Impacts of Global Warming

At first global warming sounded like a good idea, especially to people in Northern climes. But starting in the 1960s, scientists recognized long-range problems, concentrating at first on sea-level rise and a threat to food supplies. New items were gradually added to the list, ranging from the degradation of ecosystems to threats to human health. Experts in fields from forestry to economics pitched in to assess the range of possible consequences. It was impossible to make solid predictions given the complexity of the global system, the differences from one region to another, and the ways human society itself might try to adapt to the changes. But by the start of the 21st century, it was clear that many places were liable to suffer serious harm—some more than others. Indeed many kinds of damage were already beginning to appear. (This essay does not try to cover the entire history of impact studies, but sketches some examples. Current scientific understanding of impacts is summarized at the end).

Through the first half of the 20th century, when global warming from the greenhouse effect was only a speculation, the handful of scientists who thought about it supposed any warming would be for the good. Svante Arrhenius, who published the first calculations, claimed that nations like his native Sweden "may hope to enjoy ages with more equable and better climates."[1] Most people assumed that a "balance of nature" made catastrophic consequences impossible, and if any change did result from the "progress" of human industry, it would be all to the good. In any case nobody worried about the impacts of a climate change that scientists expected would only affect their remote descendants, several centuries in the future, if it happened at all.

Some took a closer look after 1960, when the level of carbon dioxide gas (CO_2) in the atmosphere was seen to be rising rapidly, suggesting that the average global temperature might climb three or four degrees Celsius before the end of the 21st century. In 1963 a path-breaking meeting on "Implications of Rising Carbon Dioxide Content of the Atmosphere" was convened by the private Conservation Foundation. "Conservation" was the traditional term for a movement that was developing into "environmentalism," centered on the growing realization that human activities had grown to the point where they could damage vital ecosystems on a global scale. Participants in the meeting began to frame greenhouse warming as an environmental problem—something "potentially dangerous" to biological systems as well as to humans. The group could scarcely say what dangers might await a century ahead. The clearest problem they noted was that rising temperatures would surely melt glaciers, raising the sea level and flooding coastal areas.[2]

Global warming caught the attention of the U.S. President's Scientific Advisory Committee. In 1965 they reported that "By the year 2000 the increase in atmospheric CO_2 ... may be sufficient

[1] Arrhenius (1908), p. 63.

[2] Conservation Foundation (1963).

to produce measurable and perhaps marked changes in climate..." Without attempting to say anything specific, they remarked dryly that the resulting changes "could be deleterious from the point of view of human beings."[1] The following year, a panel of the U.S. National Academy of Sciences warned against "dire predictions of drastic climatic changes." Dire predictions had in fact been a staple of the popular press for decades, as magazines, books and other media peddled colorful speculations about climate catastrophes. These usually revolved around a return of the Ice Ages with their deadly cold, a scenario far more apt to draw in readers than talk about gradual warming. The Academy panel remarked that the geological record showed swings of temperature comparable to what the greenhouse effect might cause, and "although some of the natural climatic changes have had locally catastrophic effects, they did not stop the steady evolution of civilization."[2]

That was not entirely reassuring, and concern grew among the few scientists who paid attention to climate theories. A landmark study on "Man's Impact on the Global Environment," conducted at the Massachusetts Institute of Technology in 1970, suggested that greenhouse warming might bring "widespread droughts, changes of the ocean level, and so forth," but could not get beyond such vague worries[3]. A meeting in Stockholm the following year came to similar conclusions, and added that we might pass a point of no return if the Arctic Ocean's ice cover disappeared. That would change the world's weather in ways that the scientists could not guess at, but that they thought might be serious. Their main point in bringing up the Arctic ice, however, was simply to illustrate "the sensitivity of a complex and perhaps unstable system that man might significantly alter."[4]

Up to this point, scientists expected that greenhouse warming, if it happened at all, would bring no serious impacts until well into the 21st century. And the 21st century seemed so far away! But was climate change really so distant? In the early 1970's the world saw vivid illustrations of climate fluctuations as savage droughts afflicted the American Midwest, devastated the Russian wheat crop and brought starvation upon millions in Africa. Studies of climate were still in their infancy, and scientists were debating whether the greenhouse effect from CO_2 emissions might be overwhelmed by the cooling caused by other forms of pollution, or by natural climate cycles. Studies of the impacts of climate change therefore tended to address generalities such as how a given type of crop would respond to either a rise or a drop in temperature. An example was a 1974 study commissioned by the U.S. Central Intelligence Agency (CIA). What if the climate altered radically within a few decades—perhaps the sudden freeze that some journalists warned might befall us? The report concluded that the entire world's food supply might be imperilled. There would be mass migrations, perhaps even wars as starving nations fought for the remaining resources. Scientists scoffed at the scenario, for none of them expected a radical climate shift, whether warming or cooling, could come so swiftly. But for a more distant future, the grim speculations could not be entirely dismissed.

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[1] President's Science Advisory Committee (1965), pp. 126-27.

[2] National Academy of Sciences (1966), Vol. 2, "Research and Development," p. 88.

[3] SCEP (1970), p. 18.

[4] Wilson (1971), pp. 17, 182.

Governments were now putting some of the environmental movement's demands into law, creating a practical need for formal "environmental impact" assessments. A new industry of expert consultants strove to forecast effects on the natural environment of everything from building a dam to regulating factory emissions. On a broader scale, people concerned about the environment applied increasingly sophisticated scientific tools to study the impacts of deforestation, acid rain, and many other large-scale activities. They looked at impacts not only on natural ecosystems but on human health and economic activities. Assessing the long-term impact of greenhouse gases fitted easily into this model.

One example was a 1977 report on "Energy and Climate" from a panel of geophysicists convened by the U.S. National Academy of Sciences. By this time, many scientists felt that greenhouse warming was a strong possibility, and the panel got fairly specific about the potential consequences. On the positive side, the Arctic Ocean might eventually be opened to shipping. On the negative side, there would be "significant effects in the geographic extent and location of important commercial fisheries... marine ecosystems might be seriously disrupted." Stresses on the polar ice caps might lead to a surge of ice into the sea, bringing a "rise in sea level of about 4 meters within 300 years." As for agriculture, there would be "far-reaching consequences" which "we cannot specify... We can only suggest some of the possible effects. A few of these would be beneficial; others would be disruptive." There could be terrible "human disasters" like the recent African droughts. However, the panel made clear they could not foresee what might actually happen. They concluded vaguely that "world society could probably adjust itself, given sufficient time and a sufficient degree of international cooperation. But over shorter times, the effects might be adverse, perhaps even catastrophic."[1] Two years later another Academy panel said much the same, and took brief note of an additional threat—the rise of CO_2 in the atmosphere would make the oceans more acidic. Here too they found the consequences beyond guessing. Overall the experts could only conclude that as the world warmed, "the socioeconomic consequences may well be significant, but... cannot yet be adequately projected."[2]

As studies proliferated, the topic of "climate impact studies" was starting to look like a respectable field of research. Both scientists and the public recognized a need to study consequences that might be "catastrophic" (as a 1983 report by the U.S. Environmental Protection Agency warned). The American reports of the late 1970s inspired an international effort to assess impacts, and a Stockholm team endorsed the conclusions of the American panels—global warming would have profound consequences for ecosystems, agriculture, water resources, the sea level and so forth. More categories of impacts emerged, each attracting its own little band of specialists. For example, a 1983 Academy report included not only familiar categories like agriculture and sea-level rise, but pointed out that an increase in extreme summer temperatures would worsen the "excess human death and illness" that came with heat waves. Also, melting of permafrost in the Arctic could require adaptations in engineering. Also, climate

[1] National Academy of Sciences (1977), pp. 8-14.

[2] National Academy of Sciences (1979), pp. 3, 24-27.

shifts "may change the habitats of disease vectors." And finally, "we may be overlooking things that should alarm us."[1]

The studies to this point had used a simple cause-and-effect model. Physical scientists would run computer models to predict changes in precipitation and the like. Others would follow by calculating immediate consequences, for example using historical records to predict how crop yields would vary with the weather. But if farmers could no longer get good results from corn, wouldn't they plant something more suited to their new climate? During the 1980s, impact studies began to take account of how humans might adapt to climate change. By the end of the decade, some studies were linking models of crop responses with economic models. Complex interactions were no less crucial in natural ecosystems. Life scientists began to calculate scenarios on how forests, coral reefs and so forth might respond to the rise of greenhouse gases. For example, could tree species move their ranges poleward fast enough to keep up with the temperature rise? At a still higher level of complexity, some studies began to account for the way one type of climate impact might interact with another.

These more sophisticated approaches guided the first official U.S. government report, ordered up by Congress from the Environmental Protection Agency. The EPA's findings continued the trend toward predicting more numerous and more specific kinds of damage. The experts concluded (as summarized by *New York Times* in 1989) that "Some ecological systems, particularly forests... may be unable to adapt quickly enough to a rapid increase in temperature... most of the nation's coastal marshes and swamps would be inundated by salt water... an earlier snowmelt and runoff could disrupt water management systems... Diseases borne by insects, including malaria and Rocky Mountain spotted fever, could spread as warmer weather expanded the range of the insects." Some of this was already vaguely grasped by the minority of people who followed scientific news closely. Other predictions, notably the expansion of diseases, had been mentioned in passing before but were only now coming under detailed discussion.[2]

Studies of how climate change might affect human health expanded particularly swiftly in the 1990s, catching the attention not only of experts but the public. Here as in some other categories, the work was increasingly supervised not by a particular government but by international organizations, from the venerable World Health Organization to the new International Panel on Climate Change (IPCC). Yet here as in some other categories, it was becoming clear that global

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[1] National Academy of Sciences (1983), pp. 45, 50, 53, on pests see also pp. 405-07. Here and below I draw especially on Long and Iles (1997). They identify the first World Climate Conference (Geneva, 1979) as "the first major conference to address human health" (p. 8).

[2] Philip Shabecoff, "Draft Report on Global Warming Foresees Environmental Havoc in U.S.," *New York Times*, October 20, 1988; United States, Office of Scientific Research and Development (1989) My search of the Google news archive at http://news.google.com/archivesearch/ found that newspaper and news magazine items on disease spread by climate change and the threat to water supplies from earlier snowmelt began to appear in 1988-89. Items on impacts on water supplies due to the disappearance of glaciers started appearing only in 1997. Harm to water supplies was noted, for example, by Revelle and Waggoner (1983).

generalizations were of little value compared with studies at a regional level. For example, insect vectors of tropical diseases like dengue fever and malaria (which already affected half a billion people) would expand their ranges. The main impacts would be felt in developing nations, but people in the developed world tended to worry chiefly about how such diseases might spread to the temperate zones.[1]

Any regional analysis had to start with the climate changes that computer models calculated would result from a given level of greenhouse gases. But although the increasingly sophisticated models had come to a rough agreement on global features like the rise of average temperature, they differed in the details. In places where many factors balanced one another, for example the Sahel region between the Sahara desert and the African rain-forest, one model might predict a benign increase of rainfall and another, terrible droughts. Policy-makers did not much care about the average global temperature—they wanted to know how things would change in their own locality. The IPCC addressed this problem in 1997 with a pioneering report on "The Regional Impacts of Climate Change." Unable to make quantitative predictions of what might actually happen, the panel analyzed "vulnerabilities," that is, the nature of damage that a given system might sustain from any of the likely sorts of climate change (the experts also considered benefits, but the very term "vulnerability" showed their main concern).

At the regional scale it was obviously necessary to consider not only the local climate and ecological systems, but also the local economic, social and political conditions and trends. For example, the panel concluded that Africa was "the continent most vulnerable to the impacts of projected changes." That was not just because so many parts of Africa were already water-stressed, subject to tropical diseases, and so forth, but still more because population pressure and political failings were already causing environmental degradation that would multiply the problems of climate change. Moreover, Africa's "widespread poverty limits adaptation capabilities." By contrast, the carefully managed agricultural systems of Europe and North America might even contrive to benefit from a modest warming and rise in the level of CO_2 (which could act as a fertilizer for some crops), although the developed nations would certainly suffer some harmful impacts as well.[2]

An elaborate assessment exercise that the U.S. government pursued in the 1990s took a different approach. The authors displayed, side by side, the results of two separate computer models (one from the United Kingdom and one from Canada). In some regions the model predictions agreed—there seemed little doubt, for example, that Southern California would get a lot drier. In other regions they diverged, as when one model projected more rain in the Southeast and the other, less. Overall, the American experts agreed with the IPCC that highly managed ecosystems of farming and forestry might do quite well in the first half century of serious warming. On the other hand, nothing could prevent damaging changes in some natural ecosystems and expensive difficulties along the coasts. As for threats to health, there would be some problems but "adaptation is likely to help protect much of the U.S. population." And finally, "some aspects and impacts of climate change will be totally unanticipated," which people could interpret

[1] Long and Iles (1997), pp. 29-33.

[2] Watson et al. (2001), quote p. 6

optimistically or pessimistically, according to taste.[1] Scientists in another major industrial country, chilly Russia, foresaw even less worrisome results from global warming. These assessments, and the publics they addressed, could see the impacts as manageable because they were looking no more than half a century or so ahead. Surely by then, humanity would have taken control of its emissions so that CO_2 would not rise to three or four times the pre-industrial level... wouldn't we? At any rate, the 22nd century was so far away!

The IPCC offered a basis for better understanding with a set of six "scenarios," first published in 1992, describing a range of ways that the world's population, economies, and political structures might evolve over the decades.[2] Experts in various fields of physical and social science could try to figure how much greenhouse gases would be emitted by the society of a given scenario, then compute the likely climate changes, and then estimate how that society would try to adapt. But there were so many unknowns, and so many differences from region to region, that the small community of researchers could explore only a few of the possibilities. Many research projects used only one scenario, the middle one with emissions neither sharply restricted nor rising explosively. In its own reports, the IPCC not only laid out clearly the range of scenarios it had investigated, but got increasingly specific about whether the consensus of experts judged a given impact to be "likely," or "very likely," or "virtually certain." In the panel's 2001 and 2007 reports, the most impressive parts resembled the earlier reports that simply laid out a variety of the likely direct impacts, and suggested which regions would be especially vulnerable. The conclusions are summarized below.

The attempts at precision could be misleading. For example, studies published from the 1970s into the mid 1980s estimated that by 2100, the sea level might rise anywhere from a few tenths of a meter to a few meters. The upper limit dropped to about half a meter in the IPCC's 1995 report, and it remained there in later reports. But in fact, there was still a wide range of scientific estimates on how high the seas could rise in the 21st century. It could only exceed a meter if polar ice sheets began to surge into the oceans in the next few decades. Most scientists had always considered that very unlikely, but there were always some who argued it was possible. The IPCC gave scant attention to such impacts that did not seem at least fairly likely to happen, even if they would be catastrophic in the event they did befall us.

Reality descended upon the abstract world of impact studies as actual consequences of global warming began to appear. In the late 1990s, field surveys of sensitive and well-studied groups like birds and butterflies found them measurably shifting their ranges, or even facing extinction, in just the ways that could be predicted from the observed warming.[3] In the early years of the

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[1] National Assessment Synthesis Team (2000-2001), quotes p. 9

[2] J. Leggett et al., "Emissions Scenarios for the IPCC: an Update," in IPCC (1992) #378, pp. 68-95. The scenarios are available at http://sedac.ciesin.org/ddc/is92/.

[3] Landmark studies included Parmesan (1996), finding a latitude shift in a North American butterfly (Edith's Checkerspot) and attributing it to climate change, and Parmesan et al. (1999) with "the first large-scale evidence of poleward shifts in entire species' ranges" from Europe.

21st century, instead of future possibilities some experts began to estimate the role that global warming might have played in one or another actual disaster. It turned out that because of unexpected complexities, the rich nations were not as safe as some had thought. One example: in 2003 a heat wave of unprecedented scope killed tens of thousands in Europe. Nobody had foreseen that old people could not save themselves when the traditional August vacation emptied the cities. Another example: bark beetles, no longer controlled by winter freezes, devastated millions of acres of forests from Alaska to Arizona, leaving the weakened timber prey to an unprecedented outbreak of forest fires. Nobody had prepared for this particular impact of global warming.

A description of impacts meant little to people unless it was translated into specific human terms. For example, if an aquifer turned brackish as the sea level rose, exactly what difference would that make to anyone? Since the 1970s, economists had been developing increasingly detailed projections of the economic benefits and costs of global warming, working up from regional examples to global estimates.[1] Of course, it was not easy to put a dollar value on the degradation of the Everglades or the extermination of the Golden Toad. Free-market economists worked up calculations that found negligible costs from climate change, and warned that taxing or regulating emissions would wreck the economy. Other groups replied with calculations that gave opposite results. Governmental and international bodies stepped in, supporting elaborate professional studies.

An outstanding example was the *Stern Review on the Economics of Climate Change*, produced for the British government in 2006 by Nicholas Stern, former chief economist of the World Bank, with a staff of 20. Stern framed the question in the businesslike "risk management" manner, studying the worst case plausible enough to be worth buying insurance against. His team calculated that if global warming in the 21st century was in the upper range of what scientists thought likely, the direct effects would cut the annual Global Domestic Product by some 5%. Indirect effects might possibly raise that as high as 20%, equivalent to the Great Depression of the 1930s or the damage in one of the 20th century's world wars—maintained perpetually. The economists made a rough estimate of the cost of preventing that, most likely a modest 1% reduction in Global Domestic Product. (The IPCC's 2007 report reached a similar conclusion.) "Climate change," Stern concluded, "is the greatest market failure the world has ever seen."[2]

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[1] Long and Iles (1997) point to the U.S. Department of Transportation's Climatic Impact Assessment Program (aimed not at the greenhouse effect but aircraft emissions) for producing, in 1975, "the first assessment to focus on social and economic measures," (p. 6) and the 1989 U.S. Environmental Protection Agency study as "the first extensive appearance of an economic analysis of impacts."

[2] Stern (2006). All these numbers were highly uncertain; the cost of stabilizing CO_2 at a fairly safe level (550ppm) might be anywhere from 3.5% of GDP to -1% (net benefit), p. xiv. IPCC (2007d), and check the IPCC website http://www.ipcc.ch for subsequent reports.

There was an even more sobering way to frame climate change—as a security threat. For half a century, forward-looking military officers had considered with increasing concern what global warming might mean in their area of responsibility. They would surely be called upon, for example, if weather disasters multiplied. In 2003, defense intellectuals in the Pentagon commissioned a report on "An Abrupt Climate Change Scenario and its Implications for United States National Security." As reported in a leak to the press, the authors warned of a risk that "mega-droughts, famine and widespread rioting will erupt across the world.... abrupt climate change could bring the planet to the edge of anarchy as countries develop a nuclear threat to defend and secure dwindling food, water and energy supplies." The authors concluded that "the threat to global stability vastly eclipses that of terrorism." The report was strikingly similar to the CIA report prepared three decades before (see above). Again the specific "worst-case"scenario, an abrupt change in ocean circulation, was something scientists considered extremely unlikely. By now, however, impact studies had sketched out more plausible scenarios that looked bad enough. Many well-informed military officers, along with many political leaders and a majority of the world's public, had come to agree that the impacts of global warming ranked among the most dangerous long-term risks that civilization faced.[1]

What do we know about the impacts of global warming? A large body of scientific studies, exhaustively reviewed, has produced a long list of possibilities. Nobody can say that any of the items on the list are certain to happen. But all the world's climate experts, virtually

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[1] In 1956 a leading scientist speculated that in a distant future we might "find that the Arctic Ocean will become navigable... If the Russian coastline increases by something like 2,000 miles or so, the Russians will become a great maritime nation." Testimony of Roger Revelle, U.S. Congress, House 84 H1526-5, Committee on Appropriations, *Hearings on Second Supplemental Appropriation Bill(1956)*, pp. 474 and 473. (See also note on submarines in "Government" essay.) Already in the 1970s, a couple of studies like the CIA study noted above had framed global warming as a security problem. Environmentalists since the early 1970s had argued more generally that the world would be more secure if it spent less money on military defense and more on defense against pollution and other environmental dangers. The groundbreaking 1988 Toronto Conference concluded that changes in the atmosphere were a major threat to global "security," and for climate change in particular the "ultimate consequences could be second only to a global nuclear war." For all this see Barnett (2001), who gives the quote from World Meteorological Organization (1989). CIA report: Schwartz and Randall (2003), reported by Stipp (2004); quote: Mark Townsend and Paul Harris, "Now the Pentagon Tells Bush: Climate Change Will Destroy Us," *The Observer,* February 22, 2004. An internet newspaper archive search will show, e.g., the Science Advisor to UK Prime Minister Tony Blair, Sir David King, calling climate change "the greatest threat facing mankind" and "worse than terrorism." See report issued in 2007 by a group of retired three- and four-star admirals and generals: CNA corporation (2007). I met a number of concerned serving officers in a conference on "The National Security Implications of Global Climate Change" held by the Triangle Institute for Security Studies, Durham, NC, March 2007. 64% of all Americans in 2007 felt that their country was "in as much danger from environmental hazards, such as air pollution and global warming, as it is from terrorists:"Yale Center for Environmental Law and Policy: www.yale.edu/envirocenter.

without dissent, agree that the impacts listed below are *more likely than not* to happen. For some items, the probabilities range up to almost certain.

The following are the likely consequences of warming by a few degrees Celsius—that is, what we may expect if humanity manages to begin restraining its emissions within the next few decades, so that greenhouse gases do not rise beyond twice the pre-industrial level (we are already 30% above it and rising a percent each year, at an accelerating rate). By 2007, many of the predicted changes were observed to be actually happening. (For details see the IPCC impacts report.[1])

*** Most places will continue to get warmer,** especially at night and in winter. The temperature change will benefit some regions, at least for a time, while harming others—for example, patterns of tourism will shift. The warmer winters will benefit health in some areas, but globally, mortality will rise due to summer heat waves and other effects.

*** Sea levels will continue to rise for many centuries.** The last time the planet was 3°C warmer than now, the sea level was roughly 5 meters higher. That submerged coastlines where many millions of people now live, including cities from New York to Shanghai. The rise will probably be so gradual that later generations can simply abandon their parents' homes, but a ruinously swift rise cannot be entirely ruled out. Meanwhile storm surges will cause emergencies.

*** Weather patterns will keep changing,** probably toward an intensified water cycle with stronger floods and droughts. Most regions that are now subject to droughts are expected to get drier (because of warming as well as less precipitation), and most wet regions will get wetter. Changes in extreme weather events are hard to predict, but in some regions storms with more intense rainfall are liable to bring worse floods. Mountain glaciers and winter snowpack will shrink, jeopardizing many water supply systems. Each of these things has already begun to happen in some regions.

*** Ecosystems will be stressed,** although some managed agricultural and forestry systems will benefit, at least in the early decades of warming. Uncounted valuable species, especially in the Arctic, mountain areas, and tropical seas, must shift their ranges. Many that cannot will face extinction. A variety of pests and tropical diseases are expected to spread to warmed regions. Each of these problems has already been observed in numerous places.

*** Increased carbon dioxide levels will affect biological systems** independent of climate change. Some crops will be fertilized, as will some invasive weeds (the balance of benefit vs. harm is uncertain). The oceans will continue to become markedly more acidic, gravely endangering coral reefs, and probably harming fisheries and other marine life.

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[1] IPCC (2007) summarizes knowledge as of mid 2006. The 2007 Impacts Report is online at http://www.ipcc.ch/SPM13apr07.pdf, for latest results see http://www.ipcc.ch. Note that reviews such as Grassi (2000) have been only modestly revised by more recent work.

*** There will be significant unforeseen impacts.** Most of these will probably be harmful, since human and natural systems are well adapted to the present climate.

The climate system and ecosystems are complex and only partly understood, so there is a chance that the impacts will not be as bad as predicted. There is a similar chance of impacts grievously worse than predicted. If the CO_2 level keeps rising to well beyond twice the pre-industrial level along with a rise of other greenhouse gases, as must inevitably happen if we do not take strong action soon, the results will certainly be worse—probably including a radical reorganization and impoverishment of many of the ecosystems that sustain our civilization.

> *What can people do about global warming, and what should we do? See my Personal Note and Links.*

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