

BY THE SAME AUTHOR

The Prophet of Love

FIELD NOTES
from a
CATASTROPHE

MAN, NATURE,
AND CLIMATE CHANGE

Elizabeth Kolbert

BLOOMSBURY

To my boys

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PREFACE

THERE ISN'T MUCH to do at the Hotel Arctic except watch the icebergs flow by. The hotel is located in the town of Ilulissat, on the west coast of Greenland, four degrees north of the Arctic Circle. The icebergs originate some fifty miles away, at the end of a long and fast-moving ice stream known as the Jakobshavn Isbrae. They drift down a fjord and through a wide-mouthed bay, and, if they last long enough, end up in the North Atlantic. (It is likely that the iceberg encountered by the *Titanic* followed this route.)

To the tourists who visit the Hotel Arctic, the icebergs are a thrilling sight: beautiful and terrible in equal measure. They are a reminder of the immensity of nature and the smallness of man. To the people who spend more time in Ilulissat—native Greenlanders, European tour guides, American scientists—the icebergs have come to acquire a different significance. Since the late 1990s, the Jakobshavn Isbrae has doubled its speed. In the process, the height of the ice stream has been dropping by up to fifty feet a year and the calving front has retreated by several

miles. What locals now notice about the icebergs is not their power or immensity—though they are still powerful and immense—but a disquieting diminishment.

"You don't get the big icebergs anymore," an Ilulissat town councilman named Jeremias Jensen told me. We were having coffee on a late-spring afternoon in the Hotel Arctic lobby. Outside, it was foggy and the icebergs seemed to be rising up out of the mist. "It's very strange the last few years; you can see a lot of strange changes."

This is a book about watching the world change. It grew out of three articles that I wrote for the *New Yorker* magazine, which ran in the spring of 2005, and its goal remains much the same as that of the original series: to convey, as vividly as possible, the reality of global warming. The opening chapters are set near or above the Arctic Circle—in Deadhorse, Alaska; in the countryside outside of Reykjavik; at Swiss Camp, a research station on the Greenland ice sheet. I went to these particular places for all the usual journalistic reasons—because someone invited me to tag along on an expedition, because someone let me a hitch a ride on a helicopter, because someone sounded interesting over the telephone. The same is true of the choices that were made in subsequent chapters, whether it was a decision to track butterflies in northern England or to visit floating houses in the Netherlands. Such is the impact of global warming that I could have gone to hundreds if not thousands of other places—from Siberia to the Austrian Alps to the Great Barrier Reef to the South African fynbos—to document its effects. These alternate choices

would have resulted in an account very different in its details, but not in its conclusions.

Humans aren't the first species to alter the atmosphere; that distinction belongs to early bacteria, which, some two billion years ago, invented photosynthesis. But we are the first species to be in a position to understand what we are doing. Computer models of the earth's climate suggest that a critical threshold is approaching. Crossing over it will be easy, crossing back quite likely impossible. The second part of this book explores the complicated relationship between the science and the politics of global warming, between what we know and what we refuse to know.

My hope is that this book will be read by everyone, by which I mean not only those who follow the latest news about the climate but also those who prefer to skip over it. For better or (mostly) for worse, global warming is all about scale, and the sheer number of figures involved can be daunting. I've tried to offer what is essential without oversimplifying. Similarly, I have tried to keep the discussion of scientific theory to a minimum while offering a full-enough account to convey what is truly at stake.

Chapter 7

BUSINESS AS USUAL

IN CLIMATE-SCIENCE CIRCLES, a future in which current emissions trends continue, unchecked, is known as "business as usual," or BAU. About five years ago, Robert Socolow, a professor of engineering at Princeton, began to think about BAU and what it implied for the fate of mankind. At that point, Socolow had recently become codirector 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 visit him at his office 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 1970s, 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 codirector of the Carbon Mitigation Initiative, he decided that the first thing he needed to do was get a handle on the scale of the carbon problem. He found that the existing literature on the subject offered almost too much information. In addition to BAU, 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.

Here in the United States, most of us begin generating CO₂ as soon as we get out of bed. Seventy percent of our electricity is generated by burning fossil fuels—a little

more than 50 percent from burning coal and another 17 percent from natural gas—so that to turn on the lights is, indirectly at least, to pump carbon dioxide into the atmosphere. Making a pot of coffee, either on an electric or a gas range, adds more emissions, as does taking a hot shower, watching the morning news on TV, and driving to work. Exactly how much CO₂ any particular action produces depends on a variety of factors. Though all fossil fuels produce carbon dioxide as an inevitable product of combustion, some fuels, most notably coal, give off more than others for each unit of power generated. A kilowatt-hour of electricity delivered from a coal-fired plant will produce slightly more than half a pound of carbon, while if the power is originating from a plant that runs on natural gas, it will produce roughly half that amount. (When measuring CO₂, it is customary to count not the full weight of the gas, but just the weight of the carbon—to convert back, multiply by 3.7.) Every gallon of gasoline that is consumed produces about five pounds of carbon, meaning that in the course of a forty-mile commute, a vehicle like a Ford Explorer or a GM Yukon throws about a dozen pounds of carbon into the air. On average, every single person in America generates twelve thousand pounds of carbon per year. (If you would like to figure out your own annual contribution to greenhouse warming, go to the Environmental Protection Agency's Web site and plug various facts about your lifestyle—what kind of car you drive, how much of your trash you recycle, and so on—into the "personal emis-

sions calculator" provided there.) The largest single source of carbon emissions in the United States is electricity production, at 39 percent, followed by transportation, at 32 percent. In a country like France, where three quarters of the power is produced by nuclear plants, this ratio is very different, and it's different again in countries like Bhutan, where many people don't even have access to electricity and where they burn wood and animal waste to cook and heat their homes.

In the future, the growth of carbon emissions is likely to be determined by several forces. One is the rate of population growth; estimates of how many people will be living on the planet in 2050 range from a low of 7.4 billion to a high of 10.6 billion. Another is economic growth. A third factor is the rate at which new technologies are adopted. Particularly in the developing world, the demand for electricity is increasing rapidly; in China, for example, electricity consumption is expected to more than double by 2025. If developing nations satisfy this demand by adopting the latest, most energy-efficient technologies, then emissions will grow at one rate. (This possibility is sometimes referred to as "leapfrogging," since it would require developing countries to "leapfrog" ahead of industrialized nations.) If they satisfy demand by deploying less efficient—but often cheaper—technologies, emissions will increase at a much faster rate.

"Business as usual" refers to a whole range of projections, all of which take as their primary assumption that

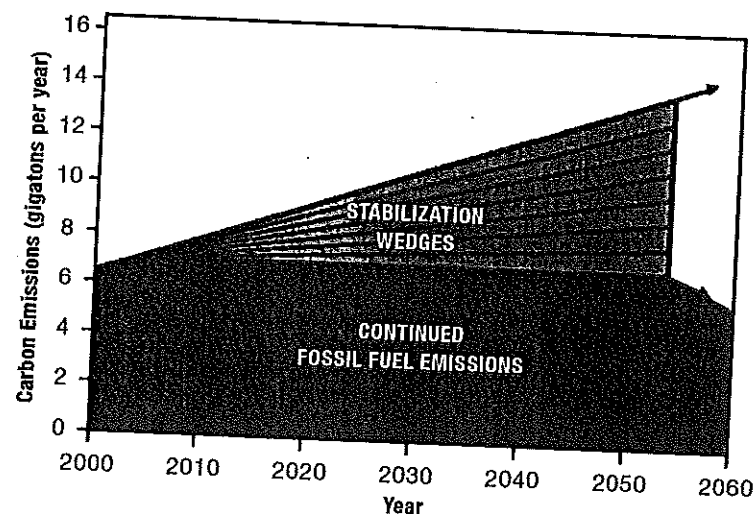
emissions will continue to grow without regard to the climate. In 2005, global emissions amounted to roughly 7 billion metric tons of carbon. Under a midrange BAU projection, they will grow to 10.5 billion metric tons a year by 2029, and 14 billion tons a year by 2054. Under this same projection, CO₂ levels in the atmosphere will reach 500 parts per million by the middle of the century, and if things continue on the same trajectory, CO₂ will reach 750 parts per million, or roughly three times preindustrial levels, by the year 2100.

Looking at these figures, Socolow reached a couple of conclusions right away. The first was that to avoid exceeding CO₂ concentrations of 500 parts per million, immediate action would be needed. The second was that to meet this target, emissions growth would have to be held essentially to zero. Stabilizing CO₂ emissions would be such an enormous undertaking that Socolow 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. Since annual carbon emissions now amount to 7 billion metric tons, and in fifty years are expected to reach 14 billion metric tons, seven wedges would be needed to hold emissions constant at today's level. With the help of a Princeton colleague, Stephen Pacala, Socolow eventually came up with fifteen different wedges—theoretically, at least, eight more than would be neces-

sary. In August 2004, Socolow and Pacala published their findings in a paper in *Science* that 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. For the purpose of their calculations, Socolow and Pacala assumed that a one-thousand-megawatt coal-fired power plant would produce about 1.5 million tons of carbon a year. (Today's coal plants actually produce some 2 million tons of carbon a year, but in the future, plants are expected to become more efficient.) To reduce emissions by a billion metric tons a year, enough solar cells would therefore have to be installed to obviate the need for nearly seven hundred thousand-megawatt coal plants. Since sunshine is not constant—it is interrupted by nightfall and by clouds—some two million megawatts of capacity would be needed. This, it

BUSINESS AS USUAL



One "wedge" would prevent a billion tons of carbon a year from being emitted by 2054. Credit: S. Pacala and R. Socolow, *Science*, vol. 305 (2004).

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. Again, the technology has the advantage of being both safe and emissions-free. A large turbine can generate two megawatts of power, but since the wind, like sunlight, is intermittent, to get a wedge out of wind power would require at least a million two-megawatt turbines. Wind turbines are generally installed either offshore, or on hilltops or windy plains. When they are installed on land, the area around them can be used for other purposes, such as farming, but a million turbines would effectively "occupy"

thirty million acres, an area roughly the size of New York state.

Other wedges present different challenges, some technical, some social. Nuclear power produces no carbon dioxide, but it generates radioactive waste, with all the attendant difficulties of storage, disposal, and international policing. More than forty years after the first commercial reactors went online, the United States has been unable to solve its nuclear waste problems, and several power plant operators have sued the federal government over its failure to construct a long-term waste storage site. Worldwide, there are 441 nuclear power plants currently in operation; one wedge could be achieved by doubling their capacity. There is also one heating and lighting wedge, which would result from cutting energy use in residential and commercial buildings by a quarter, and two automobile wedges. The first auto wedge would require that every car in the world be driven half as much as it is today, the second that it be twice as efficient. (Since the late 1980s, the fuel efficiency of passenger vehicles in the United States has actually declined, by more than 5 percent.)

Another possible option is a technology known as "carbon capture and storage," or CCS. As the name suggests, with CCS carbon dioxide is "captured" at the source—presumably a large emitter—and then injected at very high pressure into geological formations, such as depleted oil fields, underground. (At such pressure, CO₂ becomes "supercritical," a phase in which it is not quite a

liquid and not quite a gas.) One wedge in Socolow's plan comes from "capturing" CO₂ from power plants, another from capturing it from synthetic-fuel manufacturers. The basic techniques of CCS are currently employed to increase production from oil and natural gas wells. However, at this point, there are no synthetic-fuel or power plants using the process. Nor does anyone know for certain how long CO₂ injected underground will remain there. The world's longest-running CCS effort, maintained by the Norwegian oil company Statoil at a natural gas field in the North Sea, has been operational only for about a decade. A wedge of CCS 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.

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 United States, the average new car gets about twenty miles to the gallon; if it is driven a hundred thousand miles, it will produce more than eleven metric tons of carbon. A thousand-megawatt coal plant built today, meanwhile, is likely to last fifty years and to 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 500 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. Carbon dioxide is a persistent gas; it lasts for about a

century. Thus, while it is possible to increase CO₂ concentrations relatively quickly, the opposite is not the case. (The effect might be compared to driving a car equipped with an accelerator but no brakes.) After a while, I asked Socolow whether he thought that stabilizing emissions was a politically practical 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-1960s, was helping to develop the United States's antiballistic-missile system. During the week, Hoffert worked at a lab in New York, and sometimes he would go down to Washington to meet with Pentagon officials. Over the weekend, on occasion, he would travel back to Washington to protest Pentagon policy. Eventually, he decided that he wanted to work on something, in his words, "more productive." In this way, he became involved in climate research. 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 NYU 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."

Hoffert is primarily interested in finding new, carbon-

free ways to generate energy. Currently, the technology that he is pushing is space-based solar power, or SSP. In theory, at least, SSP 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. SSP 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 SSP has ever been conducted. (In the 1970s, 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 arrays 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 focused. He believes, as he put it to me, that SSP 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 says, is not *which* new technology will work but simply that *some* new technology be found: "There's an argument that our civilization can continue to exist with the

present number of people and the present kind of high technology through conservation. I see that argument as similar to a man being locked in a sealed room with a limited amount of oxygen. And if he breathes more slowly, he'll be able to live longer, but what he really needs is to get out of the room. And I want to get out of the room." A few years ago, Hoffert published an influential paper in *Science* in which he argued that holding CO₂ levels below 500 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." This has slowed the growth of emissions relative to the growth of the global economy; without it, CO₂ levels today would be significantly higher.

In the "business as usual" scenario that Socolow uses, it is assumed that decarbonization will continue. To assume this, however, is to overlook 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 is adding new coal-fired generating capacity at the rate of more than a gigawatt a month, is expected to overtake the United States 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 ideas 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."