one-litre vessels. After examining these and other artifacts, Weiss constructed a time line of the city’s history, from its origins as a small farming village (around 5000 B.C.), to its growth into an independent city of some thirty thousand people (2600 B.C.), and on to its reorganization under imperial rule (2300 B.C.).

Wherever Weiss and his team dug, they also encountered a layer of dirt that contained no signs of human habitation. This layer, which was more than three feet deep, corresponded to the years 2200 to 1900 B.C., and it indicated that, around the time of Akkad’s fall, Tell Leilan had been completely abandoned. In 1991, Weiss sent soil samples from Tell Leilan to a lab for analysis. The results showed that, around the year 2200 B.C., even the city’s earthworms had died out. Eventually, Weiss came to believe that the lifeless soil of Tell Leilan and the end of the Akkadian empire were products of the same phenomenon—a drought so prolonged and so severe that, in his words, it represented an example of “climate change.”

Weiss first published his theory, in the journal Science, in August, 1993. Since then, the list of cultures whose demise has been linked to climate change has continued to grow. They include the Classic Mayan civilization, which collapsed at the height of its development, around 800 A.D.; the Tiwanaku civilization, which thrived near Lake Titicaca, in the Andes, for more than a millennium, then disintegrated around 1100 A.D.; and the Old Kingdom of Egypt, which collapsed around the same time as the Akkadian empire. (In an account eerily reminiscent of “The Curse of Akkad,” the Egyptian sage Ipuwer described the anguish of the period: “Lo, the desert claims the land. Towns are ravaged. . . . Food is lacking. . . . Ladies suffer like maidservants. Lo, those who were entombed are cast on high grounds.”) In each of these cases, what began as a provocative hypothesis has, as new information has emerged, come to seem more and more compelling. For example, the notion that Mayan civilization had been undermined by climate change was first proposed in the late nineteen-eighties, at which point there was little climatological evidence to support it. Then, in the mid-nineteen-nineties, American scientists studying sediment cores from Lake Chichancanab, in north-central Yucatán, reported that precipitation patterns in the region had indeed shifted during the ninth and tenth centuries, and that this shift had led to periods of prolonged drought. More recently, a group of researchers examining ocean-sediment cores collected off the coast of Venezuela produced an even more detailed record of rainfall in the area. They found that the region experienced a series of severe, “multiyear drought events” beginning around 750 A.D. The collapse of the Classic Mayan civilization, which has been described as “a demographic disaster as profound as any other in human history,” is thought to have cost millions of lives.

The climate shifts that affected past cultures predate industrialization by hundreds—or, in the case of the Akkadians, thousands—of years. They reflect the climate system’s innate variability and were caused by forces that, at this point, can only be guessed at. By contrast, the climate shifts predicted for the coming century are attributable to forces that are now well known. Exactly how big these shifts will be is a matter of both intense scientific interest and the greatest possible historical significance. In this context, the discovery that large and sophisticated cultures have already been undone by climate change presents what can only be called an uncomfortable precedent.

The Goddard Institute for Space Studies, or giss, is situated just south of Columbia University’s main campus, at the corner of Broadway and West 112th Street. The institute is not well marked, but most New Yorkers would probably recognize the building: its ground floor is home to Tom’s Restaurant, the coffee shop made famous by “Seinfeld.”

giss, an outpost of nasa, started out, forty-four years ago, as a planetary-research center; today, its major function is making forecasts about climate change. giss employs about a hundred and fifty people, many of whom spend their days working on calculations that may—or may not—end up being incorporated in the institute’s climate model. Some work on algorithms that describe the behavior of the atmosphere, some on the behavior of the oceans, some on vegetation, some on clouds, and some on making sure that all these algorithms, when they are combined, produce results that seem consistent with the real world. (Once, when some refinements were made to the model, rain nearly stopped falling over the rain forest.) The latest version of the giss model, called ModelE, consists of a hundred and twenty-five thousand lines of computer code.

giss’s director, James Hansen, occupies a spacious, almost comically cluttered office on the institute’s seventh floor. (I must have expressed some uneasiness the first time I visited him, because the following day I received an e-mail assuring me that the office was “a lot better organized than it used to be.”) Hansen, who is sixty-three, is a spare man with a lean face and a fringe of brown hair. Although he has probably done as much to publicize the dangers of global warming as any other scientist, in person he is reticent almost to the point of shyness. When I asked him how he had come to play such a prominent role, he just shrugged. “Circumstances,” he said.

Hansen first became interested in climate change in the mid-nineteen-seventies. Under the direction of James Van Allen (for whom the Van Allen radiation belts are named), he had written his doctoral dissertation on the climate of Venus. In it, he had proposed that the planet, which has an average surface temperature of eight hundred and sixty-seven degrees Fahrenheit, was kept warm by a smoggy haze; soon afterward, a space probe showed that Venus was actually insulated by an atmosphere that consists of ninety-six per cent carbon dioxide. When solid data began to show what was happening to greenhouse-gaslevels on earth, Hansen became, in his words, “captivated.” He decided that a planet whose atmosphere could change in the course of a human lifetime was more interesting than one that was going to continue, for all intents and purposes, to broil away forever. A group of scientists at nasa had put together a computer program to try to improve weather forecasting using satellite data. Hansen and a team of half a dozen other researchers set out to modify it, in order to make longer-range forecasts about what would happen to global temperatures as greenhouse gasescontinued to accumulate. The project, which resulted in the first version of the giss climate model, took nearly seven years to complete.

At that time, there was little empirical evidence to support the notion that the earth was warming. Instrumental temperature records go back, in a consistent fashion, only to the mid-nineteenth century. They show that average global temperatures rose through the first half of the twentieth century, then dipped in the nineteen-fifties and sixties. Nevertheless, by the early nineteen-eighties Hansen had gained enough confidence in his model to begin to make a series of increasingly audacious predictions. In 1981, he forecast that “carbon dioxide warming should emerge from the noise of natural climate variability” around the year 2000. During the exceptionally hot summer of 1988, he appeared before a Senate subcommittee and announced that he was “ninety-nine per cent” sure that “global warming is affecting our planet now.” And in the summer of 1990 he offered to bet a roomful of fellow-scientists a hundred dollars that either that year or one of the following two years would be the warmest on record. To qualify, the year would have to set a record not only for land temperatures but also for sea-surface temperatures and for temperatures in the lower atmosphere. Hansen won the bet in six months.

Like all climate models, giss’s divides the world into a series of boxes. Thirty-three hundred and twelve boxes cover the earth’s surface, and this pattern is repeated twenty times moving up through the atmosphere, so that the whole arrangement might be thought of as a set of enormous checkerboards stacked on top of one another. Each box represents an area of four degrees latitude by five degrees longitude. (The height of the box varies depending on altitude.) In the real world, of course, such a large area would have an incalculable number of features; in the world of the model, features such as lakes and forests and, indeed, whole mountain ranges are reduced to a limited set of properties, which are then expressed as numerical approximations. Time in this grid world moves ahead for the most part in discrete, half-hour intervals, meaning that a new set of calculations is performed for each box for every thirty minutes that is supposed to have elapsed in actuality. Depending on what part of the globe a box represents, these calculations may involve dozens of different algorithms, so that a model run that is supposed to simulate climate conditions over the next hundred years involves more than a quadrillion separate operations. A single run of the giss model, done on a supercomputer, usually takes about a month.

Very broadly speaking, there are two types of equations that go into a climate model. The first group expresses fundamental physical principles, like the conservation of energy and the law of gravity. The second group describes—the term of art is “parameterize”—patterns and interactions that have been observed in nature but may be only partly understood, or processes that occur on a small scale, and have to be averaged out over huge spaces. Here, for example, is a tiny piece of ModelE, written in the computer language fortran, which deals with the formation of clouds:

```
c**** compute the autoconversion rate of cloud water to precipitation
rho=1.e5*pl(l)/(rgas*tl(l))
tem=rho*wmx(l)/(wconst*fcld+ 1.e-20)
if(lhx.eq.lhs) tem=rho*wmx(l)/ (wmui*fcld+1.e-20)
tem=tem*tem
if(tem.gt.10.) tem=10.
cm1=cm0
if(bandf) cm1=cm0*cbf
if(lhx.eq.lhs) cm1=cm0
cm=cm1*(1.-1./exp(tem*tem))+1.
*100.*(prebar(l+1)+
* precnvl(l+1)*bydtsrc)
if(cm.gt.bydtsrc) cm=bydtsrc
prep(l)=wmx(l)*cm
end if
c**** form clouds only if rh gt rh00
219 if(rh1(l).lt.rh00(l)) go to 220.
```

All climate models treat the laws of physics in the same way, but, since they parameterize phenomena like cloud formation differently, they come up with different results. (At this point, there are some fifteen major climate models in operation around the globe.) Also, because the real-world forces influencing the climate are so numerous, different models tend, like medical students, to specialize in different processes. giss’s model, for example, specializes in the behavior of the atmosphere, other models in the behavior of the oceans, and still others in the behavior of land surfaces and ice sheets.

Last fall, I attended a meeting at giss which brought together members of the institute’s modelling team. When I arrived, about twenty men and five women were sitting in battered chairs in a conference room across from Hansen’s office. At that particular moment, the institute was performing a series of runs for the U.N. Intergovernmental Panel on Climate Change. The runs were overdue, and apparently the I.P.C.C. was getting impatient. Hansen flashed a series of charts on a screen on the wall summarizing some of the results obtained so far.

The obvious difficulty in verifying any particular climate model or climate-model run is the prospective nature of the results. For this reason, models are often run into the past, to see how well they reproduce trends that have already been observed. Hansen told the group that he was pleased with how ModelE had reproduced the aftermath of the eruption of Mt. Pinatubo, in the Philippines, which took place in June of 1991. Volcanic eruptions release huge quantities of sulfur dioxide—Pinatubo produced some twenty million tons of the gas—which, once in the stratosphere, condenses into tiny sulfate droplets. These droplets, or aerosols, tend to cool the earth by reflecting sunlight back into space. (Man-made aerosols, produced by burning coal, oil, and biomass, also reflect sunlight and are a countervailing force to greenhouse warming, albeit one with serious health consequences of its own.) This cooling effect lasts as long as the aerosols remain suspended in the atmosphere. In 1992, global temperatures, which had been rising sharply, fell by half of a degree. Then they began to climb again. ModelE had succeeded in simulating this effect to within nine-hundredths of a degree. “That’s a pretty nice test,” Hansen observed laconically.

One day, when I was talking to Hansen in his office, he pulled a pair of photographs out of his briefcase. The first showed a chubby-faced five-year-old girl holding some miniature Christmas-tree lights in front of an even chubbier-faced five-month-old baby. The girl, Hansen told me, was his granddaughter Sophie and the boy was his new grandson, Connor. The caption on the first picture read, “Sophie explains greenhouse warming.” The caption on the second photograph, which showed the baby smiling gleefully, read, “Connor gets it.”

When modellers talk about what drives the climate, they focus on what they call “forcings.” A forcing is any ongoing process or discrete event that alters the energy of the system. Examples of natural forcings include, in addition to volcanic eruptions, periodic shifts in the earth’s orbit and changes in the sun’s output, like those linked to sunspots. Many climate shifts of the past have no known forcing associated with them; for instance, no one is certain what brought about the so-called Little Ice Age, which began in Europe some five hundred years ago. A very large forcing, meanwhile, should produce a commensurately large—and obvious—effect. One giss scientist put it to me this way: “If the sun went supernova, there’s no question that we could model what would happen.”

Adding carbon dioxide, or any other greenhouse gas, to the atmosphere by, say, burning fossil fuels or levelling forests is, in the language of climate science, an anthropogenic forcing. Since pre-industrial times, the concentration of CO2in the earth's atmosphere has risen by roughly a third, from 280 parts per million to 378 p.p.m. During the same period, concentrations of methane, an even more powerful (but more short-lived) greenhouse gas, have more than doubled, from .78 p.p.m. to 1.76 p.p.m. Scientists measure forcings in terms of watts per square metre, or w/m2, by which they mean that a certain number of watts of energy have been added (or, in the case of a negative forcing, subtracted) for every single square metre of the earth's surface. The size of the greenhouse forcing is estimated, at this point, to be 2.5 w/m2. A miniature Christmas light gives off about four tenths of a watt of energy, mostly in the form of heat, so that, in effect (as Sophie supposedly explained to Connor), we have covered the earth with tiny bulbs, six for every square metre. These bulbs are burning twenty-four hours a day, seven days a week, year in and year out.

If greenhouse gases were held constant at today's levels, it is estimated that it would take several decades for the full impact of the forcing that is already in place to be felt. This is because raising the earth's temperature involves not only warming the air and the surface of the land but also melting sea ice, liquefying glaciers, and, most significant, heating the oceans—all processes that require tremendous amounts of energy. (Imagine trying to thaw a gallon of ice cream or warm a pot of water using an Easy-Bake oven.) It could be argued that the delay that is built into the system is socially useful, because it enables us—with the help of climate models—to prepare for what lies ahead, or that it is socially disastrous, because it allows us to keep adding CO2to the atmosphere while fobbing the impacts off on our children and grandchildren. Either way, if current trends continue, which is to say, if steps are not taken to reduce emissions, carbon-dioxide levels will probably reach 500 parts per million—nearly double pre-industrial levels—sometime around the middle of the century. By that point, of course, the forcing associated with greenhouse gases will also have increased, to four watts per square metre and possibly more. For comparison's sake, it is worth keeping in mind that the total forcing that ended the last ice age—a forcing that was eventually sufficient to melt mile-thick ice sheets and raise global sea levels by four hundred feet—is estimated to have been just six and a half watts per square metre.

There are two ways to operate a climate model. In the first, which is known as a transient run, greenhouse gases are slowly added to the simulated atmosphere—just as they would be to the real atmosphere—and the model forecasts what the effect of these additions will be at any given moment. In the second, greenhouse gases are added to the atmosphere all at once, and the model is run at these new levels until the climate has fully adjusted to the forcing by reaching a new equilibrium. Not surprisingly, this is known as an equilibrium run. For doubled CO2, equilibrium runs of the giss model predict that average global temperatures will rise by 4.9 degrees Fahrenheit. Only about a third of this increase is directly attributable to more greenhouse gases; the rest is a result of indirect effects, the most important among them being the so-called "water-vapor feedback." (Since warmer air holds more moisture, higher temperatures are expected to produce an atmosphere containing more water vapor, which is itself a greenhouse gas.) giss's forecast is on the low end of the most recent projections; the Hadley Centre model, which is run by the British Met Office, predicts that for doubled CO2the eventual temperature rise will be 6.3 degrees Fahrenheit, while Japan's National Institute for Environmental Studies predicts 7.7 degrees.

In the context of ordinary life, a warming of 4.9, or even of 7.7, degrees may not seem like much to worry about; in the course of a normal summer's day, after all, air temperatures routinely rise by twenty degrees or more. Average global temperatures, however, have practically nothing to do with ordinary life. In the middle of the last glaciation, Manhattan, Boston, and Chicago were deep under ice, and sea levels were so low that Siberia and Alaska were connected by a land bridge nearly a thousand miles wide. At that point, average global temperatures were roughly ten degrees colder than they are today. Conversely, since our species evolved, average temperatures have never been much more than two or three degrees higher than they are right now.

This last point is one that climatologists find particularly significant. By studying Antarctic ice cores, researchers have been able to piece together a record both of the earth's temperature and of the composition of its atmosphere going back four full glacial cycles. (Temperature data can be extracted from the isotopic composition of the ice, and the makeup of the atmosphere can be reconstructed by analyzing tiny bubbles of trapped air.) What this record shows is that the planet is now nearly as warm as it has been at any point in the last four hundred and twenty thousand years. A possible consequence of even a four- or five-degree temperature rise—on the low end of projections for doubled CO2—is that the world will enter a completely new climate regime, one with which modern humans have no prior experience. Meanwhile, at 378 p.p.m., CO2 levels are significantly higher today than they have been at any other point in the Antarctic record. It is believed that the last time carbon-dioxide levels were in this range was three and a half million years ago, during what is known as the mid-Pliocene warm period, and they likely have not been much above it for tens of millions of years. A scientist with the National Oceanic and Atmospheric Administration (noaa) put it to me—only half-jokingly—this way: "It's true that we've had higher CO2levels before. But, then, of course, we also had dinosaurs."

David Rind is a climate scientist who has worked at giss since 1978. Rind acts as a trouble-shooter for the institute's model, scanning reams of numbers known as diagnostics, trying to catch problems, and he also works with giss's Climate Impacts Group. (His office, like Hansen’s, is filled with dusty piles of computer printouts.) Although higher temperatures are the most obvious and predictable result of increased CO2, other, second-order consequences—rising sea levels, changes in vegetation, loss of snow cover—are likely to be just as significant. Rind’s particular interest is how CO2levels will affect water supplies, because, as he put it to me, “you can’t have a plastic version of water.”

One afternoon, when I was talking to Rind in his office, he mentioned a visit that President Bush’s science adviser, John Marburger, had paid to giss a few years earlier. “He said, ‘We’re really interested in adaptation to climate change,’ ” Rind recalled. “Well, what does ‘adaptation’ mean?” He rummaged through one of his many file cabinets and finally pulled out a paper that he had published in the Journal of Geophysical Research entitled “Potential Evapotranspiration and the Likelihood of Future Drought.” In much the same way that wind velocity is measured using the Beaufort scale, water availability is measured using what’s known as the Palmer Drought Severity Index. Different climate models offer very different predictions about future water availability; in the paper, Rind applied the criteria used in the Palmer index to giss’s model and also to a model operated by noaa’s Geophysical Fluid Dynamics Laboratory. He found that as carbon-dioxide levels rose the world began to experience more and more serious water shortages, starting near the equator and then spreading toward the poles. When he applied the index to the giss model for doubled CO2, it showed most of the continental United States to be suffering under severe drought conditions. When he applied the index to the G.F.D.L. model, the results were even more dire. Rind created two maps to illustrate these findings. Yellow represented a forty-to-sixty-per-cent chance of summertime drought, ochre a sixty-to-eighty-per-cent chance, and brown an eighty-to-a-hundred-per-cent chance. In the first map, showing the giss results, the Northeast was yellow, the Midwest was ochre, and the Rocky Mountain states and California were brown. In the second, showing the G.F.D.L. results, brown covered practically the entire country.

“I gave a talk based on these drought indices out in California to water-resource managers,” Rind told me. “And they said, ‘Well, if that happens, forget it.’ There’s just no way they could deal with that.”

He went on, “Obviously, if you get drought indices like these, there’s no adaptation that’s possible. But let’s say it’s not that severe. What adaptation are we talking about? Adaptation in 2020? Adaptation in 2040? Adaptation in 2060? Because the way the models project this, as global warming gets going, once you’ve adapted to one decade you’re going to have to change everything the next decade.

“We may say that we’re more technologically able than earlier societies. But one thing about climate change is it’s potentially geopolitically destabilizing. And we’re not only more technologically able; we’re more technologically able destructively as well. I think it’s impossible to predict what will happen. I guess—though I won’t be around to see it—I wouldn’t be shocked to find out that by 2100 most things were destroyed.” He paused. “That’s sort of an extreme view.”

On the other side of the Hudson River and slightly to the north of giss, the Lamont-Doherty Earth Observatory occupies what was once a weekend estate in the town of Palisades, New York. The observatory is an outpost of Columbia University, and it houses, among its collections of natural artifacts, the world’s largest assembly of ocean-sediment cores—more than thirteen thousand in all. The cores are kept in steel compartments that look like drawers from a filing cabinet, only longer and much skinnier. Some of the cores are chalky, some are clayey, and some are made up almost entirely of gravel. All can be coaxed to yield up—in one way or another—information about past climates.

Peter deMenocal is a paleoclimatologist who has worked at Lamont-Doherty for fifteen years. He is an expert on ocean cores, and also on the climate of the Pliocene, which lasted from roughly five million to two million years ago. Around two and a half million years ago, the earth, which had been warm and relatively ice-free, started to cool down until it entered an era—the Pleistocene—of recurring glaciations. DeMenocal has argued that this transition was a key event in human evolution: right around the time that it occurred, at least two types of hominids—one of which would eventually give rise to us—branched off from a single ancestral line. Until quite recently, paleoclimatologists like deMenocal rarely bothered with anything much closer to the present day; the current interglacial—the Holocene—which began some ten thousand years ago, was believed to be, climatically speaking, too stable to warrant much study. In the mid-nineties, though, deMenocal, motivated by a growing concern over global warming—and a concomitant shift in government research funds—decided to look in detail at some Holocene cores. What he learned, as he put it to me when I visited him at Lamont-Doherty last fall, was “less boring than we had thought.”

One way to extract climate data from ocean sediments is to examine the remains of what lived or, perhaps more pertinently, what died and was buried there. The oceans are rich with microscopic creatures known as foraminifera. There are about thirty planktonic species in all, and each thrives at a different temperature, so that by counting a species’ prevalence in a given sample it is possible to estimate the ocean temperatures at the time the sediment was formed. When deMenocal used this technique to analyze cores that had been collected off the coast of Mauritania, he found that they contained evidence of recurring cool periods; every fifteen hundred years or so, water temperatures dropped for a few centuries before climbing back up again. (The most recent cool period corresponds to the Little Ice Age, which ended about a century and a half ago.) Also, perhaps even more significant, the cores showed profound changes in precipitation. Until about six thousand years ago, northern Africa was relatively wet—dotted with small lakes. Then it became dry, as it is today. DeMenocal traced the shift to periodic variations in the earth's orbit, which, in a generic sense, are the same forces that trigger ice ages. But orbital changes occur gradually, over thousands of years, and northern Africa appears to have switched from wet to dry all of a sudden. Although no one knows exactly how this happened, it seems, like so many climate events, to have been a function of feedbacks—the less rain the continent got, the less vegetation there was to retain water, and so on until, finally, the system just flipped. The process provides yet more evidence of how a very small forcing sustained over time can produce dramatic results.

"We were kind of surprised by what we found," deMenocal told me about his work on the supposedly stable Holocene. "Actually, more than surprised. It was one of these things where, you know, in life you take certain things for granted, like your neighbor's not going to be an axe murderer. And then you discover your neighbor is an axe murderer."

Not long after deMenocal began to think about the Holocene, a brief mention of his work on the climate of Africa appeared in a book produced by National Geographic. On the facing page, there was a piece on Harvey Weiss and his work at Tell Leilan. DeMenocal vividly remembers his reaction. "I thought, Holy cow, that's just amazing!" he told me. "It was one of these cases where I lost sleep that night, I just thought it was such a cool idea."

DeMenocal also recalls his subsequent dismay when he went to learn more. "It struck me that they were calling on this climate-change argument, and I wondered how come I didn't know about it," he said. He looked at the Science paper in which Weiss had originally laid out his theory. "First of all, I scanned the list of authors and there was no paleoclimatologist on there," deMenocal said. "So then I started reading through the paper and there basically was no paleoclimatology in it." (The main piece of evidence Weiss adduced for a drought was that Tell Leilan had filled with dust.) The more deMenocal thought about it, the more unconvincing he found the data, on the one hand, and the more compelling he found the underlying idea, on the other. "I just couldn't leave it alone," he told me. In the summer of 1995, he went with Weiss to Syria to visit Tell Leilan. Subsequently, he decided to do his own study to prove—or disprove—Weiss's theory.

Instead of looking in, or even near, the ruined city, deMenocal focussed on the Gulf of Oman, nearly a thousand miles downwind. Dust from the Mesopotamian floodplains, just north of Tell Leilan, contains heavy concentrations of the mineral dolomite, and since arid soil produces more wind-borne dust, deMenocal figured that if there had been a drought of any magnitude it would show up in gulf sediments."In a wet period, you'd be getting none or very, very low amounts of dolomite, and during a dry period you'd be getting a lot," he explained. He and a graduate student named Heidi Cullen developed a highly sensitive test to detect dolomite, and then Cullen assayed, centimetre by centimetre, a sediment core that had been extracted near where the Gulf of Oman meets the Arabian Sea.

"She started going up through the core," DeMenocal told me. "It was like nothing, nothing, nothing, nothing, nothing. Then one day, I think it was a Friday afternoon, she goes, 'Oh, my God.' It was really classic." DeMenocal had thought that the dolomite level, if it were elevated at all, would be modestly higher; instead, it went up by four hundred per cent. Still, he wasn't satisfied. He decided to have the core re-analyzed using a different marker: the ratio of strontium 86 and strontium 87 isotopes. The same spike showed up. When deMenocal had the core carbon-dated, it turned out that the spike lined up exactly with the period of Tell Leilan's abandonment.

Tell Leilan was never an easy place to live. Much like, say, western Kansas today, the Khabur plains received enough annual rainfall—about seventeen inches—to support cereal crops, but not enough to grow much else. "Year-to-year variations were a real threat, and so they obviously needed to have grain storage and to have ways to buffer themselves," deMenocal observed. "One generation would tell the next, 'Look, there are these things that happen that you've got to be prepared for.' And they were good at that. They could manage that. They were there for hundreds of years."

He went on, "The thing they couldn't prepare for was the same thing that we won't prepare for, because in their case they didn't know about it and because in our case the political system can't listen to it. And that is that the climate system has much greater things in store for us than we think."

Shortly before Christmas, Harvey Weiss gave a lunchtime lecture at Yale's Institute for Biospheric Studies. The title was "What Happened in the Holocene," which, as Weiss explained, was an allusion to a famous archeology text by V. Gordon Childe, entitled "What Happened in History." The talk brought together archeological and paleoclimatic records from the Near East over the last ten thousand years.

Weiss, who is sixty years old, has thinning gray hair, wire-rimmed glasses, and an excitable manner. He had prepared for the audience—mostly Yale professors and graduate students—a handout with a time line of Mesopotamian history. Key cultural events appeared in black ink, key climatological ones in red. The two alternated in a rhythmic cycle of disaster and innovation. Around 6200 B.C., a severe global cold snap—red ink—produced aridity in the Near East. (The cause of the cold snap is believed to have been a catastrophic flood that emptied an enormous glacial lake—called Lake Agassiz—into the North Atlantic.) Right around the same time—black ink—farming villages in northern Mesopotamia were abandoned, while in central and southern Mesopotamia the art of irrigation was invented. Three thousand years later, there was another cold snap, after which settlements in northern Mesopotamia once again were deserted. The most recent red event, in 2200 B.C., was followed by the dissolution of the Old Kingdom in Egypt, the abandonment of villages in ancient Palestine, and the fall of Akkad. Toward the end of his talk, Weiss, using a PowerPoint program, displayed some photographs from the excavation at Tell Leilan. One showed the wall of a building—probably intended for administrative offices—that had been under construction when the rain stopped. The wall was made from blocks of basalt topped by rows of mud bricks. The bricks gave out abruptly, as if construction had ceased from one day to the next.

The monochromatic sort of history that most of us grew up with did not allow for events like the drought that destroyed Tell Leilan. Civilizations fell, we were taught, because of wars or barbarian invasions or political unrest. (Another famous text by Childe bears the exemplary title "Man Makes Himself.") Adding red to the time line points up the deep contingency of the whole enterprise. Civilization goes back, at the most, ten thousand years, even though, evolutionarily speaking, modern man has been around for at least ten times that long. The climate of the Holocene was not boring, but at least it was dull enough to allow people to sit still. It is only after the immense climatic shifts of the glacial epoch had run their course that writing and agriculture finally emerged.

Nowhere else does the archeological record go back so far or in such detail as in the Near East. But similar red-and-black chronologies can now be drawn up for many other parts of the world: the Indus Valley, where, some four thousand years ago, the Harappan civilization suffered a decline after a change in monsoon patterns; the Andes, where, fourteen hundred years ago, the Moche abandoned their cities in a period of diminished rainfall; and even the United States, where the arrival of the English colonists on Roanoke Island, in 1587, coincided with a severe regional drought. (By the time English ships returned to resupply the colonists, three years later, no one was left.) At the height of the Mayan civilization, population density was five hundred per square mile, higher than it is in most parts of the U. S. today. Two hundred years later, much of the territory occupied by the Mayans had been completely depopulated. You can argue that man through culture creates stability, or you can argue, just as plausibly, that stability is for culture an essential precondition.

After the lecture, I walked with Weiss back to his office, which is near the center of the Yale campus, in the Hall of Graduate Studies. This past year, Weiss decided to suspend excavation at Tell Leilan. The site lies only fifty miles from the Iraqi border, and, owing to the uncertainties of the war, it seemed like the wrong sort of place to bring graduate students. When I visited, Weiss had just returned from a trip to Damascus, where he had gone to pay the guards who watch over the site when he isn't there. While he was away from his office, its contents had been piled up in a corner by repairmen who had come to fix some pipes. Weiss considered the piles disconsolately, then unlocked a door at the back of the room.

The door led to a second room, much larger than the first. It was set up like a library, except that instead of books the shelves were stacked with hundreds of cardboard boxes. Each box contained fragments of broken pottery from Tell Leilan. Some were painted, others were incised with intricate designs, and still others were barely distinguishable from pebbles. Every fragment had been inscribed with a number, indicating its provenance.

I asked what he thought life in Tell Leilan had been like. Weiss told me that that was a "corny question," so I asked him about the city's abandonment. "Nothing allows you to go beyond the third or fourth year of a drought, and by the fifth or sixth year you're probably gone," he observed. "You've given up hope for the rain, which is exactly what they wrote in 'The Curse of Akkad.' " I asked to see something that might have been used in Tell Leilan's last days. Swearing softly, Weiss searched through the rows until he finally found one particular box. It held several potsherds that appeared to have come from identical bowls. They were made from a greenish-colored clay, had been thrown on a wheel, and had no decoration. Intact, the bowls had held about a litre, and Weiss explained that they had been used to mete out rations—probably wheat or barley—to the workers of Tell Leilan. He passed me one of the fragments. I held it in my hand for a moment and tried to imagine the last Akkadian who had touched it. Then I passed it back.
(This is the second part of a three-part article.)

THE CLIMATE OF MAN—III

by ELIZABETH KOLBERT

What can be done?

Issue of 2005-05-09

In February, 2003, a series of ads on the theme of inundation began appearing on Dutch TV. The ads were sponsored by the Netherlands' Ministry of Transport, Public Works, and Water Management, and they featured a celebrity weatherman named Peter Timofeeff. In one commercial, Timofeeff, who looks a bit like Albert Brooks and a bit like Gene Shalit, sat relaxing on the shore in a folding chair. "Sea level is rising," he announced, as waves started creeping up the beach. He continued to sit and talk even as a boy who had been building a sandcastle abandoned it in panic. At the end of the ad, Timofeeff, still seated, was immersed in water up to his waist.

In another commercial, Timofeeff was shown wearing a business suit and standing by a bathtub. “These are our rivers,” he explained, climbing into the tub and turning on the shower full blast. “The climate is changing. It will rain more often, and more heavily.” Water filled the tub and spilled over the sides. It dripped through the floorboards, onto the head of his screeching wife, below. “We should give the water more space and widen the rivers,” he advised, reaching for a towel.

Both the beach-chair and the shower ads were part of a public-service campaign that also included radio spots, newspaper announcements, and free tote bags. Notwithstanding their comic tone—other commercials showed Timofeeff trying to start a motorboat in a cow pasture and digging a duck pond in his back yard—their message was sombre.

A quarter of the Netherlands lies below sea level, much of it on land wrested from either the North Sea or the Rhine or the River Meuse. Another quarter, while slightly higher, is still low enough that, in the natural course of events, it would regularly be flooded. What makes the country habitable is the world’s most sophisticated water-management system, which comprises more than ten thousand miles of dikes, dams, weirs, flood barriers, and artificial dunes, not to mention countless pumps, holding ponds, and windmills. (People in Holland like to joke, “God made the world, but the Dutch made the Netherlands.”)

Until recently, it was assumed that any threat to low-lying areas would be dealt with the same way such threats always had been: by raising the dikes, or by adding new ones. (The latest addition, the Maeslant barrier, which is supposed to protect Rotterdam from storm surges with the aid of two movable arms, each the size of a skyscraper, was completed in 1997.) But this is no longer the case. The very engineers who perfected the system have become convinced that it is unsustainable. After centuries of successfully manipulating nature, the Dutch, the ads warn, will have to switch course.

Eelke Turkstra runs a water-ministry program called Room for the River, which is just the sort of enterprise that Timofeeff was advocating when he climbed into the bathtub. A few months ago, I arranged to speak with Turkstra, and he suggested that we meet at a nature center along a branch of the Rhine known as the Nieuwe Merwede. The center featured an exhibit about the effects of climate change. One kid-friendly display allowed visitors to turn a crank and, in effect, drown the countryside. By 2100, the display showed, the Nieuwe Merwede could be running several feet above the local dikes.

From the nature center, Turkstra took me by car ferry across the river. On the other side, we drove through an area that was made up entirely of “polders”—land that has been laboriously reclaimed from the water. The polders were shaped like ice trays, with sloping sides and perfectly flat fields along the bottom. Every once in a while, there was a sturdy-looking farmhouse. The whole scene—the level fields, the thatched barns, even the gray clouds sitting on the horizon—could have been borrowed from a painting by Hobbema. Turkstra explained that the plan of Room for the River was to buy out the farmers who were living in the polders, then lower the dikes and let the Nieuwe Merwede flood when necessary. It was expected that the project would cost three hundred and ninety million dollars. Similar projects are under way in other parts of the Netherlands, and it is likely that in the future even more drastic measures will be necessary, including, some experts argue, the construction of a whole new outlet channel for the Rhine.

“Some people don’t get it,” Turkstra told me as we zipped along. “They think this project is stupid. But I think it’s stupid to continue in the old way.”

A few years ago, in an article in Nature, the Dutch chemist Paul Crutzen coined a term. No longer, he wrote, should we think of ourselves as living in the Holocene, as the period since the last glaciation is known. Instead, an epoch unlike any of those which preceded it had begun. This new age was defined by one creature—man—who had become so dominant that he was capable of altering the planet on a geological scale. Crutzen, a Nobel Prize winner, dubbed this age the Anthropocene. He proposed as its starting date the seventeen-eighties, the decade in which James Watt perfected his steam engine and, inadvertently, changed the history of the earth.

In the seventeen-eighties, ice-core records show, carbon-dioxide levels stood at about two hundred and eighty parts per million. Give or take ten parts per million, this was the same level that they had been at two thousand years earlier, in the era of Julius Caesar, and two thousand years before that, at the time of Stonehenge, and two thousand years before that, at the founding of the first cities. When, subsequently, industrialization began to drive up CO2 levels, they rose gradually at first—it took more than a hundred and fifty years to get to three hundred and fifteen parts per million—and then much more rapidly. By the mid-nineteen-seventies, they had reached three hundred and thirty parts per million, and, by the mid-nineteen-nineties, three hundred and sixty parts per million. Just in the past decade, they have risen by as much—twenty parts per million—as they did during the previous ten thousand years of the Holocene.

For every added increment of carbon dioxide, the earth will experience a temperature rise, which represents what is called the equilibrium warming. If current trends continue, atmospheric CO2 will reach five hundred parts per million—nearly double pre-industrial levels—around the middle of the century. It is believed that the last time CO2 concentrations were that high was during the period known as the Eocene, some fifty million years ago. In the Eocene, crocodiles roamed Colorado and sea levels were nearly three hundred feet higher than they are today.

For all practical purposes, the recent "carbonation" of the atmosphere is irreversible. Carbon dioxide is a persistent gas; it lasts for about a century. Thus, while it is possible to increase CO2 concentrations relatively quickly, by, say, burning fossil fuels or levelling forests, the opposite is not the case. The effect might be compared to driving a car equipped with an accelerator but no brakes.

The long-term risks of this path are well known. Barely a month passes without a new finding on the dangers posed by rising CO2 levels—to the polar ice cap, to the survival of the world's coral reefs, to the continued existence of low-lying nations. Yet the world has barely even begun to take action. This is particularly true of the United States, which is the largest emitter of carbon dioxide by far. (The average American produces some twelve thousand pounds of CO2 emissions annually.) As we delay, the opportunity to change course is slipping away. "We have only a few years, and not ten years but less, to do something," the Dutch state secretary for the environment, Pieter van Geel, told me when I went to visit him in The Hague.

In climate-science circles, a future in which current emissions trends continue, unchecked, is known as "business as usual," or B.A.U. A few years ago, Robert Socolow, a professor of engineering at Princeton, began to think about B.A.U. and what it implied for the fate of mankind. Socolow had recently become co-director of the Carbon Mitigation Initiative, a project funded by BP and Ford, but he still considered himself an outsider to the field of climate science. Talking to insiders, he was struck by the degree of their alarm. "I've been involved in a number of fields where there's a lay opinion and a scientific opinion," he told me when I went to talk to him shortly after returning from the Netherlands. "And, in most of the cases, it's the lay community that is more exercised, more anxious. If you take an extreme example, it would be nuclear power, where most of the people who work in nuclear science are relatively relaxed about very low levels of radiation. But, in the climate case, the experts—the people who work with the climate models every day, the people who do ice cores—they are more concerned. They're going out of their way to say, 'Wake up! This is not a good thing to be doing.' "

Socolow, who is sixty-seven, is a trim man with wire-rimmed glasses and gray, vaguely Einsteinian hair. Although by training he is a theoretical physicist—he did his doctoral research on quarks—he has spent most of his career working on problems of a more human scale, like how to prevent nuclear proliferation or construct buildings that don't leak heat. In the nineteen-seventies, Socolow helped design an energy-efficient housing development, in Twin Rivers, New Jersey. At another point, he developed a system—never commercially viable—to provide air-conditioning in the summer using ice created in the winter. When Socolow became co-director of the Carbon Mitigation Initiative, he decided that the first thing he needed to do was get a handle on the scale of the problem. He found that the existing literature on the subject offered almost too much information. In addition to B.A.U., a dozen or so alternative scenarios, known by code names like A1 and B1, had been devised; these all tended to jumble together in his mind, like so many Scrabble tiles. "I'm pretty quantitative, but I could not remember these graphs from one day to the next," he recalled. He decided to try to streamline the problem, mainly so that he could understand it.

There are two ways to measure carbon-dioxide emissions. One is to count the full weight of the CO2; the other, favored by the scientific community, is to count just the weight of the carbon. Using the latter measure, global emissions last year amounted to seven billion metric tons. (The United States contributed more than twenty per cent of the total, or 1.6 billion metric tons of carbon.) "Business as usual" yields several different estimates of future emissions: a mid-range projection is that carbon emissions will reach 10.5 billion metric tons a year by 2029, and fourteen billion tons a year by 2054. Holding emissions constant at today's levels means altering this trajectory so that fifty years from now seven billion of those fourteen billion tons of carbon aren't being poured into the atmosphere.

Stabilizing CO2 emissions, Socolow realized, would be a monumental undertaking, so he decided to break the problem down into more manageable blocks, which he called "stabilization wedges." For simplicity's sake, he defined a stabilization wedge as a step that would be sufficient to prevent a billion metric tons of carbon per year from being emitted by 2054. Along with a Princeton colleague, Stephen Pacala, he eventually came up with fifteen different wedges—theoretically, at least eight more than would be necessary to stabilize emissions. These fall, very roughly, into three categories—wedges that deal with energy demand, wedges that deal with energy supply, and wedges that deal with "capturing" CO2 and storing it somewhere other than the atmosphere. Last year, the two men published their findings in a paper in Science which received a great deal of attention. The paper was at once upbeat—"Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century," it declared—and deeply sobering. "There is no easy wedge" is how Socolow put it to me.

Consider wedge No. 11. This is the photovoltaic, or solar-power, wedge—probably the most appealing of all the alternatives, at least in the abstract. Photovoltaic cells, which have been around for more than fifty years, are already in use in all sorts of small-scale applications and in some larger ones where the cost of connecting to the electrical grid is prohibitively high. The technology, once installed, is completely emissions-free, producing no waste products, not even water. Assuming that a thousand-megawatt coal-fired power plant produces about 1.5 million tons of carbon a year—in the future, coal plants are expected to become more efficient—to get a wedge out of photovoltaics would require enough cells to produce seven hundred thousand megawatts. Since sunshine is intermittent, two million megawatts of capacity is needed to produce that much power. This, it turns out, would require PV arrays covering a surface area of five million acres—approximately the size of Connecticut.

Wedge No. 10 is wind electricity. The standard output of a wind turbine is two megawatts, so to get a wedge out of wind power would require at least a million turbines. Other wedges present different challenges, some technical, some social. Nuclear power produces no carbon dioxide; instead, it generates radioactive waste, with all the attendant problems of storage, disposal, and international policing. Currently, there are four hundred and forty-one nuclear power plants in the world; one wedge would require doubling their capacity. There are also two automobile wedges. The first requires that every car in the world be driven half as much as it is today. The second requires that it be twice as efficient. (Since 1987, the fuel efficiency of passenger vehicles in the U.S. has actually declined, by more than five per cent.)

Three of the possible options are based on a technology known as “carbon capture and storage,” or C.C.S. As the name suggests, with C.C.S. carbon dioxide is “captured” at the source—presumably a power plant or other large emitter. Then it is injected at very high pressure into geological formations, such as depleted oil fields, underground. No power plants actually use C.C.S. at this point, nor is it certain that CO2 injected underground will remain there permanently; the world’s longest-running C.C.S. effort, maintained by the Norwegian oil company Statoil at a natural-gas field in the North Sea, has been operational for only eight years. One wedge of C.C.S. would require thirty-five hundred projects on the scale of Statoil’s.

In a world like today’s, where there is, for the most part, no direct cost to emitting CO2, none of Socolow’s wedges are apt to be implemented; this is, of course, why they represent a departure from “business as usual.” To alter the economics against carbon requires government intervention. Countries could set a strict limit on CO2, and then let emitters buy and sell carbon “credits.” (In the United States, this same basic strategy has been used successfully with sulfur dioxide in order to curb acid rain.) Another alternative is to levy a tax on carbon. Both of these options have been extensively studied by economists; using their work, Socolow estimates that the cost of emitting carbon would have to rise to around a hundred dollars a ton to provide a sufficient incentive to adopt many of the options he has proposed. Assuming that the cost were passed on to consumers, a hundred dollars a ton would raise the price of a kilowatt-hour of coal-generated electricity by about two cents, which would add roughly fifteen dollars a month to the average American family’s electricity bill. (In the U.S., more than fifty per cent of electricity is generated by coal.)

All of Socolow’s calculations are based on the notion—clearly hypothetical—that steps to stabilize emissions will be taken immediately, or at least within the next few years. This assumption is key not only because we are constantly pumping more CO2 into the atmosphere but also because we are constantly building infrastructure that, in effect, guarantees that that much additional CO2 will be released in the future. In the U.S., the average new car gets about twenty miles to the gallon; if it is driven a hundred thousand miles, it will produce almost forty-three metric tons of carbon during its lifetime. A thousand-megawatt coal plant built today, meanwhile, is likely to last fifty years; if it is constructed without C.C.S. capability, it will emit some hundred million tons of carbon during its life. The overriding message of Socolow’s wedges is that the longer we wait—and the more infrastructure we build without regard to its impact on emissions—the more daunting the task of keeping CO2 levels below five hundred parts per million will become. Indeed, even if we were to hold emissions steady for the next half century, Socolow’s graphs show that much steeper cuts would be needed in the following half century to keep CO2 concentrations from exceeding that level. After a while, I asked Socolow whether he thought that stabilizing emissions was a politically feasible goal. He frowned.

“I’m always being asked, ‘What can you say about the practicability of various targets?’ ” he told me. “I really think that’s the wrong question. These things can all be done.

“What kind of issue is like this that we faced in the past?” he continued. “I think it’s the kind of issue where something looked extremely difficult, and not worth it, and then people changed their minds. Take child labor. We decided we would not have child labor and goods would become more expensive. It’s a changed preference system. Slavery also had some of those characteristics a hundred and fifty years ago. Some people thought it was wrong, and they made their arguments, and they didn’t carry the day. And then something happened and all of a sudden it was wrong and we didn’t do it anymore. And there were social costs to that. I suppose cotton was more expensive. We said, ‘That’s the trade-off; we don’t want to do this anymore.’ So we may look at this and say, ‘We are tampering with the earth.’ The earth is a twitchy system. It’s clear from the record that it does things that we don’t fully understand. And we’re not going to understand them in the time period we have to make these decisions. We just know they’re there. We may say, ‘We just don’t want to do this to ourselves.’ If it’s a problem like that, then asking whether it’s practical or not is really not going to help very much. Whether it’s practical depends on how much we give a damn.”

Marty Hoffert is a professor of physics at New York University. He is big and bearish, with a wide face and silvery hair. Hoffert got his undergraduate degree in aeronautical engineering, and one of his first jobs, in the mid-nineteen-sixties, was helping to develop the U.S.'s antiballistic-missile system. Eventually, he decided that he wanted to work on something, in his words, "more productive." In this way, he became involved in climate research. Hoffert is primarily interested in finding new, carbon-free ways to generate energy. He calls himself a "technological optimist," and a lot of his ideas about electric power have a wouldn't-it-be-cool, Buck Rogers sound to them. On other topics, though, Hoffert is a killjoy.

"We have to face the quantitative nature of the challenge," he told me one day over lunch at the N.Y.U. faculty club. "Right now, we're going to just burn everything up; we're going to heat the atmosphere to the temperature it was in the Cretaceous, when there were crocodiles at the poles. And then everything will collapse."

Currently, the new technology that Hoffert is pushing is space-based solar power, or S.S.P. In theory, at least, S.S.P. involves launching into space satellites equipped with massive photovoltaic arrays. Once a satellite is in orbit, the array would unfold or, according to some plans, inflate. S.S.P. has two important advantages over conventional, land-based solar power. In the first place, there is more sunlight in space—roughly eight times as much, per unit of area—and, in the second, this sunlight is constant: satellites are not affected by clouds or by nightfall. The obstacles, meanwhile, are several. No full-scale test of S.S.P. has ever been conducted. (In the nineteen-seventies, nasa studied the idea of sending a photovoltaic array the size of Manhattan into space, but the project never, as it were, got off the ground.) Then, there is the expense of launching satellites. Finally, once the satellites are up, there is the difficulty of getting the energy down. Hoffert imagines solving this last problem by using microwave beams of the sort used by cell-phone towers, only much more tightly focussed. He believes, as he put it to me, that S.S.P. has a great deal of "long-term promise"; however, he is quick to point out that he is open to other ideas, like putting solar collectors on the moon, or using superconducting wires to transmit electricity with minimal energy loss, or generating wind power using turbines suspended in the jet stream. The important thing, he argues, is not which new technology will work but simply that some new technology be found. A few years ago, Hoffert published an influential paper in Science in which he argued that holding CO2 levels below five hundred parts per million would require a "Herculean" effort and probably could be accomplished only through "revolutionary" changes in energy production.

"The idea that we already possess the 'scientific, technical, and industrial know-how to solve the carbon problem' is true in the sense that, in 1939, the technical and scientific expertise to build nuclear weapons existed," he told me, quoting Socolow. "But it took the Manhattan Project to make it so."

Hoffert's primary disagreement with Socolow, which both men took pains to point out to me and also took pains to try to minimize, is over the future trajectory of CO2 emissions. For the past several decades, as the world has turned increasingly from coal to oil, natural gas, and nuclear power, emissions of CO2 per unit of energy have declined, a process known as "decarbonization." In the "business as usual" scenario that Socolow uses, it is assumed that decarbonization will continue. To assume this, however, is to ignore several emerging trends. Most of the growth in energy usage in the next few decades is due to occur in places like China and India, where supplies of coal far exceed those of oil or natural gas. (China, which has plans to build five hundred and sixty-two coal-fired plants by 2012, is expected to overtake the U.S. as the world's largest carbon emitter around 2025.) Meanwhile, global production of oil and gas is expected to start to decline—according to some experts, in twenty or thirty years, and to others by the end of this decade. Hoffert predicts that the world will start to "recarbonize," a development that would make the task of stabilizing carbon dioxide that much more difficult. By his accounting, recarbonization will mean that as many as twelve wedges will be needed simply to keep CO2 emissions on the same upward trajectory they're on now. (Socolow readily acknowledges that there are plausible scenarios that would push up the number of wedges needed.) Hoffert told me that he thought the federal government should be budgeting between ten and twenty billion dollars a year for primary research into new energy sources. For comparison's sake, he pointed out that the "Star Wars" missile-defense program, which still hasn't yielded a workable system, has already cost the government nearly a hundred billion dollars.

A commonly heard argument against acting to curb global warming is that the options now available are inadequate. To his dismay, Hoffert often finds his work being cited in support of this argument, with which, he says, he vigorously disagrees. "I want to make it very clear," he told me at one point. "We have to start working immediately to implement those elements that we know how to implement and we need to start implementing these longer-term programs. Those are not opposing ideas."

"Let me say this," he said at another point. "I'm not sure we can solve the problem. I hope we can. I think we have a shot. I mean, it may be that we're not going to solve global warming, the earth is going to become an ecological disaster, and, you know, somebody will visit in a few hundred million years and find there were some intelligent beings who lived here for a while, but they just couldn't handle the transition from being hunter-gatherers to high technology. It's certainly possible. Carl Sagan had an equation—the Drake equation—for how many intelligent species there are in the galaxy. He figured it out by saying, How many stars are there, how many planets are there around these stars, what's the probability that life will evolve on a planet, what's the probability if you have life evolve of having intelligent species evolve, and, once that happens, what's the average lifetime of a technological civilization? And that last one is the most sensitive number. If the average lifetime is about a hundred years, then probably, in the whole galaxy of four hundred billion stars, there are only a few that have intelligent civilizations. If the lifetime is several million years, then the galaxy is teeming with intelligent life. It's sort of interesting to look at it that way. And we don't know. We could go either way."

In theory, at least, the world has already committed itself to addressing global warming, a commitment that dates back more than a decade. In June of 1992, the United Nations held the so-called Earth Summit, in Rio de Janeiro. There, representatives from virtually every nation on earth met to discuss the U.N. Framework Convention on Climate Change, which had as its sweeping objective the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic"—man-made—"interference with the climate system." One of the early signatories was President George H. W. Bush, who, while in Rio, called on world leaders to translate "the words spoken here into concrete action to protect the planet." Three months later, Bush submitted the Framework Convention to the U.S. Senate, which approved it by unanimous consent. Ultimately, the treaty was ratified by a hundred and sixty-five countries.

What "dangerous anthropogenic interference," or D.A.I., consists of was not precisely defined in the Framework Convention, although there are, it is generally agreed, a number of scenarios that would fit the bill—climate change dramatic enough to destroy entire ecosystems, for instance, or severe enough to disrupt the world's food supply. The disintegration of one of the planet's remaining ice sheets is often held up as the exemplary climate disaster; were the Greenland or the West Antarctic Ice Sheet to be destroyed, sea levels around the world would rise by at least fifteen feet, inundating areas where today hundreds of millions of people live. (Were both ice sheets to disintegrate, global sea levels would rise by thirty-five feet.) It could take hundreds, perhaps even thousands, of years for either of the ice sheets to disappear entirely, but, once the disintegration was under way, it would start to feed on itself, most likely becoming irreversible. D.A.I. is understood, therefore, to refer not to the end of the process but to the very beginning, which is to say, to the point at which greenhouse-gas levels became high enough to set disaster in motion.

Among the stipulations of the Framework Convention was that the parties meet regularly to assess their progress. (These meetings became known as the Conference of the Parties, or C.O.P., sessions.) As it turned out, there was hardly any progress to assess. Article 4, paragraph 2, subparagraph b of the convention instructs industrialized nations to "aim" to reduce their greenhouse-gas emissions to 1990 levels. By 1995, the collective emissions from these nations were still rising. (Virtually the only countries that had succeeded in returning to 1990 levels were some former members of the Soviet bloc, and this was because their economies were in free fall.) Several rounds of often bitter negotiations followed, culminating in an eleven-day session at the Kyoto International Conference Hall in December, 1997.

Technically speaking, the agreement that emerged from that session is an addendum to the Framework Convention. (Its full title is the Kyoto Protocol to the United Nations Framework Convention on Climate Change.) For lofty exhortations, the Kyoto Protocol substitutes mandatory commitments. These commitments apply to industrialized, or so-called Annex 1, nations, a group that includes the United States, Canada, Japan, Europe, Australia, New Zealand, and several countries of the erstwhile Eastern bloc. Different Annex 1 nations have slightly different obligations, based on a combination of historical and political factors. The European Union nations, for example, are supposed to reduce their greenhouse-gas emissions eight per cent below 1990 levels. The U.S. has a target of seven per cent below 1990 levels, and Japan has a target of six per cent below. The treaty covers five greenhouse gases in addition to CO2—methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride—which, for the purposes of accounting, are converted into units known as "carbon-dioxide equivalents." Industrialized nations can meet their targets, in part, by buying and selling emissions credits and by investing in "clean development" projects in developing, or so-called non-Annex 1, nations. This second group includes emergent industrial powers like China and India, oil-producing states like Saudi Arabia and Kuwait, and nations with mostly subsistence economies, like Sudan. Non-Annex 1 nations have no obligation to reduce their emissions during the period covered by the protocol, which ends in 2012.

In political terms, global warming might be thought of as the tragedy of the commons writ very, very large. The goal of stabilizing CO2 concentrations effectively turns emissions into a limited resource, which nobody owns but everybody with a book of matches has access to.

Even as Kyoto was being negotiated, it was clear that the treaty was going to face stiff opposition in Washington. In July of 1997, Senator Chuck Hagel, Republican of Nebraska, and Senator Robert Byrd, Democrat of West Virginia, introduced a "sense of the Senate" resolution that, in effect, warned the Clinton Administration against the direction that the talks were taking. The so-called Byrd-Hagel Resolution stated that the U.S. should reject any agreement that committed it to reducing emissions unless concomitant obligations were imposed on developing countries as well. The Senate approved the resolution by a vote of 95-0, an outcome that reflected lobbying by both business and labor. Although the Clinton Administration eventually signed Kyoto, it never submitted the protocol to the Senate for ratification, citing the need for participation by “key developing nations.”

From a certain perspective, the logic behind the Byrd-Hagel Resolution is unimpeachable. Emissions controls cost money, and this cost has to be borne by somebody. If the U.S. were to agree to limit its greenhouse gases while economic competitors like China and India were not, then American companies would be put at a disadvantage. “A treaty that requires binding commitments for reduction of emissions of greenhouse gases for the industrial countries but not developing countries will create a very damaging situation for the American economy” is how Richard Trumka, the secretary-treasurer of the A.F.L.-C.I.O., put it when he travelled to Kyoto to lobby against the protocol. It is also true that an agreement that limits carbon emissions in some countries and not in others could result in a migration, rather than an actual reduction, of CO2 emissions. (Such a possibility is known in climate parlance as “leakage.”)

From another perspective, however, the logic of Byrd-Hagel is deeply, even obscenely, self-serving. Suppose for a moment that the total anthropogenic CO2 that can be emitted into the atmosphere were a big ice-cream cake. If the aim is to keep concentrations below five hundred parts per million, then roughly half that cake has already been consumed, and, of that half, the lion’s share has been polished off by the industrialized world. To insist now that all countries cut their emissions simultaneously amounts to advocating that industrialized nations be allocated most of the remaining slices, on the ground that they’ve already gobbled up so much. In a year, the average American produces the same greenhouse-gas emissions as four and a half Mexicans, or eighteen Indians, or ninety-nine Bangladeshis. If both the U.S. and India were to reduce their emissions proportionately, then the average Bostonian could continue indefinitely producing eighteen times as much greenhouse gases as the average Bangalorean. But why should anyone have the right to emit more than anyone else? At a climate meeting in New Delhi three years ago, Atal Bihari Vajpayee, then the Indian prime minister, told world leaders, “Our per capita greenhouse gas emissions are only a fraction of the world average and an order of magnitude below that of many developed countries. We do not believe that the ethos of democracy can support any norm other than equal per capita rights to global environmental resources.”

Outside the U.S., the decision to exempt developing nations from Kyoto’s mandates was generally regarded as an adequate—if imperfect—solution. The point was to get the process started, and to persuade countries like China and India to sign on later. This “two-world” approach had been employed—successfully—in the nineteen-eighties to phase out chlorofluorocarbons, the chemicals responsible for depleting atmospheric ozone. Pieter van Geel, the Dutch environment secretary, who is a member of the Netherlands’ center-right Christian Democratic Party, described the European outlook to me as follows: “We cannot say, ‘Well, we have our wealth, based on the use of fossil fuels for the last three hundred years, and, now that your countries are growing, you may not grow at this rate, because we have a climate-change problem.’ We should show moral leadership by giving the example. That’s the only way we can ask something of these other countries.”

The Kyoto Protocol finally went into effect on February 16th of this year. In many cities, the event was marked by celebration; the city of Bonn hosted a reception in the Rathaus, Oxford University held an “Entry Into Force” banquet, and in Hong Kong there was a Kyoto prayer meeting. As it happened, that day, an exceptionally warm one in Washington, D.C., I went to speak to the Under-Secretary of State for Global Affairs, Paula Dobriansky.

Dobriansky is a slight woman with shoulder-length brown hair and a vaguely anxious manner. Among her duties is explaining the Bush Administration’s position on global warming to the rest of the world; in December, for example, she led the U.S. delegation to the tenth Conference of the Parties, which was held in Buenos Aires. Dobriansky began by assuring me that the Administration took the issue of climate change “very seriously.” She went on, “Also let me just add, because in terms of taking it seriously, not only stating to you that we take it seriously, we have engaged many countries in initiatives and efforts, whether they are bilateral initiatives—we have some fourteen bilateral initiatives—and in addition we have put together some multilateral initiatives. So we view this as a serious issue.”

Besides the U.S., the only other major industrialized nation that has rejected Kyoto—and, with it, mandatory cuts in emissions—is Australia. I asked Dobriansky how she justified the U.S.’s stance to its allies. “We have a common goal and objective as parties to the U. N. Framework Convention on Climate Change,” she told me. “Where we differ is on what approach we believe is and can be the most effective.”

Running for President in 2000, George W. Bush called global warming “an issue that we need to take very seriously.” He promised, if elected, to impose federal limits on CO2. Soon after his inauguration, he sent the head of the Environmental Protection Agency, Christine Todd Whitman, to a meeting of environment ministers from the world’s leading industrialized nations, where she elaborated on his position. Whitman assured her colleagues that the new President believed global warming to be “one of the greatest environmental challenges that we face” and that he wanted to "take steps to move forward." Ten days after her presentation, Bush announced that not only was he withdrawing the U.S. from the ongoing negotiations over Kyoto—the protocol had left several complex issues of implementation to be resolved later—he was now opposed to any mandatory curbs on carbon dioxide. Explaining his change of heart, Bush asserted that he no longer believed that CO2 limits were justified, owing to the "state of scientific knowledge of the causes of, and solutions to, global climate change," which he labelled "incomplete." (Former Treasury Secretary Paul O'Neill, who backed the President's original position, has speculated publicly that the reversal was engineered by Vice-President Dick Cheney.)

The following year, President Bush came forward with the Administration's current position on global warming. Central to this policy is a reworking of the key categories. Whereas Kyoto and the original Framework Convention aim at controlling greenhouse-gas emissions, the President's policy targets greenhouse-gas "intensity." Bush has declared his approach preferable because it recognizes "that a nation that grows its economy is a nation that can afford investments and new technology."

Greenhouse-gas intensity is not a quantity that can be measured directly. Rather, it is a ratio that relates emissions to economic output. Say, for example, that one year a business produces a hundred pounds of carbon and a hundred dollars' worth of goods. Its greenhouse-gas intensity in that case would be one pound per dollar. If the next year that company produces the same amount of carbon but an extra dollar's worth of goods, its intensity will have fallen by one per cent. Even if it doubles its total emissions of carbon, a company—or a country—can still claim a reduced intensity provided that it more than doubles its output of goods. (Typically, a country's greenhouse-gas intensity is measured in terms of tons of carbon per million dollars' worth of gross domestic product.)

To focus on greenhouse-gas intensity is to give a peculiarly sunny account of the United States' situation. Between 1990 and 2000, the U.S.'s greenhouse-gas intensity fell by some seventeen per cent, owing to several factors, including the shift toward a more service-based economy. Meanwhile, over-all emissions rose by some twelve per cent. (In terms of greenhouse-gas intensity, the U.S. actually performs better than many Third World nations, because even though we consume a lot more energy, we also have a much larger G.D.P.) In February of 2002, President Bush set the goal of reducing the country's greenhouse-gas intensity by eighteen per cent over the following ten years. During that same decade, the Administration expects the American economy to grow by three per cent annually. If both expectations are met, over-all emission of greenhouse gases will rise by about twelve per cent.

The Administration's plan, which relies almost entirely on voluntary measures, has been characterized by critics as nothing more than a subterfuge—"a total charade" is how Philip Clapp, the president of the Washington-based National Environmental Trust, once put it. Certainly, if the goal is to prevent "dangerous anthropogenic interference," then greenhouse-gas intensity is the wrong measure to use. (Essentially, the President's approach amounts to following the path of "business as usual.") The Administration's response to such criticism is to attack its premise. "Science tells us that we cannot say with any certainty what constitutes a dangerous level of warming and therefore what level must be avoided," Dobriansky declared recently. When I asked her how, in that case, the U.S. could support the U.N. Framework Convention's aim of averting D.A.I., she answered by saying—twice—"We predicate our policies on sound science."

Earlier this year, the chairman of the Senate Environment and Public Works Committee, James Inhofe, gave a speech on the Senate floor, which he entitled "An Update on the Science of Climate Change." In the speech, Inhofe, an Oklahoma Republican, announced that "new evidence" had come to light that "makes a mockery" of the notion that human-induced warming is occurring. The Senator, who has called global warming "the greatest hoax ever perpetrated on the American people," went on to argue that this important new evidence was being suppressed by "alarmists" who view anthropogenic warming as "an article of religious faith." One of the authorities that Inhofe repeatedly cited in support of his claims was the fiction writer Michael Crichton.

It was an American scientist, Charles David Keeling, who, in the nineteen-fifties, developed the technology to measure CO2 levels precisely, and it was American researchers who, working out of Hawaii's Mauna Loa Observatory, first showed that these levels were steadily rising. In the half century since then, the U.S. has contributed more than any other nation to the advancement of climate science, both theoretically, through the work of climate modellers, and experimentally, through field studies conducted on every continent.

At the same time, the U.S. is also the world's chief purveyor of the work of so-called global-warming "skeptics." The ideas of these skeptics are published in books with titles like "The Satanic Gases" and "Global Warming and Other Eco-Myths" and then circulated on the Web by groups like Tech Central Station, which is sponsored by, among others, ExxonMobil and General Motors. While some skeptics' organizations argue that global warming isn't real, or at least hasn't been proved—"Predicting weather conditions a day or two in advance is hard enough, so just imagine how hard it is to forecast what our climate will be," Americans for Balanced Energy Choices, a lobbying organization funded by mining and power companies, declares on its Web site—others maintain that rising CO2 levels are actually cause for celebration.

"Carbon dioxide emissions from fossil fuel combustion are beneficial to life on earth," the Greening Earth Society, an organization created by the Western Fuels Association, a utility group, states. Atmospheric levels of seven hundred and fifty parts per million—nearly triple pre-industrial levels—are nothing to worry about, the society maintains, because plants like lots of CO2, which they need for photosynthesis. (Research on this topic, the group's Web site acknowledges, has been "frequently denigrated," but "it's exciting stuff" and provides an "antidote to gloom-and-doom about potential changes in earth's climate.")

In legitimate scientific circles, it is virtually impossible to find evidence of disagreement over the fundamentals of global warming. This fact was neatly demonstrated last year by Naomi Oreskes, a professor of history and science studies at the University of California at San Diego. Oreskes conducted a study of the more than nine hundred articles on climate change published in refereed journals between 1993 and 2003 and subsequently made available on a leading research database. Of these, she found that seventy-five per cent endorsed the view that anthropogenic emissions were responsible for at least some of the observed warming of the past fifty years. The remaining twenty-five per cent, which dealt with questions of methodology or climate history, took no position on current conditions. Not a single article disputed the premise that anthropogenic warming is under way.

Still, pronouncements by groups like the Greening Earth Society and politicians like Senator Inhofe help to shape public discourse on climate change in this country. And this is clearly their point. A few years ago, the pollster Frank Luntz prepared a strategy memo for Republican members of Congress, coaching them on how to deal with a variety of environmental issues. (Luntz, who first made a name for himself by helping to craft Newt Gingrich's "Contract with America," has been described as "a political consultant viewed by Republicans as King Arthur viewed Merlin.") Under the heading "Winning the Global Warming Debate," Luntz wrote, "The scientific debate is closing (against us) but not yet closed. There is still a window of opportunity to challenge the science." He warned, "Voters believe that there is no consensus about global warming in the scientific community. Should the public come to believe that the scientific issues are settled, their views about global warming will change accordingly." Luntz also advised, "The most important principle in any discussion of global warming is your commitment to sound science."

It is in this context, and really only in this context, that the Bush Administration's conflicting claims about the science of global warming make any sense. Administration officials are quick to point to the scientific uncertainties that remain about global warming, of which there are many. But where there is broad scientific agreement they are reluctant to acknowledge it. "When we make decisions, we want to make sure we do so on sound science," the President said, announcing his new approach to global warming in February, 2002. Just a few months later, the Environmental Protection Agency delivered a two-hundred-and-sixty-three-page report to the U.N. which stated that "continuing growth in greenhouse gas emissions is likely to lead to annual average warming over the United States that could be as much as several degrees Celsius (roughly 3 to 9 degrees Fahrenheit) during the 21st century." The President dismissed the report—the product of years of work by federal researchers—as something "put out by the bureaucracy." The following spring, the E.P.A. made another effort to give an objective summary of climate science, in a report on the state of the environment. The White House interfered so insistently in the writing of the global-warming section—at one point, it tried to insert excerpts from a study partly financed by the American Petroleum Institute—that, in an internal memo, agency staff members complained that the section "no longer accurately represents scientific consensus." (When the E.P.A. finally published the report, the climate-science section was missing entirely.) Just two months ago, a top official with the federal Climate Change Science Program announced that he was resigning, owing to differences with the White House. The official, Rick Piltz, said that he was disturbed that the Administration insisted on vetting climate-science reports, "rather than asking independent scientists to write them and let the chips fall where they may."

The day after the Kyoto Protocol took effect, I went to the United Nations to attend a conference entitled, appositely, "One Day After Kyoto." The conference, whose subtitle was "Next Steps on Climate," was held in a large room with banks of curved desks, each equipped with a little plastic earpiece. The speakers included scientists, insurance-industry executives, and diplomats from all over the world, among them the U.N. Ambassador from the tiny Pacific island nation of Tuvalu, who described how his country was in danger of simply disappearing. Britain's permanent representative to the U.N., Sir Emyr Jones Parry, began his remarks to the crowd of two hundred or so by stating, "We can't go on as we are."

When the U.S. withdrew from negotiations over Kyoto, in 2001, the entire effort nearly collapsed. According to the protocol's elaborate ratification mechanism, in order to take effect it had to be approved by countries responsible for at least fifty-five per cent of the industrialized world's CO2 emissions. All on its own, America accounts for thirty-four per cent of those emissions. European leaders spent more than three years working behind the scenes, lining up support from the remaining industrialized nations. The crucial threshold was finally crossed this past October, when the Russian Duma voted in favor of ratification. The Duma's vote was understood to be a condition of European backing for Russia's bid to join the World Trade

Organization. (“russia forced to ratify kyoto protocol to become w.t.o. member,” read the headline in Pravda.)

As speaker after speaker at the U.N. conference noted, Kyoto is only the first step in a long process. Even if every country—including the U.S.—were to fulfill its obligations under the protocol before it lapses in 2012, CO2 concentrations in the atmosphere would still reach dangerous levels. Kyoto merely delays this outcome. The “next step on climate” requires, among other things, substantive commitments from countries like China and India. So long as U.S. emissions continue to grow, essentially unchecked, obtaining these commitments seems next to impossible. In this way, the U.S., having failed to defeat Kyoto, may be in the process of doing something even more damaging: ruining the chances of reaching a post-Kyoto agreement. “The blunt reality is that, unless America comes back into some form of international consensus, it is very hard to make progress” is how Britain’s Prime Minister, Tony Blair, diplomatically put it at a recent press conference.

Astonishingly, standing in the way of progress seems to be Bush’s goal. Paula Dobriansky explained the Administration’s position to me as follows: While the rest of the industrialized world is pursuing one strategy (emissions limits), the U.S. is pursuing another (no emissions limits), and it is still too early to say which approach will work best. “It is essential to really implement these programs and approaches now and to take stock of their effectiveness,” she said, adding, “We think it is premature to talk about future arrangements.” At C.O.P.-10, in Buenos Aires, many delegations pressed for a preliminary round of meetings so that work could start on mapping out Kyoto’s successor. The U.S. delegation opposed these efforts so adamantly that finally the Americans were asked to describe, in writing, what sort of meeting they would find acceptable. They issued half a page of conditions, one of which was that the session “shall be a one-time event held during a single day.” Another condition was, paradoxically, that, if they were going to discuss the future, the future would have to be barred from discussion; presentations, they wrote, should be limited to “an information exchange” on “existing national policies.” Annie Petsonk, a lawyer with the advocacy group Environmental Defense, who previously worked for the Administration of George Bush, Sr., attended the talks in Buenos Aires. She recalled the effect that the memo had on the members of the other delegations: “They were ashen.”

European leaders have made no secret of their dismay at the Administration’s stance. “It’s absolutely obvious that global warming has started,” France’s President, Jacques Chirac, said after attending last year’s G-8 summit with Bush. “And so we have to act responsibly, and, if we do nothing, we would bear a heavy responsibility. I had the chance to talk to the United States President about this. To tell you that I convinced him would be a total exaggeration, as you can imagine.” Blair, who currently holds the presidency of the G-8, recently warned that only “timely action” on climate change will avert “disaster.” He has promised to make the issue one of the top items on the agenda of this year’s summit, to be held in Scotland in July, but no one seems to be expecting a great deal to come of it. While attending a meeting in London this spring, the head of the White House Council on Environmental Quality, James Connaughton, announced that he wasn’t yet convinced that anthropogenic warming was a problem. “We are still working on the issue of causation, the extent to which humans are a factor,” he said.

The town of Maasbommel, sixty miles southeast of Amsterdam, is a popular tourist destination along the banks of the River Meuse. Every summer, it is visited by thousands of people who come to go boating and camping. Thanks to the risk of flooding, building is restricted along the river, but a few years ago one of the Netherlands’ largest construction firms, Dura Vermeer, received permission to turn a former R.V. park into a development of “amphibious homes.” The first of these were completed last fall, and a few months later I went to see them.

The amphibious homes all look alike. They are tall and narrow, with flat sides and curved metal roofs, so that, standing next to one another, they resemble a row of toasters. Each one is moored to a metal pole and sits on a set of hollow concrete pontoons. Assuming that all goes according to plan, when the Meuse floods the homes will bob up and then, when the water recedes, they will gently be deposited back on land. Dura Vermeer is also working to construct buoyant roads and floating greenhouses. While each of these projects represents a somewhat different engineering challenge, they have a common goal, which is to allow people to continue to inhabit areas that, periodically at least, will be inundated. The Dutch, because of their peculiar vulnerability, can’t afford to misjudge climate change, or to pretend that by denying it they can make it go away. “There is a flood market emerging,” Chris Zevenbergen, Dura Vermeer’s environmental director, told me. Half a dozen families were already occupying their amphibious homes when I visited Maasbommel. Anna van der Molen, a nurse and mother of four, gave me a tour of hers. She said that she expected that in the future people all over the world would live in floating houses, since, as she put it, “the water is coming up.”

Resourcefulness and adaptability are, of course, essential human qualities. People are always imagining new ways to live, and then figuring out ways to remake the world to suit what they’ve imagined. This capacity has allowed us, collectively, to overcome any number of threats in the past, some imposed by nature, some by ourselves. It could be argued, taking this long view, that global warming is just one more test in a sequence that already stretches from plague and pestilence to the prospect of nuclear annihilation. If, at this moment, the bind that we’re in appears insoluble, once we’ve thought long and hard enough about it we’ll find—or maybe float—our way clear.

But it’s also possible to take an even longer view of the situation. We now have detailed climate records going back four full glacial cycles. What these records show, in addition to a clear correlation between CO2 levels and global temperatures, is that the last glaciation was a period of frequent and traumatic climate swings. During that period, which lasted nearly a hundred thousand years, humans who were, genetically speaking, just like ourselves wandered the globe, producing nothing more permanent than isolated cave paintings and large piles of mastodon bones. Then, ten thousand years ago, at the start of the Holocene, the climate changed. As the weather settled down, so did we. People built villages, towns, and, finally, cities, along the way inventing all the basic technologies—agriculture, metallurgy, writing—that future civilizations would rely upon. These developments would not have been possible without human ingenuity, but, until the climate coöperated, ingenuity, it seems, wasn’t enough.

Climate records also show that we are steadily drawing closer to the temperature peaks of the last interglacial, when sea levels were some fifteen feet higher than they are today. Just a few degrees more and the earth will be hotter than it has been at any time since our species evolved. Scientists have identified a number of important feedbacks in the climate system, many of which are not fully understood; in general, they tend to take small changes to the system and amplify them into much larger forces. Perhaps we are the most unpredictable feedback of all. No matter what we do at this point, global temperatures will continue to rise in the coming decades, owing to the gigatons of extra CO2 already circulating in the atmosphere. With more than six billion people on the planet, the risks of this are obvious. A disruption in monsoon patterns, a shift in ocean currents, a major drought—any one of these could easily produce streams of refugees numbering in the millions. As the effects of global warming become more and more apparent, will we react by finally fashioning a global response? Or will we retreat into ever narrower and more destructive forms of self-interest? It may seem impossible to imagine that a technologically advanced society could choose, in essence, to destroy itself, but that is what we are now in the process of doing.
(This is the third part of a three-part article.)

A Planetary Problem
Elizabeth Kolbert discusses climate change.
Issue of 2005-04-25

Elizabeth Kolbert travelled from Alaska to Greenland, and visited top scientists, to get to the heart of the debate over global warming. In this week’s magazine, she publishes the last of a three-part series on climate change; the first and second parts are here online. Below, she discusses the series with Amy Davidson.

AMY DAVIDSON: What is global warming? Is it real, or theoretical?

ELIZABETH KOLBERT: I guess you could say that that depends on what the meaning of the word “is” is. The principles of global warming are as well established as any in physics. Nearly a hundred and fifty years ago, a British physicist named John Tyndall discovered that certain gases in the atmosphere—we now refer to these as “greenhouse gases”—trap heat on earth by absorbing infrared radiation. There are several naturally occurring greenhouse gases, including carbon dioxide and water vapor, and together they produce the so-called “natural greenhouse effect.” Without the natural greenhouse effect, the planet would essentially be frozen. Any basic earth-science textbook talks about the natural greenhouse effect; it’s a phenomenon that is not in any way debated. All that the theory of global warming says is that if you increase the concentration of greenhouse gases in the atmosphere, you will also increase the earth’s average temperature. It’s indisputable that we have increased greenhouse-gas concentrations in the air as a result of human activity, and it’s also indisputable that over the last few decades average global temperatures have gone up. As best as can be determined, the world is now warmer than it has been at any point in the last two millennia, and, if current trends continue, by the end of the century it will likely be hotter than at any point in the last two million years.

How would warming the world change the world—that is, the world for human beings?

There are countless ways in which we humans are dependent on the climate: it determines what crops we can grow, what pests and diseases we have to worry about, how we get water, and on and on. Warming the world is likely to change the climate patterns that we rely on; some areas, for example, are apt to become drier while others will become wetter. Sea levels will probably rise, possibly quite dramatically, and that will affect coastal areas where hundreds of millions of people now live. No one knows exactly how higher average temperatures will translate into, say, changes in precipitation, but, considering that there are more than six billion people on the planet, it wouldn’t take a very large alteration to create very significant problems.

Climate does vary naturally. How is what we’re talking about here different?

It’s true that the climate varies naturally, and some of the recent rise in global temperatures may well be part of a natural cycle. The point that’s important to keep in mind is that the greenhouse gases we are adding to the atmosphere are overwhelming the natural forces that cause climate variability. In effect, we humans are becoming the drivers of the climate system, and we are doing so without knowing where we are going.

Your reporting for the article took you to Alaska. What did you find?

Alaska is being very dramatically affected by climate change; the state is warming up just about as fast as any place on earth. This is producing a lot of problems in Native communities; several Native villages may have to be moved owing to erosion that is being caused, or at least hastened, by climate change. It's also affecting daily life in places like Fairbanks, parts of which are built on permafrost. As the permafrost degrades, people's houses are starting to split apart. The roads need to be repaired more often; sometimes they just cave in. Ironically, it's also affecting the oil industry. The kind of heavy equipment used in oil exploration is allowed out on the tundra only when the ground is frozen to a depth of twelve inches. Since 1970 the number of days that meet that condition has been reduced by half. Early on, computer models developed by scientists working on climate change predicted that global warming would have a disproportionate effect in the Arctic.

You also spent some time sleeping in a tent out on the ice in Greenland. What brought you there?

Outside of Antarctica's, Greenland's ice sheet is the largest in the world. It contains enough water to raise global sea levels by twenty-three feet. There is a very real possibility that global warming will set in motion the destruction of the Greenland ice sheet. No one really knows how warm the world would have to get before that happens, but the signs are not encouraging. Scientists are already seeing changes to the ice sheet that suggest that it could occur at temperatures not much higher than today's. And although the process could take centuries, or even millennia, to fully play out, once the ice sheet started to melt it would become self-reinforcing and therefore impossible to stop.

I was very struck by your description of the work being done by Donald Perovich, a government scientist, who measures something called albedo. What is its significance?

Albedo is a measure of reflectivity. The ice in the Arctic, and also in the Antarctic, reflects a tremendous amount of sunlight back into space. This is a very significant factor in shaping the earth's climate. In the Arctic, the ice, and particularly the sea ice, is melting, and this is changing the earth's reflectivity. More heat is being absorbed, which is causing more sea ice to melt, and so on. This is a good example of positive feedback. It's taking a relatively small change to the system and amplifying it into a much larger one. There are several positive feedbacks in the climate system that are known, and quite possibly others that haven't yet been identified, and all are cause for concern.

How good is the science? We often hear it said, at least in this country, that there are conflicting views.

There is a very broad consensus in the scientific community that global warming is under way. To the extent that there are conflicting views, they are usually over how exactly the process will play out. This is understandable. The climate affects just about every natural system on earth, and these systems in turn affect the climate. So making predictions is very complicated. Meanwhile, we have only one planet, so it's impossible to run a controlled experiment. To focus on the degree of disagreement, rather than on the degree of consensus, is, I think, fundamentally misguided. If ten people told you your house was on fire, you would call the fire department. You wouldn't really care whether some of them thought that the place would be incinerated in an hour and some of them thought it would take a whole day.

In your second article in the series, you talk about climate modelling. How do scientists use computers to predict the future of the environment?

Scientists use very elaborate climate models, which are run on supercomputers, to try to predict the future. These models use equations to describe hundreds of different processes that affect the climate: the formation of clouds, the evaporation of water, heat transport in the oceans, and so on. The model I'm most familiar with, which was produced by nasa's Goddard Institute for Space Studies, here in New York, consists of a hundred and twenty-five thousand lines of computer code. Of course, even the most detailed climate models can only approximate reality very crudely, and it's hard to know in advance which will prove to be the most accurate. I think it's important to note, though, that all climate models—there are about fifteen major ones in operation—predict that global temperatures will increase in coming decades. They also all predict that if we double CO2 concentrations in the atmosphere this increase will be quite substantial.

Some scientists look backward instead of forward. In the second piece, you discuss the Akkadian civilization. What about that story is especially relevant now?

Akkad is often referred to as the world's first empire. It was, for its time (around 2300 B.C.), a very sophisticated civilization, and it collapsed in a period of prolonged drought. As a result of global warming, it's predicted that some regions of the world will start to experience droughts, while others will receive more rain and be vulnerable to flooding. The question is, how will society deal with that? In this context, the history of Akkad, and of other civilizations whose demise has been linked to climate change, is not very encouraging.

One disturbing thing about your article is just how alarmed many seemingly sober-minded scientists are.

What sort of a gap is there between expert and lay opinion on climate change?

That's a good question. I think there is a surprisingly large—you might even say frighteningly large—gap between the scientific community and the lay community's opinions on global warming. As you point out, I spoke to many very sober-minded, coolly analytical scientists who, in essence, warned of the end of the world as we know it. I think there are a few reasons why their message hasn't really got out. One is that scientists tend, as a group, to interact more with each other than with the general public. Another is that there has been a very well-financed disinformation campaign designed to convince people that there is still scientific disagreement about the problem, when, as I mentioned before, there really is quite broad agreement. And third, the climate operates on its own timetable. It will take several decades for the warming that is already inevitable to be felt. People tend to focus on the here and now. The problem is that, once global warming is something that most people can feel in the course of their daily lives, it will be too late to prevent much larger, potentially catastrophic changes.

If human beings have caused climate change, can we also reverse it?

We cannot reverse climate change. This is because carbon dioxide is a long-lived gas. What we do have the power to do is to mitigate climate change by reducing emissions. The longer we wait to do this, the riskier the situation will become.

Why are we waiting? Is this a scientific problem or a political problem?

I think one would have to say at this point that the problem is political. As I mentioned, there are a great number of uncertainties about how, exactly, global warming will play out—how much sea levels will rise, where precisely there is likely to be drought, and so on. But none of those uncertainties alter the basic fact that the more we increase greenhouse-gas concentrations in the atmosphere the hotter the planet will become. The only way to mitigate that is to curb our emissions. It's pretty basic. It seems to me that the claim that we need more research before we can act is often used as excuse for the fact that we don't want to act. Curbing emissions isn't easy. Practically every activity of modern life—from driving and flying to turning on the lights —produces greenhouse gases.

What has the Bush Administration done to address global warming?

The Administration has financed a variety of research programs into technologies like "carbon capture and storage," which could one day prove useful in addressing global warming. However, in terms of actually addressing the problem in the here and now, it has done relatively little. Early in his first term, President Bush withdrew the U.S. from negotiations over the Kyoto Protocol, the international treaty that deals with greenhouse-gas emissions. The President also has rejected any kind of mandatory domestic CO2 curbs, like those proposed by Senators John McCain and Joseph Lieberman. Without some kind of curb—or tax—on greenhouse-gas emissions, it's hard to imagine how they will be controlled. There's just no incentive.

Some opponents of the Kyoto accord argue that it is unfair to America, because it asks us to limit emissions but does not ask the same of the developing world—China, for instance, which is poised to become a major producer of greenhouse gases. There's a certain logic to this argument, isn't there?

There definitely is a logic to this argument. However, there is also a very strong argument to be made that the U.S., which is by far the world's largest emitter of greenhouse gases, has an obligation to lead the world on this issue. If we curb our emissions, perhaps we can persuade the Chinese, who are in the process of ramping up their CO2 production, to take similar steps. If we continue to increase our emissions, then why should the Chinese, who still have a much lower standard of living than we do, bother to curb theirs? When Kyoto was drafted, it was always understood to be just a first step. We have been unwilling to take that first step, and until we do so it's hard to see how progress can be made.

Human beings have responded to challenges for millennia. For most of that time, we have had far fewer technological tools at our disposal than we have now. Why shouldn't we be optimistic about our ability to face climate change and adapt?

I certainly hope that we can face climate change. My oldest son is ten years old and, for his sake, I would very much like to think that we will be able to cope with this challenge. It's hard for me to be optimistic, though. Scientists have been warning about the dangers of global warming for more than twenty-five years now, and in that time we have increased our energy usage—and, with it, our production of greenhouse gases—quite dramatically.

In terms of adaptation, it's a nice idea, and certainly it will be necessary; the amount of warming that is already inevitable is quite significant and may cause severe disruptions. At a certain point, though, the changes will become so great that adaptation will become extremely difficult; a five-foot rise in sea levels, for example, would put parts of the state of Florida underwater. If you imagine that sort of scenario being played out all around the globe, it gets pretty frightening. And, as one climatologist pointed out to me, while we are more technologically sophisticated than earlier societies, we are also more sophisticated when it comes to destruction.