from *Plan B 3.0: Mobilizing to Save Civilization*, by Lester R. Brown

3

Rising Temperatures and Rising Seas

Civilization has evolved during a period of remarkable climate stability, but this era is drawing to a close. We are entering a new era, a period of rapid and often unpredictable climate change. The new climate norm is change.

In the spring of 2007, while giving a lecture at Kyoto University, I noted that there had been a remarkable shift during the decade since the Kyoto Protocol was negotiated. In 1997, climate change was discussed in the future tense. Today we discuss it in the present tense. It is no longer something that may happen. It is happening now.

Today not only do we know that the earth is getting warmer, but we can begin to see some of the effects of higher temperatures. Mountain glaciers are melting almost everywhere. Himalayan glaciers that feed the rivers that irrigate the rice fields of China and the wheat fields of India are fast disappearing.[1]

The attention of climate scientists is turning to the melting ice sheets of Greenland and West Antarctica. If we cannot cut carbon emissions quickly enough to save these, then sea level will rise 12 meters (39 feet). Many of the world's coastal cities

will be under water; over 600 million coastal dwellers will be forced to move.[2]

The destructive effects of higher temperatures are visible on many fronts. Crop-withering heat waves have lowered grain harvests in key food-producing regions in recent years. In 2002, record-high temperatures and drought reduced grain harvests in India, the United States, and Canada, dropping the world harvest 90 million tons, or 5 percent below consumption. The record-setting 2003 European heat wave contributed to a world harvest that again fell short of consumption by 90 million tons. Intense heat and drought in the U.S. Corn Belt in 2005 contributed to a world grain shortfall of 34 million tons.[3]

Such intense heat waves also take a direct human toll. In 2003, the searing heat wave that broke temperature records across Europe claimed more than 52,000 lives in nine countries. Italy alone lost more than 18,000 people, while 14,800 died in France. More than 18 times as many people died in Europe in this heat wave as died during the terrorist attacks on the World Trade Center on September 11, 2001.[4]

The insurance industry is painfully aware of the relationship between higher temperatures and storm intensity. As weather-related damage claims have soared, the last few years have brought a drop in earnings and a flurry of lowered credit ratings for insurance companies as well as the reinsurance companies that insure them.[5]

Companies using historical records as a basis for calculating insurance rates for future storm damage are realizing that the past is no longer a reliable guide to the future. This is a problem not only for the insurance industry but for all of us. We are altering the earth's climate, setting in motion trends we do not always understand with consequences we cannot anticipate.

Rising Temperature and Its Effects

Scientists at the Goddard Institute for Space Studies of the National Aeronautics and Space Administration (NASA) gather data from a global network of some 800 climate-monitoring stations to measure changes in the earth's average temperature. Their direct measurements go back to 1880.[6]

Since 1970, the earth's average temperature has risen by 0.6 degrees Celsius, or 1 degree Fahrenheit. Meteorologists note that the 23 warmest years on record have come since 1980. And the seven warmest years since recordkeeping began in 1880 have come in the last nine years. Four of these—2002, 2003, 2005, and 2006—were years in which major food-producing regions saw their crops wither in the face of record temperatures.[7]

The amount of carbon dioxide (CO_2) in the atmosphere has risen substantially since the start of the Industrial Revolution, growing from 277 parts per million (ppm) to 384 ppm in 2007. The annual rise in the atmospheric CO_2 level, one of the world's most predictable environmental trends, is the result of the annual discharge into the atmosphere of 7.5 billion tons of carbon from burning fossil fuels and 1.5 billion tons from deforestation. The current annual rise is nearly four times what it was in the 1950s, largely because of increased emissions from burning fossil fuels. As more CO_2 accumulates in the atmosphere, temperatures go up.[8]

Against this backdrop of record increases, the projections that the earth's average temperature will rise 1.1–6.4 degrees Celsius (2.0–11.5 degrees Fahrenheit) during this century seem all too possible. These projections are the latest from the Intergovernmental Panel on Climate Change (IPCC), the body of more than 2,500 scientists from around the world that in 2007 released a consensus report affirming humanity's role in climate change.[9]

The IPCC-projected rise in temperature is a global average. In reality, the rise will be very uneven. It will be much greater over land than over oceans, in the high northern latitudes than over the equator, and in the continental interiors than in coastal regions.[10]

Higher temperatures diminish crop yields, melt the snow/ice reservoirs in the mountains that feed the earth's rivers, cause more-destructive storms, increase the area affected by drought, and cause more frequent and destructive wildfires.

In a paper presented at the American Meteorological Society's annual meeting in San Diego, California, in January 2005, a team of scientists from the National Center for Atmospheric Research reported a dramatic increase in the land surface affected by drought over the last few decades. The area experiencing very dry conditions expanded from less than 15 percent of the earth's total land area in the 1970s to roughly 30 percent by 2002. The scientists attributed part of the change to a rise in temperature and part to reduced precipitation, with high temperatures becoming progressively more important during the latter part of the period. Lead author Aiguo Dai reported that most of the drying was concentrated in Europe and Asia, Canada, western and southern Africa, and eastern Australia.[11]

Researchers with the U.S. Department of Agriculture's Forest Service, drawing on 85 years of fire and temperature records, reported in August 2004 that even a 1.6-degree-Celsius rise in summer temperature could double the area of wildfires in the 11 western states.[12]

Ecosystems everywhere will be affected by higher temperatures, sometimes in ways we cannot easily predict. The 2007 IPCC report notes that a rise in temperature of 1 degree Celsius will put up to 30 percent of all species at risk of extinction. The Pew Center on Global Climate Change sponsored a meta-study analyzing some 40 scientific reports that link rising temperature with changes in ecosystems. Among the many changes reported are spring arriving nearly two weeks earlier in the United States, tree swallows nesting nine days earlier than they did 40 years ago, and a northward shift of red fox habitat that has it encroaching on the Arctic fox's range. Inuits have been surprised by the appearance of robins, a bird they have never seen before. Indeed, there is no word in Inuit for "robin."[13]

The National Wildlife Federation (NWF) reports that if temperatures continue to rise, by 2040 one out of five of the Pacific Northwest's rivers will be too hot for salmon, steelhead, and trout to survive. Paula Del Giudice, Director of NWF's Northwest Natural Resource Center, notes that "global warming will add an enormous amount of pressure onto what's left of the region's prime cold-water fish habitat."[14]

Douglas Inkley, NWF Senior Science Advisor and senior author of a report to The Wildlife Society, notes, "We face the prospect that the world of wildlife that we now know—and many of the places we have invested decades of work in conserving as refuges and habitats for wildlife—will cease to exist as we know them, unless we change this forecast."[15]

The Crop Yield Effect

Agriculture as it exists today has been shaped by a climate system that has changed little over farming's 11,000-year history. Crops were developed to maximize yields in this long-standing climatic regime. As the temperature rises, agriculture will be increasingly out of sync with its natural environment. Nowhere is this more evident than in the relationship between temperature and crop yields.

Since crops in many countries are grown at or near their thermal optimum, even a relatively minor increase during the growing season of 1 or 2 degrees Celsius can shrink the grain harvest in major food-producing regions, such as the North China Plain, the Gangetic Plain of India, and the U.S. Corn Belt.[16]

Higher temperatures can reduce or even halt photosynthesis, prevent pollination, and lead to crop dehydration. Although the elevated concentrations of atmospheric CO_2 that raise temperature can also raise crop yields, the detrimental effect of higher temperatures on yields overrides the CO_2 fertilization effect for the major crops.

In a study of local ecosystem sustainability, Mohan Wali and his colleagues at Ohio State University noted that as temperature rises, photosynthetic activity in plants increases until the temperature reaches 20 degrees Celsius (68 degrees Fahrenheit). The rate of photosynthesis then plateaus until the temperature hits 35 degrees Celsius (95 degrees Fahrenheit), whereupon it begins to decline, until at 40 degrees Celsius (104 degrees Fahrenheit), photosynthesis ceases entirely.[17]

The most vulnerable part of a plant's life cycle is the pollination period. Of the world's three food staples—rice, wheat, and corn—corn is particularly vulnerable. In order for corn to reproduce, pollen must fall from the tassel to the strands of silk that emerge from the end of each ear of corn. Each of these silk strands is attached to a kernel site on the cob. If the kernel is to develop, a grain of pollen must fall on the silk strand and then journey to the kernel site. When temperatures are uncommonly high, the silk strands quickly dry out and turn brown, unable to play their role in the fertilization process.

The effects of temperature on rice pollination have been studied in detail in the Philippines. Scientists there report that the pollination of rice falls from 100 percent at 34 degrees Celsius to near zero at 40 degrees Celsius, leading to crop failure.[18]

High temperatures can also dehydrate plants. While it may take a team of scientists to understand how temperature affects

rice pollination, anyone can tell that a wilted cornfield is suffering from heat stress. When a corn plant curls its leaves to reduce exposure to the sun, photosynthesis is reduced. And when the stomata on the underside of the leaves close to reduce moisture loss, CO_2 intake is reduced, thereby restricting photosynthesis. At elevated temperatures, the corn plant, which under ideal conditions is so extraordinarily productive, goes into thermal shock.

Within the last few years, crop ecologists in several countries have been focusing on the precise relationship between temperature and crop yields. One of the most comprehensive of these studies was conducted at the International Rice Research Institute (IRRI) in the Philippines. A team of eminent crop scientists using crop yield data from experimental field plots of irrigated rice confirmed the rule of thumb emerging among crop ecologists—that a 1-degree Celsius rise in temperature above the norm lowers wheat, rice, and corn yields by 10 percent. The IRRI finding was consistent with those of other recent research projects. The scientists concluded that "temperature increases due to global warming will make it increasingly difficult to feed Earth's growing population."[19]

Two scientists in India, K. S. Kavi Kumar and Jyoti Parikh, assessed the effect of higher temperatures on wheat and rice yields. Basing their model on data from 10 sites, they concluded that in north India a 1-degree Celsius rise in mean temperature did not meaningfully reduce wheat yields, but a 2-degree rise lowered yields at almost all the sites. When they looked at temperature change alone, a 2-degree Celsius rise led to a decline in irrigated wheat yields ranging from 37 percent to 58 percent. When they combined the negative effects of higher temperature with the positive effects of CO_2 fertilization, the decline in yields among the various sites ranged from 8 percent to 38 percent. For a country projected to add 500 million people by mid-century, this is a troubling prospect.[20]

Reservoirs in the Sky

Snow and ice masses in mountains are nature's freshwater reservoirs—nature's way of storing water to feed rivers during the dry season. Now they are being threatened by the rise in temperature. Even a 1-degree rise in temperature in mountainous regions can markedly reduce the share of precipitation falling as snow and boost that coming down as rain. This in turn increases flooding during the rainy season and reduces the snowmelt that flows into rivers.

Beyond this, the glaciers that feed rivers during the dry season are melting. Some have disappeared entirely. Nowhere is the melting of glaciers of more concern than in Asia, where 1.3 billion people depend for their water supply on rivers originating in the Himalayan Mountains and the adjacent Tibet-Qinghai Plateau.[21]

India's Gangotri Glacier, which supplies 70 percent of the water to the Ganges, is not only melting, it is doing so at an accelerated rate. If this melting continues to accelerate, the Gangotri's life expectancy will be measured in decades and the Ganges will become a seasonal river, flowing only during the rainy season. For the 407 million Indians and Bangladeshis who live in the Ganges basin, this could be a life-threatening loss of water.[22]

In China, which is even more dependent than India on river water for irrigation, the situation is particularly challenging. Chinese government data show the glaciers on the Tibet-Qinghai Plateau that feed both the Yellow and Yangtze Rivers are melting at 7 percent a year. The Yellow River, whose basin is home to 147 million people, could experience a large dry-season flow reduction. The Yangtze River, by far the larger of the two, is threatened by the disappearance of glaciers as well. The basin's 369 million people rely heavily on rice from fields irrigated with Yangtze River water.[23]

Yao Tandong, a leading Chinese glaciologist, predicts that two thirds of China's glaciers could be gone by 2060. "The full-scale glacier shrinkage in the plateau region," Yao says, "will eventually lead to an ecological catastrophe."[24]

Other Asian rivers that originate in this rooftop of the world include the Indus, with 178 million people in its basin in India and Pakistan; the Brahmaputra, which flows through Bangladesh; and the Mekong, which waters Cambodia, Laos, Thailand, and Viet Nam.[25]

In Africa, Tanzania's snow-capped Kilimanjaro may soon be snow- and ice-free. Ohio State University glaciologist Lonnie Thompson's studies of Kilimanjaro show that Africa's tallest

mountain lost 33 percent of its ice field between 1989 and 2000. He projects that its snowcap could disappear entirely by 2015. Nearby Mount Kenya has lost 7 of its 18 glaciers. Local rivers fed by these glaciers are becoming seasonal rivers, generating conflict among the 2 million people who depend on them for water supplies during the dry season.[26]

Bernard Francou, research director for the French government's Institute of Research and Development, believes that 80 percent of South American glaciers will disappear within the next 15 years. For countries like Bolivia, Ecuador, and Peru, which rely on glaciers for water for household and irrigation use, this is not good news.[27]

Peru, which stretches some 1,600 kilometers along the vast Andean mountain range and which is home to 70 percent of the earth's tropical glaciers, is in trouble. Some 22 percent of its glacial endowment, which feeds the many Peruvian rivers that supply water to the cities in the semi-arid coastal regions, has disappeared. Lonnie Thompson reports that the Quelccaya Glacier in southern Peru, which was retreating by 6 meters per year in the 1960s, is now retreating by 60 meters annually.[28]

Many of Peru's farmers irrigate their wheat and potatoes with the river water from these disappearing glaciers. During the dry season, farmers are totally dependent on irrigation water. For Peru's 28 million people, shrinking glaciers will eventually mean a shrinking food supply.[29]

Lima, a city of 7 million people, gets most of its water from three rivers high in the Andes, rivers that are fed partly by glacial melt. While the glaciers are melting, the river flows are above normal, but once they are gone, the river flows will drop sharply, leaving Lima with severe water shortages.[30]

In many agricultural regions, snow and ice masses are the leading source of irrigation and drinking water. In the southwestern United States, for instance, the Colorado River—the region's primary source of irrigation water—depends on snowfields in the Rockies for much of its flow. California, in addition to depending heavily on the Colorado, also relies on snowmelt from the Sierra Nevada in the eastern part of the state. Both the Sierra Nevada and the coastal range supply irrigation water to California's Central Valley, the world's fruit and vegetable basket.[31]

Preliminary results of an analysis of rising temperature effects on three major river systems in the western United States—the Columbia, the Sacramento, and the Colorado—indicate that the winter snow pack in the mountains feeding them will be dramatically reduced and that winter rainfall and flooding will increase.[32]

With a business-as-usual energy policy, global climate models project a 70-percent reduction in the amount of snow pack for the western United States by mid-century. A detailed study of the Yakima River Valley, a vast fruit-growing region in Washington state, conducted by the U.S. Department of Energy's Pacific Northwest National Laboratory shows progressively heavier harvest losses as the snow pack shrinks, reducing irrigation water flows.[33]

Agriculture in the Central Asian countries of Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan depends heavily on snowmelt from the Hindu Kush, Pamir, and Tien Shan mountain ranges for irrigation water. Nearby Iran gets much of its water from the snowmelt in the 5,700-meter-high Alborz Mountains between Tehran and the Caspian Sea.[34]

The snow and ice masses in the world's leading mountain ranges and the water they store are taken for granted simply because they have been there since before agriculture began. Now that is changing. If we continue raising the earth's temperature, we risk losing the reservoirs in the sky on which cities and farmers depend.

Melting Ice and Rising Seas

Ice melting in mountainous regions not only affects river flows, it also affects sea level rise. On a larger scale, the melting of the earth's two massive ice sheets—Antarctica and Greenland—could raise sea level enormously. If the Greenland ice sheet were to melt, it would raise sea level 7 meters (23 feet). Melting of the West Antarctic Ice Sheet would raise sea level 5 meters (16 feet). But even just partial melting of these ice sheets will have a dramatic effect on sea level rise. Senior scientists are noting that the IPCC projections of sea level rise during this century of 18 to 59 centimeters are already obsolete and that a rise of 2 meters during this time is within range.[35]

Assessing the prospects for the Greenland ice sheet begins

with looking at the warming of the Arctic region. A 2005 study, *Impacts of a Warming Arctic*, concluded that the Arctic is warming almost twice as fast as the rest of the planet. Conducted by the Arctic Climate Impact Assessment (ACIA) team, an international group of 300 scientists, the study found that in the regions surrounding the Arctic, including Alaska, western Canada, and eastern Russia, winter temperatures have already climbed by 3-4 degrees Celsius (4–7 degrees Fahrenheit) over the last half-century. Robert Corell, chair of ACIA, says this region "is experiencing some of the most rapid and severe climate change on Earth."[36]

In testimony before the U.S. Senate Commerce Committee, Sheila Watt-Cloutier, an Inuit speaking on behalf of the 155,000 Inuits who live in Alaska, Canada, Greenland, and the Russian Federation, described their struggle to survive in the fast-changing Arctic climate as "a snapshot of what is happening to the planet." She called the warming of the Arctic "a defining event in the history of this planet." And she went on to say "the Earth is literally melting."[37]

The ACIA report described how the retreat of the sea ice has devastating consequences for polar bears, whose very survival may be at stake. A subsequent report indicated that polar bears, struggling to survive, are turning to cannibalism. Also threatened are ice-dwelling seals, a basic food source for the Inuit.[38]

Since this 2005 report, there is new evidence that the problem is worse than previously thought. A team of scientists from the National Snow and Ice Data Center and the National Center for Atmospheric Research, which has compiled data on Arctic Ocean summer ice melting from 1953 to 2006, concluded that the ice is melting much faster than climate models had predicted. They found that from 1979 to 2006 the summer sea ice shrinkage accelerated to 9.1 percent a decade. In 2007, Arctic sea ice shrank some 20 percent below the previous record set in 2005. This suggests that the sea could be ice-free well before 2050, the earliest date projected by the IPCC in its 2007 report. Arctic scientist Julienne Stroeve observed that the shrinking Arctic sea ice may have reached "a tipping point that could trigger a cascade of climate change reaching into Earth's temperate regions."[39]

Reinforcing this concern is a recent study by Joséfino

Comiso, a senior scientist at NASA's Goddard Space Flight Center. Comiso reported for the first time that even the winter ice cover in the Arctic Ocean shrank by 6 percent in 2005 and again in 2006. This new development, combined with the news that the sea ice cover is thinning, provides further evidence that the ice is not recovering after its melt season, meaning that summer ice in the Arctic Ocean could disappear much sooner than earlier thought possible.[40]

Walt Meier, a researcher at the U.S. National Snow and Ice Data Center who tracks the changes in Arctic sea ice, views the winter shrinkage with alarm. He believes there is "a good chance" that the Arctic tipping point has been reached. "People have tried to think of ways we could get back to where we were. We keep going further and further in the hole, and it's getting harder and harder to get out of it." Some scientists now think that the Arctic Ocean could be ice-free in the summer as early as 2030.[41]

Scientists are concerned that "positive feedback loops" may be starting to kick in. This term refers to a situation where a trend already under way begins to reinforce itself. Two of these potential feedback mechanisms are of particular concern to scientists. The first, in the Arctic, is the albedo effect. When incoming sunlight strikes the ice in the Arctic Ocean, up to 70 percent of it is reflected back into space. Only 30 percent is absorbed as heat. As the Arctic sea ice melts, however, and the incoming sunlight hits the much darker open water, only 6 percent is reflected back into space and 94 percent is converted into heat. This may account for the accelerating shrinkage of the Arctic sea ice and the rising regional temperature that directly affects the Greenland ice sheet.[42]

If all the ice in the Arctic Ocean melts, it will not affect sea level because the ice is already in the water. But it will lead to a much warmer Arctic region as more of the incoming sunlight is absorbed as heat. This is of particular concern because Greenland lies largely within the Arctic Circle. As the Arctic region warms, the island's ice sheet—up to 1.6 kilometers (1 mile) thick in places—is beginning to melt.[43]

The second positive feedback mechanism also has to do with ice melting. What scientists once thought was a fairly simple linear process—that is, a certain amount at the surface of an ice

sheet melts each year, depending on the temperature—is now seen to be much more complicated. As the surface ice begins to melt, some of the water filters down through cracks in the glacier, lubricating the surface between the glacier and the rock beneath it. This accelerates the glacial flow and the calving of icebergs into the surrounding ocean. The relatively warm water flowing through the glacier also carries surface heat deep inside the ice sheet far faster than it would otherwise penetrate by simple conduction.[44]

Several recent studies report that the melting of the Greenland ice sheet is accelerating. A study published in *Science* in September 2006 reported that the rate of ice melt on the vast island has tripled over the last several years. That same month a University of Colorado team published a study in *Nature* indicating that between April 2004 and April 2006 Greenland lost ice at a rate 2.5 times that of the preceding two years. In October 2006, a team of NASA scientists reported that the flow of glaciers into the sea was accelerating. Eric Rignot, a glaciologist at NASA's Jet Propulsion Laboratory, said, "None of this has been predicted by numerical models, and therefore all projections of the contribution of Greenland to sea level [rise] are way below reality."[45]

At the other end of the earth, the 2-kilometer-thick Antarctic ice sheet, which covers a continent about twice the size of Australia and contains 70 percent of the world's fresh water, is also beginning to melt. Ice shelves that extend from the continent into the surrounding seas are starting to break up at an alarming pace.[46]

In May 2007, a team of scientists from NASA and the University of Colorado reported satellite data showing widespread snow-melt on the interior of the Antarctic ice sheet over an area the size of California. This melting in 2005 was 900 kilometers inland, only about 500 kilometers from the South Pole. Konrad Steffen, one of the scientists involved, observed, "Antarctica has shown little to no warming in the recent past with the exception of the Antarctic Peninsula, but now large regions are showing the first signs of the impacts of warming."[47]

The ice shelves surrounding Antarctica are formed by the flow of glaciers off the continent into the surrounding sea. This flow of ice, fed by the continuous formation of new ice on land

and culminating in the breakup of the shelves on the outer fringe and the calving of icebergs, is not new. What is new is the pace of this process. When Larsen A, a huge ice shelf on the east coast of the Antarctic Peninsula, broke up in 1995, it was a signal that all was not well in the region. Then in 2000, a huge iceberg nearly the size of Connecticut—11,000 square kilometers, or 4,250 square miles—broke off the Ross Ice Shelf.[48]

After Larsen A broke up, it was only a matter of time, given the rise in temperature in the region, before neighboring Larsen B would do the same. So when the northern part of the Larsen B ice shelf collapsed into the sea in March 2002, it was not a total surprise. At about the same time, a huge chunk of ice broke off the Thwaites Glacier. Covering 5,500 square kilometers, this iceberg was the size of Rhode Island.[49]

Even veteran ice watchers are amazed at how quickly the disintegration is occurring. "The speed of it is staggering," said Dr. David Vaughan, a glaciologist at the British Antarctic Survey, which has been monitoring the Larsen Ice Shelf closely. Along the Antarctic Peninsula, in the vicinity of the Larsen Ice Shelf, the average temperature has risen 2.5 degrees Celsius over the last five decades.[50]

When ice shelves already largely in the water break off from the continental ice mass, this does not have much direct effect on sea level per se. But without the ice shelves to impede the flow of glacial ice, typically moving 400–900 meters a year, the flow of ice from the continent could accelerate, leading to a thinning of the ice sheet on the edges of the Antarctic continent. If this were to happen, sea level would rise accordingly.[51]

The International Institute for Environment and Development (IIED) has analyzed the effect of a 10-meter rise in sea level, providing a sense of what the melting of the world's largest ice sheets could mean. The IIED study begins by pointing out that 634 million people live along coasts at or below 10 meters above sea level, in what they call the Low Elevation Coastal Zone. This massive vulnerable group includes one eighth of the world's urban population.[52]

One of the countries most vulnerable is China, with 144 million potential climate refugees. India and Bangladesh are next, with 63 and 62 million respectively. Viet Nam has 43 million vulnerable people, and Indonesia, 42 million. Others in the top 10

include Japan with 30 million, Egypt with 26 million, and the United States with 23 million.[53]

The world has never seen such a massive potential displacement of people. Some of the refugees could simply retreat to higher ground within their own country. Others—facing extreme crowding in the interior regions of their homeland—would seek refuge elsewhere. Bangladesh, already one of the world's most densely populated countries, would face a far greater concentration: in effect, 62 million of its people would be forced to move in with the 97 million living on higher ground. Would a more sparsely populated country like the United States be willing to accommodate an influx of rising-sea refugees while it was attempting to relocate 23 million of its own citizens?[54]

Not only would some of the world's largest cities, such as Shanghai, Kolkata, London, and New York, be partly or entirely inundated, but vast areas of productive farmland would also be lost. The rice-growing river deltas and floodplains of Asia would be covered with salt water, depriving Asia of part of its food supply. This loss of prime farmland would parallel the loss of river water as Himalayan glaciers disappear.[55]

In the end, the question is whether governments are strong enough to withstand the political and economic stress of relocating large numbers of people while suffering losses of housing and industrial facilities. The relocation is not only an internal matter, as a large share of the displaced people will want to move to other countries. Can governments withstand these stresses, or will more and more states fail?

More-Destructive Storms

Rising seas are not the only threat that comes with elevated global temperatures. Higher surface water temperatures in the tropical oceans mean more energy radiating into the atmosphere to drive tropical storm systems, leading to more-destructive storms. The combination of rising seas, more powerful storms, and stronger storm surges can be devastating.[56]

Just how devastating this combination can be became evident in late August 2005, when Hurricane Katrina came onshore on the U.S. Gulf Coast near New Orleans. In some Gulf Coast towns, Katrina's powerful 28-foot-high storm surge did not leave a single structure standing. New Orleans survived the initial hit but was flooded when the inland levees were breached and water covered everything in large parts of the city except for the rooftops, where thousands of people were stranded. Even in August 2006, a year after the storm had passed, the most damaged areas of the city remained without water, power, sewage disposal, garbage collection, or telecommunications.[57]

With advance warning of the storm and official urging to evacuate coastal areas, 1 million or so evacuees fled northward into Louisiana or to neighboring states of Texas and Arkansas. Of this total, some 290,000 have not yet returned home and will likely never do so. These storm evacuees are the world's first large wave of climate refugees.[58]

Katrina was the most financially destructive hurricane ever to make landfall anywhere. It was one of eight hurricanes that hit the southeastern United States in 2004 and 2005. As a result of the unprecedented damage, insurance premiums have doubled, tripled, and even in some especially vulnerable situations gone up 10-fold. This enormous jump in insurance costs is lowering coastal real estate values and driving people and businesses out of highly exposed states like Florida.[59]

The devastation caused by Katrina was not an isolated incident. In the fall of 1998, Hurricane Mitch—one of the most powerful storms ever to come out of the Atlantic, with winds approaching 200 miles per hour—hit the east coast of Central America. As atmospheric conditions stalled the normal northward progression of the storm, some 2 meters of rain were dumped on parts of Honduras and Nicaragua within a few days. The deluge collapsed homes, factories, and schools, leaving them in ruins. It destroyed roads and bridges. Seventy percent of the crops and much of the topsoil in Honduras were washed away—topsoil that had accumulated over long stretches of geological time. Huge mudslides destroyed villages, burying some local populations.[60]

The storm left 11,000 dead. Thousands more, buried or washed out to sea, were never found. The basic infrastructure—the roads and bridges in Honduras and Nicaragua—was largely destroyed. President Flores of Honduras summed it up this way: "Overall, what was destroyed over several days took us 50 years to build." The damage from this storm, exceeding the

annual gross domestic product of the two countries, set their economic development back by 20 years.[61]

In 2004, Japan experienced a record 10 typhoons (hurricanes) that collectively caused $10 billion worth of losses. During the same season, Florida was hit by 4 of the 10 most costly hurricanes in U.S. history. These 4 hurricanes together generated insurance claims of $22 billion.[62]

Against this backdrop, insurance companies and reinsurance companies are finding it difficult to calculate a safe level of premiums, since the historical record traditionally used to calculate insurance fees is no longer a guide to the future. For example, the number of major flood disasters worldwide has grown over the last several decades, increasing from 6 major floods in the 1950s to 26 in the 1990s.[63]

Insurers are convinced that with higher temperatures and more energy driving storm systems, future losses will be even greater. They are concerned about whether the industry can remain solvent under this onslaught of growing damages. So, too, is Moody's Investors Service, which has several times downgraded the creditworthiness of some of the world's leading reinsurance companies over the last six years.[64]

Thomas Loster, a climate expert at Munich Re, a leading reinsurance company, says the overall balance of natural catastrophes is now "dominated by weather-related disasters, many of them exceptional and extreme. We need to stop this dangerous experiment humankind is conducting on the Earth's atmosphere."[65]

Munich Re has published a list of natural disasters with insured losses of $1 billion or more. The first one came in 1983, when Hurricane Alicia struck the United States, racking up $1.5 billion in insured losses. Of the 58 natural catastrophes with $1 billion or more of insured losses recorded through the end of 2006, 3 were earthquakes, including the devastating 2004 earthquake-related Asian tsunami; the other 55 were weather-related—storms, floods, hurricanes, or wildfires. During the 1980s, there were 3 such events; during the 1990s, there were 26; and between 2000 and 2006 alone there were 26.[66]

Prior to Hurricane Katrina, the two largest events in terms of total damage were Hurricane Andrew in 1992, which took down 60,000 homes and racked up $30 billion worth of damage, and the flooding of China's Yangtze River basin in 1998, which also cost an estimated $30 billion, a sum comparable to the value of China's rice harvest. Part of the growing damage toll is due to greater urban and industrial development in coastal areas and river floodplains. But part is due to more-destructive storms.[67]

In the West, the regions most vulnerable to more powerful storms currently are the Atlantic and Gulf Coasts of the United States and the Caribbean countries. In the East, it is East and Southeast Asia, including China, Japan, the Philippines, Taiwan, and Viet Nam, that are likely to bear the brunt of the powerful storms crossing the Pacific. In the Bay of Bengal, Bangladesh and the east coast of India are particularly vulnerable.

Western Europe, traditionally experiencing a heavily damaging winter storm perhaps once in a century, had its first winter storm to exceed $1 billion in 1987—one that caused $3.7 billion of destruction, $3.1 billion of which was covered by insurance. Since then, Western Europe has had nine major winter storms with insured losses ranging from $1.3 billion to $5.9 billion.[68]

As the climate changes, more extreme weather events are expected. Andrew Dlugolecki, a consultant on climate change and its effects on financial institutions, notes that damage from atmospherically related events has increased by roughly 10 percent a year. "If such an increase were to continue indefinitely," he notes, "by 2065 storm damage would exceed the gross world product. The world obviously would face bankruptcy long before then." Few double-digit annual growth trends continue for several decades, but Dlugolecki's basic point is that climate change can be destructive, disruptive, and very costly.[69]

If we allow the climate to spin out of our control, we risk huge financial costs. In a late 2006 report, former World Bank chief economist Nicholas Stern projected that the long-term costs of climate change could exceed 20 percent of gross world product (GWP). By comparison, the near-term costs of cutting greenhouse gas emissions to stabilize climate, which Stern estimates at 1 percent of GWP, would be a bargain.[70]

Cutting Carbon 80 Percent by 2020

In 2004, Stephen Pacala and Robert Socolow at Princeton University published an article in *Science* that showed how annual carbon emissions from fossil fuels could be held at 7 billion tons

instead of rising to 14 billion tons over the next 50 years, as would occur with business as usual. The goal of Pacala, an ecologist, and Socolow, an engineer, was to prevent atmospheric CO_2 concentrations, then near 375 ppm, from rising above 500 ppm.[71]

They described 15 ways, all using proven technologies, that by 2054 could each cut carbon emissions by 1 billion tons per year. Any seven of these options could be used together to prevent an increase in carbon emissions through 2054. Pacala and Socolow further theorize that advancing technology would allow for annual carbon emissions to be cut to 2 billion tons by 2104, a level that can be absorbed by natural carbon sinks in land and oceans.[72]

The Pacala/Socolow conceptualization has been extraordinarily useful in helping to think about how to cut carbon emissions. During the three years since the article was written, the urgency of acting quickly and on a much larger scale has become obvious. We also need now to go beyond the conceptual approach that treats all potential methods of reducing carbon emissions equally and concentrate on those that are most promising.

Researchers such as James Hansen, a leading climate scientist at NASA, believe that global warming is accelerating and may be approaching a tipping point, a point at which climate change acquires a momentum that makes it irreversible. They think we may have a decade to turn the situation around before this threshold is crossed. I agree.[73]

We often hear descriptions of what we need to do in the decades ahead or by 2050 to avoid "dangerous climate change," but we are already facing this. Two thirds of the glaciers that feed the Yellow and Yangtze rivers of China will disappear by 2060 if even the current 7 percent annual rate of melting continues. Glaciologists report that the Gangotri glacier, which supplies 70 percent of the ice melt that feeds the Ganges River during the dry season, could disappear entirely in a matter of decades.[74]

What could threaten world food security more than the melting of the glaciers that feed the major rivers of Asia during the dry season, the rivers that irrigate the region's rice and wheat fields? In a region with half the world's people, this potential loss of water during the dry season could lead not just to hunger but to starvation on an unimaginable scale.

Asian food security would take a second hit because its rice-growing river deltas and floodplains would be under water. The World Bank tells us that a sea level rise of only 1 meter would inundate half of the riceland in Bangladesh. While a 1-meter rise in sea level will not happen overnight, what is worrisome is that if ice melting continues at today's rates, at some point such a rise in sea level will no longer be preventable. The melting that would cause this is not just what may happen if the earth's temperature rises further; this is something that is starting to happen right now with the current temperature.[75]

As summer neared an end in 2007, reports from Greenland indicated that the flow of glaciers into the sea had accelerated beyond anything glaciologists had thought possible. Huge chunks of ice weighing several billion tons each were breaking off and sliding into the sea, causing minor earthquakes as they did so.[76]

With melt-water lubricating the surface between the glaciers and the rocks on which they rested, ice flows were accelerating, flowing into the ocean at a pace of 2 meters an hour. This accelerated flow, along with the earthquakes, shows the potential for the entire ice sheet to break up and collapse.[77]

Beyond what is already happening, the world faces a risk that some of the feedback mechanisms will begin to kick in, further accelerating the warming process. Scientists who once thought that the Arctic Ocean could be free of ice during the summer by 2100 now see it occurring by 2030. Even this could turn out to be a conservative estimate.[78]

This is of particular concern to scientists because of the albedo effect, where the replacement of highly reflective sea ice with darker open water greatly increases heat absorbed from sunlight. This, of course, has the potential to further accelerate the melting of the Greenland ice sheet.

A second feedback loop of concern is the melting of permafrost. This would release billions of tons of carbon, some as methane, a potent greenhouse gas with a global warming effect per ton 25 times that of carbon dioxide.[79]

The risk facing humanity is that climate change could spiral out of control and it will no longer be possible to arrest trends

such as ice melting and rising sea level. At this point, the future of civilization would be at risk.

This combination of melting glaciers, rising seas, and their effects on food security and low-lying coastal cities could overwhelm the capacity of governments to cope. Today it is largely weak states that begin to deteriorate under the pressures of mounting environmental stresses. But the changes just described could overwhelm even the strongest of states. Civilization itself could begin to unravel under these extreme stresses.

In contrast to Pacala and Socolow's goal of holding carbon emissions constant until 2054, in Plan B we propose an all-out effort to cut net carbon dioxide emissions 80 percent by 2020. Our goal is to prevent the atmospheric CO_2 concentration from exceeding 400 ppm, thus limiting the future rise in temperature.[80]

This is an extraordinarily ambitious undertaking. It means, for example, phasing out all coal-fired power plants by 2020 while greatly reducing the use of oil. This is not a simple matter.

We can, however, make this shift using currently available technologies. The three components of this carbon-cutting effort are halting deforestation while planting trees to sequester carbon (see Chapter 8), raising energy efficiency worldwide (see Chapter 11), and harnessing the earth's renewable sources of energy (see Chapter 12). Plan B calls for using the most energy-efficient technologies available for lighting, for heating and cooling buildings, and for transportation. It calls for an ambitious exploitation of the earth's solar, wind, and geothermal energy sources. It means, for example, a wholesale shift to plug-in hybrid cars, running them largely on wind-generated electricity.

Plan B includes a wholesale restructuring of the world energy economy with a wartime sense of urgency, much as the U.S. restructured its industrial economy in a matter of months at the beginning of World War II. (See Chapter 13.) The stakes in World War II were high, but they are far higher today. What is at issue now is whether we can mobilize fast enough to save our global civilization.