A Second Look at the Impacts of Climate Change

We may be worrying too much about crops, coastlines and quick action—but too little about water, wildlife and gaps in information

Jesse H. Ausubel

Hypothesis 1: Faster change is worse.

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With the passage of time, a picture of an issue tends to settle into the public mind. A few images and sound bites come to monopolize our thinking. Now that the "greenhouse effect" issue has been prominent in the news media for a few years, such a collection of ideas has started to form—a shared set of images and concerns about life on a warmer earth. The dominant images are probably those of parched crops and flooded coastlines. The best-remembered phrase may be "the next most serious threat after nuclear war," from the declaration of the International Conference on the Changing Atmosphere in 1987.

To what extent do such widely held ideas and impressions match the current state of knowledge about the human impacts of global climate change? This question deserves close examination. As we consider new public policies and large economic investments, it is important to recognize the picture on which society is implicitly relying for its decision-making. It is also important to examine closely the common wisdom, to understand gaps, weaknesses and contradictions in the picture, and to consider how the picture might improve.

As part of the recent study on policy implications of global warming conducted by the National Academies of Sciences and Engineering, I was asked last year to join in such an examination. In an effort to summarize popular perceptions of the human impacts of global warming, I scanned magazine and newspaper articles and records of Congressional hearings, and looked at visual material ranging from book covers and cartoons to educational video tapes. I noticed that certain themes were sounded with confidence again and again, and that eight hypotheses seemed to form the core of the conventional wisdom. The eight hypotheses are:

1. Faster change is worse.
2. Waiting to make policy and to take action will drive up the costs of response.
3. There are only losers from climatic change.
4. The most important impacts will be on agriculture and from sea level rise.
5. Changes in extremes will be more important than changes in means.
6. The changes envisioned are unprecedented.
7. Impacts will be worse on less-developed countries than on developed countries.
8. There are hedging strategies that are clearly economical.

In this article, I shall make an effort to test these hypotheses against research findings from the literature about the impacts of climate change, which has burgeoned since the late 1970s. As with any group of hypotheses, some hold up better than others on close inspection; a few appear to bear little relation to what evidence has been gathered. I would like to offer, therefore, a revised set of statements and some thoughts about the directions for future research and policy debate that are suggested by this exercise.

1. Is Faster Change Worse?

One of the most common statements made about the consequences of global warming is that they will necessarily be severe because of the unusually rapid pace at which warming is expected to proceed. An increase of 3 degrees Celsius in the annual average temperature over 50 years is seen as more threatening than a 3-degree warming that takes place over 75 years.

The research usually cited to demonstrate the importance of rates of change has to do with the migration of trees. The essential point is that in a scenario of rapid warming, trees will not be able to move as fast as the climate. The power and relevance of this example must be assessed in the context of the numerous changes likely to occur over the given time frame. Each recent century has brought massive land and ecosystem transformations. In past centuries the major forces were the spread of agriculture and the growth of cities, rather than climatic shifts.

We must ask how likely it is that during the next 100 years climatic change will match or exceed other forces—gypsy moths, spruce budworms, vacation homes—as a transforming factor for ecosystems. Rapid change in climate may be exceeded in importance for forests by changes in soil dynamics, acidification, seed sources and the direct effects of trace gases, air pollution and forest-management strategies—not to mention the markets for wood products.

This ecological example illustrates that for both natural and built systems, one must assess the importance of the rate of climatic change by comparing it with the rates at which the systems that might be affected change and adapt. We can ask, for instance: How frequently does industry acquire new capital stock, and how often does agriculture adopt new equipment and seeds to adjust to changing conditions? How quickly is the stock of residential and industrial buildings replaced and renovated? How quickly are water supply systems and dikes constructed and renewed? Surveying these rates suggests that in most cases they are rapid in relation to the projected climatic change.

It is also important to ask to what extent it is possible to separate the rate of change from the direction of change. If the forecast is for a greening of the Sahara Desert, many Africans in the regions affected would probably *prefer* that the increase in rainfall occur over 20 to 30 years rather than over 50 to 100 years. Without some notion of the direction of change, then, rates themselves may not matter much, except in an extreme scenario. In such a scenario, the climate is changing like a spinning carnival ride, and the sensations are equally disorienting whether traveling clockwise or counterclockwise. Short of such a scenario, one has to ask, "What is fast?" and look for thresholds at which rates clearly begin to be important. Would consequences differ perceptibly if the rate of change globally is, say, 0.3 degree Celsius per decade rather than 0.2 degree per decade?

In the end, the critical question for societies and their economies may be whether the climatic change is expected, rather than how rapid it is. Fast change that is anticipated may matter less than slower change that is unforeseen. The specific shape of the transition may also matter more than the rate averaged over decades. A steady, linear movement that after 50 years leaves the climate warmer by 3 degrees Celsius may be less problematic than a jagged, irregular movement to a climate warmer by 2 degrees, since in the former case conditions can be better anticipated.

2. Must We Act Now?

Those who advocate putting off actions that are proposed in anticipation of global climatic change often hear that waiting will make the costs of response higher. This position is grounded in pessimism about future technology, future economic resources and the ability to acquire new information.

Several lines of evidence argue against this pessimistic assumption. First, the menu of response options may increase through innovations, technological and otherwise. If it were decided today that societies should immediately reduce their greenhouse-gas emissions by 20 percent, several countries might achieve this reduction by building light-water nuclear reactors. Such investment would further lock these societies in to energy technologies that may be inferior to alternatives, nuclear or non-nuclear, that will be available fairly soon. In short, it is not clear that it is better for the United States to spend, say, $100 billion during the next five years on nuclear and alternative energy technologies to reduce carbon dioxide emissions than to wait and spend the equivalent amount during a future period.

In fact, if there is economic growth in the intervening period, the available and spendable resources should increase. It may then be possible to select choices from the menu that are now excluded because of high cost. In other words, if a future society is wealthier than today's, it may be able to finance highly attractive response options that are unaffordable at present; these options might render superfluous the clumsy interventions that now dominate the set of feasible choices. In the U.S. Environmental Protection Agency's scenario of unimpeded growth in the emission of greenhouse gases, annual per capita global income in the year 2100 is projected to be $35,600. Per capita income in the United States would be $150,000 or more, if current income ratios hold. Such flows of wealth open wide vistas for adaptation to climate change, as well as for expenditures to reduce greenhouse-gas concentrations.

When we shift our perspective away from the world's centers of prosperity, the decisions are different but the conclusions not necessarily so. For parts of the world such as Africa, many urgent questions of immediate survival and economic development must be faced. In these regions it is important to analyze carefully whether now is the proper time to begin allocating resources in anticipation of the uncertain impacts of global warming. And in the U. S. S. R. and the nations of Eastern Europe, the optimal timing of greenhouse investments must be explored in light of the urgent need to put in place better private and governmental decision-making processes.

The argument about timing is also depen-

Hypothesis 2: Waiting to make policy and to take action will drive up the costs of response.

dent on the quality of the information now in hand and the probability that it will improve. There are areas in which we have reason to be optimistic that we will have, as time goes on, information useful in making measured responses to the challenge of climatic change. New information could, for example, allow us to better assess the likelihood of various amounts of sea-level rise and thus guide resources more efficiently into a variety of adaptive responses. In the case of large, lumpy investments such as those needed to protect coastal regions from flooding and seawater intrusion or to transfer water between river basins, it is not apparent that the quality of current forecasts is sufficient to trigger action.

There may, however, be actions that are more easily and effectively taken now, or soon. As the world becomes more crowded with people, it is likely to become more difficult to reserve land for corridors that would allow the migration of plants and animals as climate shifts. In some regions, such as coastal zones and floodplains, waiting may further set society into patterns that increase vulnerability and reduce flexibility. A parallel argument applies to the use of fossil fuels: The further they are allowed to penetrate into the fabric of society, the larger becomes the job of substituting for them.

In summary, if society becomes better supplied with tools, money and knowledge, the menu of options for adaptation will be superior in the future—far superior, if the technological and economic progress of the past 100 years continues apace. Because information is easier to transfer than are wealth and technology, it is especially important to acquire better information as quickly as possible. A stitch in time saves nine *if* you know how to make the right stitch. It is quite possible that the optimal present strategy on the greenhouse issue, for many nations, is a continued emphasis on increasing the information available and improving its quality.

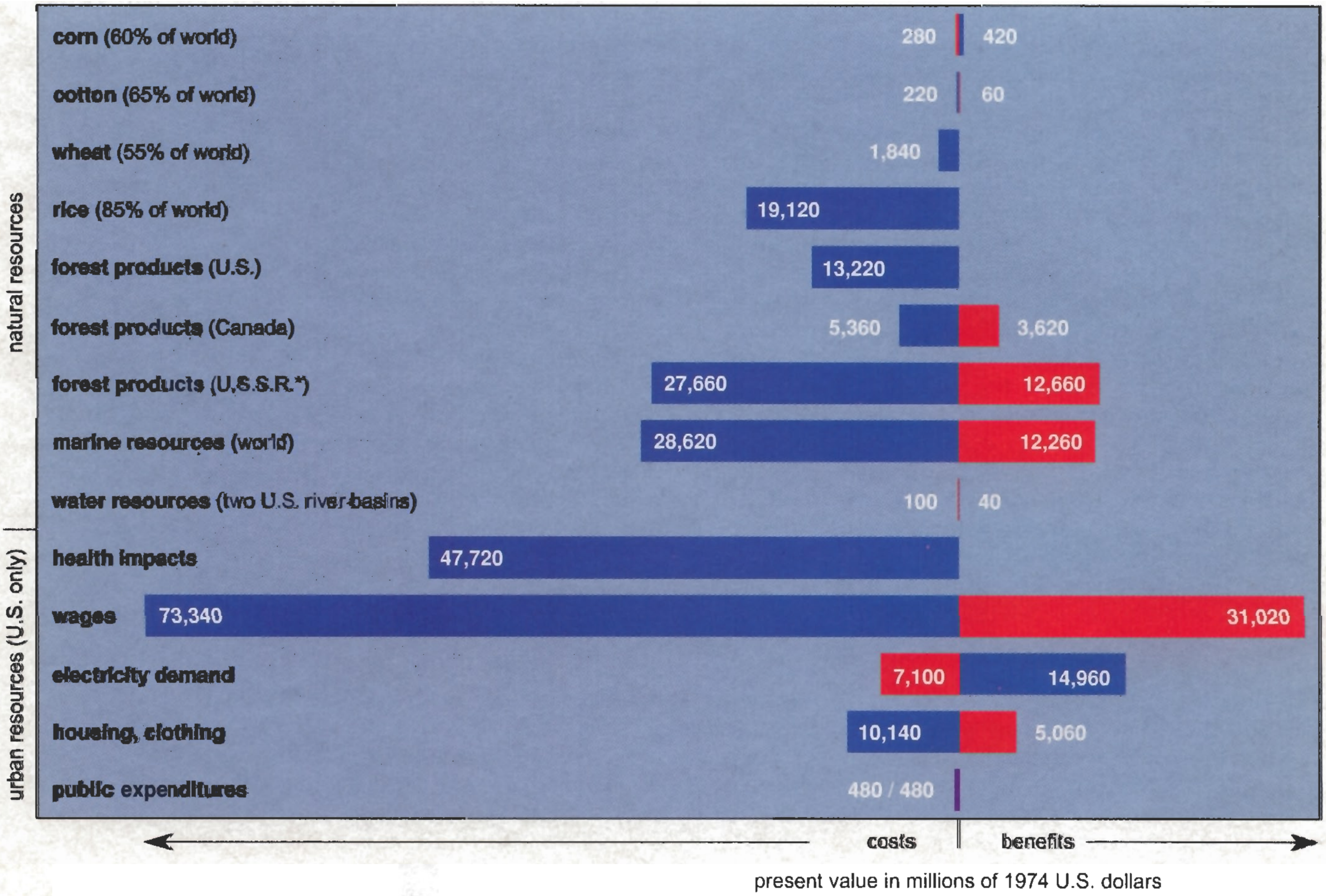


Figure 1. Economic costs of global cooling might far exceed those of global warming. A study of the costs of atmospheric cooling undertaken by the U. S. Department of Transportation in the early 1970s found that a decrease in average temperature of 1 degree Celsius would be costly, but that a warming of 0.5 degree Celsius would produce net economic benefits. The study noted that medical expenditures, mortality and wages all seemed to increase with cooler temperatures. Activities related to forest products and to marine resources were expected to benefit from warming. The effects of warming on wheat, rice, U. S. forest products and health were not estimated. Blue bars show estimated effects of cooling; red bars are effects of warming. Equivalent impacts on U.S. public expenditures were expected to result from either cooling or warming (*purple bar*). Information in parentheses describes the areas covered by the study. (Data from CIAP 1975.)

3. Will We All Be Losers?

The contention that there will be no winners from global warming seems to rest on three arguments. One is the risk of a shift to a calamitous climate, in which warming would reach a catastrophic extreme—a hot climate as extreme as the cold one experienced 18,000 years ago, when the average temperature was cooler by 5 degrees Celsius and an ice sheet buried North America. A second argument emphasizes the accumulation of global problems. The third is based on the perception that society is becoming increasingly brittle.

The first argument emphasizes the nonnegligible probability that climatic change will follow a catastrophic course, in which case the "everybody loses" statement is—tautologically—true. This could occur if greenhouse-gas emissions are extremely high, if atmospheric concentrations reach very high levels, and if the expected warming follows. A scenario of even greater concern is that of a "runaway" greenhouse effect, in which a relatively small change in concentrations triggers an unexpectedly large change in the climate system. Such a scenario is physically possible, but so far is not supported by much more than highly conjectural assertions. One set of interesting conjectures relates to shifts in ocean currents, which appear to have occurred quite rapidly and unaccountably in the past. Another relates to warming in high latitudes; this might release large amounts of methane from clathrates in the tundra and continental margins, thereby greatly increasing greenhouse-gas concentrations in the atmosphere. It might be useful to survey experts to ascertain what they think is the probability of such a scenario: 1 in 10, in 100, in 1000? Contingency plans must be developed for high-consequence, low-probability scenarios, just as contingency plans are made for earthquakes, reactor failures and threats of nuclear war.

The second argument for the "everybody loses" hypothesis is that environmental change will cause extreme and comprehensive destabilization of social and economic conditions worldwide. Like the runaway greenhouse effect argument, this is plausible but entirely conjectural. A scenario has yet to be worked out in detail, beyond popularizations. The essence of the view is that almost everything in the world is going wrong—that all the indicators about population, food, terrorism, radiation and the ozone layer, for example, are moving ominously. The overall system is heading for catastrophe, and climate is part and parcel of this. Climatic changes will add stress by reducing the reliability with which a population of 10 billion can be fed and by adding to the number of refugees as a result of rising seas. In this view, the amount of climatic change matters, with larger being worse, but even a small change could be bad—the straw that breaks the camel's back.

A variation on this argument holds that sociotechnical systems are becoming more brittle. Although for many specific contingencies societies may be insulating themselves successfully from climatic change, this protection comes through increasingly elaborate systems that are more vulnerable to catastrophe from both natural and social hazards that may occur infrequently. In the open and enlarging world system of today, vulnerability may be shared ever more

Hypothesis 3: There are only losers from climatic change.

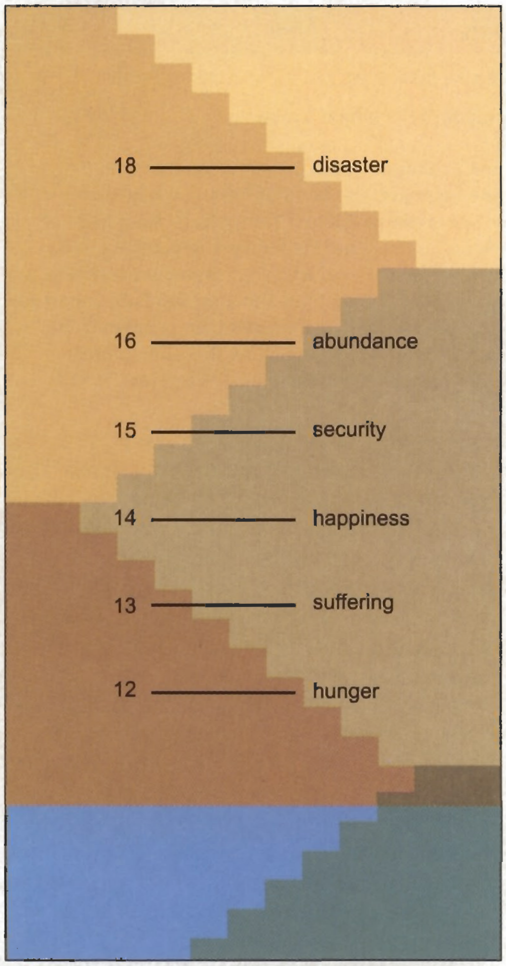


Figure 2. Nilometers of ancient Egypt measured the annual spring flood of the River Nile, which determined the success of the following growing season. This scale shows the interpretation of nilometer readings (in cubits) that was in use during the time of the Roman scholar Pliny (AD 23–79). From hard experience, the Egyptians knew that disaster—catastrophic flooding that could destroy their canals and dikes—impended just above the ideal river level (Heathcote 1985). Some would suggest that the current annual average temperature of the earth, 16 degrees Celsius, similarly places society not far below climatic disaster.

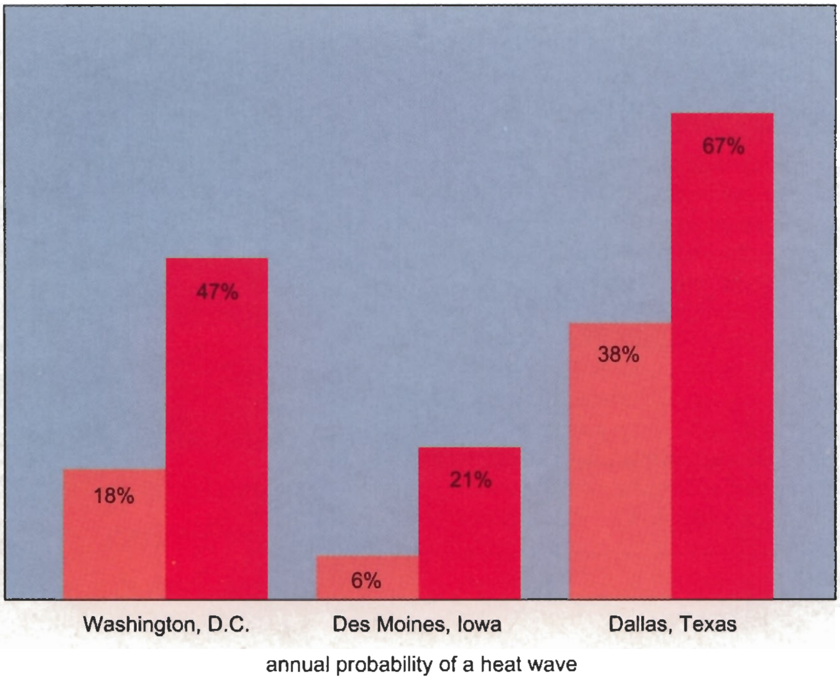


Figure 3. Heat waves are a worrisome probable consequence of an increase in global temperature. According to one estimate, the odds of having a heat wave in a given year could double or triple in some major cities if the average temperature increased by 3 degrees Celsius, with no increase in temperature variability. Bars show the annual probability of a heat wave, defined as five or more consecutive days on which the high temperature exceeds a threshold—95 degrees Fahrenheit for Washington and Des Moines, 100 degrees for Dallas. Pale-red bars represent the odds of a heat wave without a warming; bright-red bars show the odds after the increase in average temperature. (Data from Mearns, Katz and Schneider 1984.)

widely, and consequences may ripple into previously unrelated areas or societies. This argument is comparable to concerns about electricity blackouts, the implications of which multiply with our growing dependence on a reliable power supply. In this perspective, even small climatic changes could trigger collapse of social and physical structures.

Balanced against arguments that any climatic change is bad or extremely risky for everyone is specific research showing that there could be winners from climatic change. This proposition seems logical. The present climate of the earth is harsh in many, if not most, parts of the globe. It is easy to imagine that several, even many, regions will find themselves in more favorable conditions—milder winters, more abundant rainfall—as climate warms. One study suggests that there may be an increase of from 3 to 11 percent in global mean precipitation.

Indeed, there is a growing body of literature showing, based on analyses of the widely cited results of general-circulation models, that there would be benefits from global climate change. For example, on the basis of detailed studies of Japanese agriculture, Masatoshi Yoshino and his colleagues concluded in 1988 that in Japan, scenarios based on a doubling of atmospheric carbon dioxide levels "would, *ceteris paribus*, result in an enormous rice surplus." This conclusion is based on analyses of rice yields relative to the long-term baseline productivity for a "dumb farmer," that is, one who takes no adaptive steps but goes about his business in the climate brought about by doubled CO_2 in the atmosphere as if it were the climate of today. Yoshino's group noted that most of their estimates reflected a poor response for a well-managed commercial crop. The surplus would be even greater if farmers were, as is probable, to adapt their cultivation methods to the new climate by actions such as introducing more heat-loving rice varieties with earlier planting dates. Such adjustments might result in increases of rice yields in areas of Japan of up to 25 percent, relative to recent levels. A similar case study showed that major national surpluses of food grains can also be expected in Finland.

It is also worth noting that migration trends suggest that many people seem to prefer a warmer climate. Within the United States, the migration toward the Sunbelt has been widely analyzed. To a large extent this is a climate-induced migration; people even accept lower wages to live in warmer climates. A similar phenomenon has occurred in Canada. The behavior of populations over the past few decades thus suggests that many people might feel themselves winners to have a warmer climate, other things being equal or nearly so.

Finally, there is also the curious fact that previous, detailed studies showed that on balance, global cooling would be adverse and global warming beneficial. These studies, undertaken as part of the Climate Impact Assessment Program (CIAP) of the U.S. Department of Transportation in the early 1970s, were primarily concerned with the possibility of global cooling that might be associated with a large fleet of supersonic transport planes operating in the stratosphere. The warming scenarios were explored partly as a reference point. As Figure 1 shows, both warming and cooling produced a blend of benefits and costs. Global-cooling scenarios produced net costs, whereas moderate global-warming scenarios tended to produce net benefits. Studies combining warming and cooling scenarios with both increases and decreases in precipitation yielded essentially the same result, with a warmer and wetter scenario the most favorable. The numbers suggest a logical conclusion: that there are both winners and losers with any gradual climate change.

(The Japanese and Finnish studies take account of an important additional fact: that carbon dioxide is food for plants. Holding other conditions steady, doubling the CO_2

content of the atmosphere appears likely to increase yields by somewhere between 10 and 50 percent.)

It is tempting to speculate that analyses of any potential climatic change—whether cooling in the early 1970s or warming for the past decade—are somehow biased by a sense of threat. Alternatively, it is possible to argue that human societies are now precariously balanced from a socioeconomic viewpoint at a climatic optimum, reminiscent of the gradations used by the ancient Egyptians to interpret the readings on their nilometers (*Figure* 2), which measured the height of the Nile River. It is true that either a vast expansion of glaciers or Venusian heat would render human habitation of earth more difficult, very miserable, and perhaps impossible. But no convincing evidence exists to replace the stone markings used by the Pharaohs to measure the height of the Nile with measures of annual average global temperature. By coincidence, the number 16—the river level signifying "abundance," located not far below disaster—is about the current number for global average temperature, in degrees Celsius.

There are also losers from a scenario in which limitations are placed on emissions of greenhouse gases. In this case the losers are the individuals, groups or nations whose economic development is slowed because of higher energy prices or other barriers to access and use of carbon (or of other resources related to emissions of greenhouse gases). The losers also would include the carbon-rich nations whose resource, in or on the ground, is devalued by restrictions on carbon use. In fact, the biggest economic losers from a reduction in CO_2 emissions might be the less-developed countries and the oil-exporting countries. Carbon is the largest export of the poor nations of the South to the rich nations of the North. If the industrialized nations continue to increase their energy efficiency and reduce reliance on hydrocarbons, markets dry up for Mexico, Venezuela, Ecuador, Gabon, Nigeria and Indonesia. Carbon is also by far the largest export of the U.S.S.R.

Finally, a discussion of winners and losers is incomplete without mention of the direct beneficiaries of the greenhouse issue—namely, those employed in research and negotiation about it. The "greenhouse industry" will employ at least several thousand scientists, lawyers, diplomats and others.

In summary, statements that there are no winners or are only losers from global warming appear biased, unless based strictly on an apocalyptic scenario. It seems more accurate to emphasize that there will be complex distributive issues involved in climatic change, with continually shifting sets of losers and beneficiaries, both from the changes in the climate and the regulation of economic activities that may be causing the climatic changes.

4. Which Impacts Should Worry Us Most?
There is by now a large literature on the impacts of climatic change on agriculture. The findings in the literature are not alarming, in large part because farmers are not dumb; they are accustomed to continually adapting to variations in markets and technology, as well as in environment and climate. For the most part, projected impacts of climate change on agriculture are small or moderate in comparison with impacts associated with fluctuations in government subsidies, international trade and other economic factors or with productivity gains that come with technological progress. Also, for a lengthening list of nations, agriculture is no longer the outdoor activity that is of most value. In nations such as the United Kingdom and Germany, agriculture is only about 3 percent of gross national product, so impacts of climate change on agriculture pose little threat to national income. Travel and recreation may prove to be sources of jobs and revenue that are more vulnerable to climatic change than agriculture in several regions.

Hypothesis 4: The most important impacts will be on agriculture and from sea level rise.

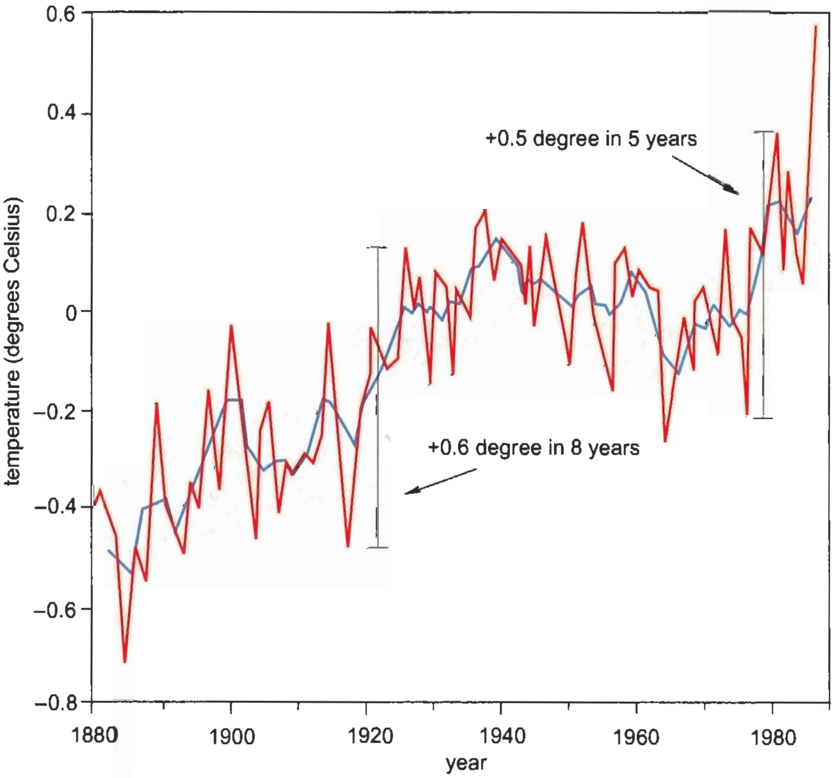


Figure 4. Significant global warming has been experienced during short periods since 1880. The record of annual average (*red*) and five-year average (*blue*) global temperatures shows that the earth's average temperature jumped 0.6 degree Celsius during the years 1918-1926, and 0.5 degree between 1976 and 1981—faster rates than are projected under current scenarios for global warming. (After Hansen and Lebedeff 1988.)

Hypothesis 5: Changes in extremes will be more important than changes in means.

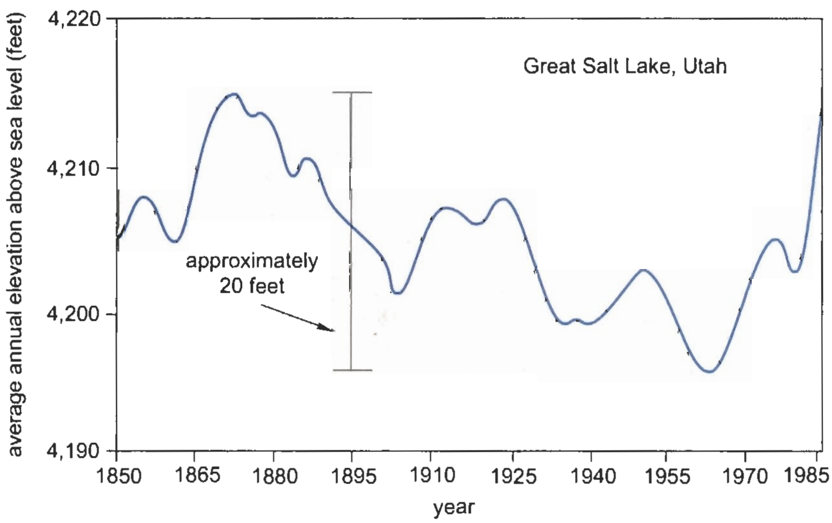
The consequences of sea-level rise are on a grand scale indeed, if one uses scenarios in which the sea level rises several meters. A quarter of Florida might be flooded if the ocean were five meters higher. The probable sea-level rise over the next 100 years—the rise that would be associated with a global temperature increase of 3 or 4 degrees Celsius—is about 70 centimeters. Of this rise, 33 centimeters are expected by 2050. Impacts from such rises are a concern to be addressed, but hardly merit images of the Great Flood. The impacts of sea-level rise may be scarcely apparent at all for the next 30 to 40 years. The fascination with sea-level rise probably originates in the fact that it could be disastrous, but it is mistaken to conflate coastal inundation with the likely impacts during the next generation or two.

Agriculture and sea level have captured much of the popular attention, but a more serious concern may be water resources. A 1989 comprehensive study of climate and water in the United States by the Panel on Climate and Water of the American Association for the Advancement of Science shows that the prospect of climatic change lights warning lamps of vulnerability in several regions. Vulnerability depends on the ratio of water supply to demand, and climate can affect both quantities. In a region such as the Missouri River basin or California, where the balance is already delicate, even small changes could bring substantial stress.

Another sector that looks worrisome is conservation of nature. Although agriculture and economic activity may shift with climate, our natural heritage—exemplified by national parks such as the Terai in India, Serengeti in East Africa, and Yosemite and the Everglades in the United States—cannot. Changes in variables, such as fire, that affect ecosystems, and changes in the delicate balance that maintains systems such as wetlands could have regrettable consequences.

It is interesting also to note that among the highest costs of *cooling* found in the CIAP study (Figure 1) were losses of forest production and marine resources. Largest of all were the economic costs of impacts on health and of wages. The high estimates of costs of health impacts from cooling arose from findings that there is a covariation between several climate variables and expenditures for physicians' services. Mortality rates also were related to various measures of climate. The central hypothesis in the analysis of wage effects was that if the cost of living rises as one moves to different climatic regimes—as seems the usual case with a move to a cooler climate—then wage earners will have to be paid a differential to compensate for this difference.

In summary, the conventional wisdom seems to rely on preconceptions about which climatic impacts will be most serious. Many commentators and experts on global warming evidently ignore or disbelieve the results of the scholarly literature. The global-warming issue may provide cultural anthropologists with an interesting case study of the ways we protect paradigms and reject information that does not fit. There is definitely a need for more systematic, thorough studies worldwide of impacts, together with adaptation, from which it would be possible to identify the greatest vulnerabilities.



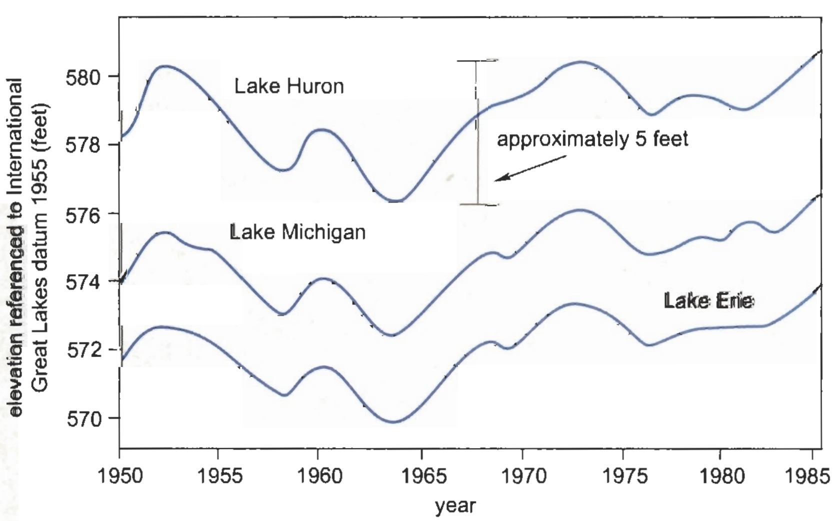


Figure 5. Levels of North America's great inland seas have exhibited large changes that may be analogous to the rises in sea level that are forecast as a result of global warming. The Great Salt Lake has fluctuated as much as 20 feet over the course of a century, and the levels of the Great Lakes have risen more than 3 feet within a decade. The shores of these lakes are developed for a range of uses similar to those of ocean coastlines. (Data from Arnow 1985 and Hitt and Miller 1986.)

5. The Importance of Extremes

Statements made about climatic change are often based on the notion that what matters more is not the average behavior of the system, but its behavior at its limits, which may be masked in consideration of averages. Important changes in extremes, it is noted, might come about in either of two ways. A shift in a climate mean (for instance, in the regional average spring temperature) could slide the complete intact distribution of climate events in such as way as to cross more frequently thresholds that are now rarely breached. Alternatively, the shape of the distribution of events might change in the direction of increased vulnerability.

So far, there are no more than a handful of papers in the scientific literature that directly examine changes in climatic extremes and their impacts. Linda Mearns, Richard Katz and Stephen Schneider in 1984 looked at the example of a change in the probability of extreme heat waves (five days or more in a row with a maximum temperature above a 95- or 100-degree Fahrenheit threshold). They examined what might happen in three U.S. locations if the mean temperature were to increase by 3 degrees Fahrenheit, while there were no changes in the standard deviation of daily maximum temperatures nor in the autocorrelation of daily temperature variations. The results are worrisome; the odds of extreme heat waves would double or triple in each city (Figure 3). It would be useful to carry out more exercises of this type, emphasizing thresholds that climatic variations may cross. In addition to heat-stress levels for crops, an obvious example of such a threshold is the melting of permafrost. It would also be useful to study whether there might be states of the climate system that would be characterized by more frequent and severe storms.

Will temperatures and precipitation become more variable with global warming? To the extent that there are research results touching on this question, they do not indicate an increase in variability. In fact, allowing for considerable noise in the results, they imply qualitatively that standard deviations of surface temperatures are more likely to decrease than to increase as a result of greenhouse warming. Precipitation variability, on the other hand, usually increases as climate warms. Of course, if the climate becomes drier on average, the chances of extremely dry weather are likely to increase, unless the rules of the system change.

In summary, we need to identify important thresholds and discontinuities, to study the likelihood that the altered natural system will reach these points, and to do more work about what consequences might, in fact, ensue. An "extreme," by itself, has little meaning. If summer temperatures in Siberia regularly breach 80 degrees Fahrenheit rather than 70 degrees, are there reasons to be concerned? Would, for example, large releases of biogenic gases be triggered from the soils?

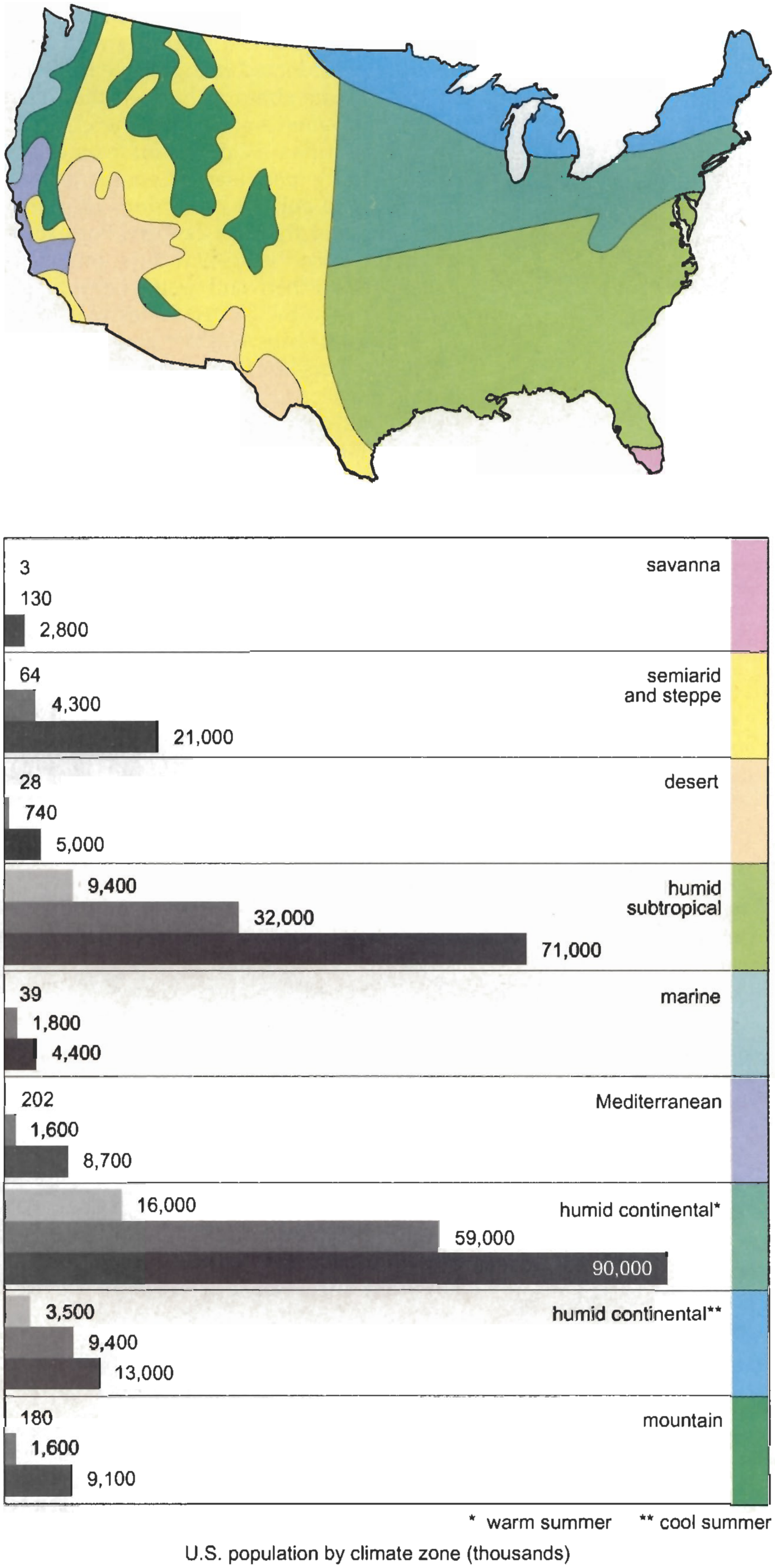
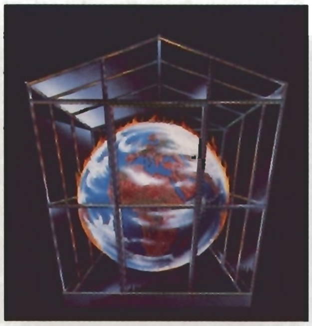


Figure 6. Climates once thought hostile have become popular human habitats with the aid of modern adaptations. In 1860 (*light gray bars*), less than 1 percent of the U.S. population lived in semiarid, desert or mountain regions. This figure rose to 6 percent in 1920 (*medium gray bars*). By 1980 (*dark gray bars*) the population in these climate zones had passed 35 million, or 15 percent of the total population. Large numbers of people now live in every type of climate. (Schelling 1983.)



Hypothesis 6: The changes envisioned are unprecedented.

6. Will the Changes Be Unprecedented?

If one says that global warming will bring about unprecedented changes, one is saying that things are about to happen that have never happened before. Yet the climatic record includes evidence of numerous changes in the past that are comparable or analogous to current projections of global warming over the next century. For example, in the period 1952–1961 the summer climate of the northern and central Great Plains and Rockies in the United States was 0.9 to 1.5 degrees Celsius warmer and had 25 to 100 millimeters less rainfall on average than during the decade 1942–1951. In fact, the nature of climate variability is such that decadal fluctuations in average temperature (up to 1 degree Celsius annually or 2 degrees from one season to the same season the following year) and precipitation (approximately 10 percent annually) have occurred in most areas of the United States during the last 60 years. Raymond Bradley and his colleagues noted in *Science* in 1987 that analysis of precipitation data on a hemispheric basis has revealed important changes in climate that, apart from the well-known declines in North African rainfall, have gone generally unnoticed over the past decades.

There have been periods of rapid global as well as regional shifts. Although the overall record of the past 100 years appears to show a warming of only about 0.5 degree Celsius, during the eight years around 1920 the average temperature of the earth jumped 0.6 degree Celsius, and between 1976 and 1981 it jumped 0.5 degree (*Figure 4*). Thus, even the "upper" scenario of a warming rate of 0.8 degree Celsius per decade used in current studies would not appear to be far from the range of recent experience, at least over the short term. Note that no global climatic catastrophe was experienced either in the early 1920s or the late 1970s.

There are other ways in which analogies might be drawn. For example, there have been large changes in the levels of the Great Lakes and Great Salt Lake (*Figure 5*). The rises and falls of these inland seas—with shores developed for a range of uses, from airports to recreation, not different from ocean coastlines—have been as much as 5 feet for the Great Lakes and 20 feet for Great Salt Lake. These changes far exceed those forecast for the next century in association with global warming. There have also been cases of subsidence of coastal land, caused by pumping out of oil and gas resources in Louisiana and other regions, that are analogous with sea-level rise. Sea-level rises of 20 centimeters have been sustained over several months during an El Niño. The microclimates of cities have also warmed considerably. A recent comparison of summertime temperatures in Atlanta and a nearby rural weather station suggests that Atlanta's temperature increased between 1974 and 1988 by about 2 degrees Celsius as a result of urbanization and the concomitant intensification of the urban heat island.

As Thomas Schelling pointed out in a 1983 National Research Council report on changing climate, human movement also creates an equivalent of climatic change. If an individual boards an airplane in New York and disembarks in Los Angeles, he or she has undergone a climatic change much greater than that forecast as a result of global warming. Moreover, large numbers of people are now living in every type of climate, including those that were considered extremely inhospitable a century ago—especially the hotter and drier climates that are usually associated with anxiety about the greenhouse effect (*Figure 6*). It is hard to imagine what would be unprecedented unless some entirely new kind of climate were created, rather than a redistribution of climates of the existing types. Many plants and animals—tomatoes, corn and horses, for example—also have experienced a range of climates during the process of spatial diffusion.

In summary, the changes expected do not appear to be unprecedented from the point of view of human experience or the experience of many other biota. They are not unprecedented for climate itself over long (geologic) time scales. They are not unprecedented on more limited time scales of a decade, or on regional spatial scales. They are much less than the changes that occur between seasons, or between day and night, or between one year and the next because of natural climate variability. The key question is: How will the projected climatic change differ from all the climate variations to which people, the economy, and ecosystems are accustomed?

Hypothesis 7: Impacts will be worse on less-developed countries than on developed countries.

7. Will Less-Developed Nations Suffer More?

The notion that the impacts of global warming will be worse on less-developed countries, or LDCs, is based on the fact that these countries are more reliant for their well-being on production in primary sectors, especially agriculture, that are vulnerable to changes in weather and climate. Even if, as suggested above, agricultural impacts of warming will not necessarily be severe, there is evidence from geographical research that the costs of natural hazards are much greater in relation to national income in LDCs (*Figure 7*). The percent loss of gross national product appears to be about 20 times greater in LDCs. Moreover, it is generally observed that the poor suffer more in plagues and that, as Aaron Wildavsky once put it, "richer is safer."

On the other hand, LDCs may have flexibility. N. S. Jodha and Adolfo Mascarenhas in 1985 described the impressive array of short-term adjustments and long-term adaptations that are available in self-provisioning societies in India and East Africa. There may be less sunk cost in infrastructure in LDCs. Having the benefit of a better forecast of the future, they may be able to "get it right." Several LDCs have particularly harsh present climates and may be open to the prospect of new climatic regimes. Most are also in tropical regions, where shifts in climate are predicted to be smaller.

All the same, what research has been performed tends to confirm the view that LDCs are qualitatively and quantitatively more vulnerable. For example, a frost in Brazil's major coffee region in 1975 left some 600,000 people jobless. It is difficult to envision an equivalent impact in a developed nation. Similarly, more than 125,000 people are estimated to have lost their lives in the recent cyclone that struck Bangladesh, whereas only 20 deaths were attributed to Hurricane Hugo in the U.S. The problems of reduced income from carbon exports and possibly from higher short-run costs to implement environmentally sustainable development policies may loom as large or even much larger than increased costs from climatic hazards. Overall, the view that LDCs are more vulnerable is persuasive. It needs to be strengthened through additional research. The possibility exists that LDCs will suffer doubly, from both climatic impacts and emission-control strategies.

8. Are There Economical Hedging Strategies? Many studies of impacts culminate in a list of adaptive strategies that should be pursued. These typically recommend augmented efforts to increase efficiency in energy use; better management of water demand; promotion of research to develop drought-resistant strains of agricultural crops; and more prudent development of coastal zones.

The question that must be asked here is: Why are actions that are supposed to be prudent anyway, even without the added impetus of global warming, in fact being pursued in such a limited way? Part of the answer would seem to rest with the reality that prudence and efficiency are only partial goals of our overall systems. Considerations including timing, quality, economic cost and alternative uses of financial resources must be taken into account. Neither an individual, nor the society as a whole, invests more than a few percent of its income in hedging or insurance. Another part of the answer probably lies in the fact that there are barriers, in information and process, to adding up many partial justifications to constitute a full one.

The burden would seem to remain with those proposing the hedging and "tie-in" strategies to show the economics in detail. Based on the ideas here, it might be logical to begin by exploring such strategies in relation to water resources and ecosystem management. With regard to water, the focus would be on decreasing existing vulnerabilities that climatic change will make more severe. In some places the vulnerabilities could be decreased by better arrangements for transferring water to new uses, in others by building new structures, and in others by increasing the benefit of each gallon.

Preservation of natural ecosystems would involve a blend of *ex situ* and *in situ* methods. The former include botanical gardens, arboretums, nurseries, zoos, farms, aquariums, seed banks, microbial and tissue cultures, and gene libraries. *In situ* methods include preserving samples of representative ecosystems and habitat types and establishing corridors along which species can move to change their ranges in response to climatic change. Tools for calculation of risks, costs

Hypothesis 8: There are hedging strategies that are clearly economical.

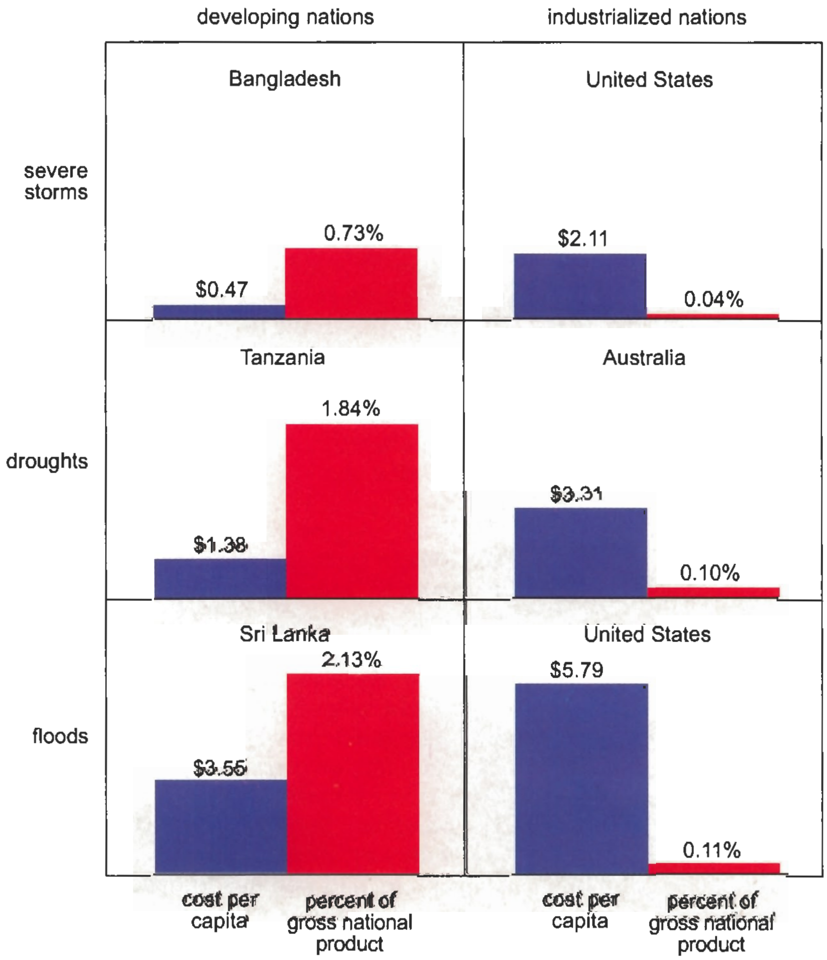


Figure 7. Natural hazards have a much greater impact on the national income of less-developed countries (LDCs) than on the economies of industrialized nations. On a per capita basis, the industrialized nations experience relatively high annual costs from natural hazards; however, in the LDCs hazard costs represent a much larger portion of gross national product. Hazard costs are calculated by combining direct damage losses and the costs of adjustment. (After Burton, Kates and White 1978.)

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and benefits should be applied in such areas to demonstrate the value of investments and how the timing and certainty of climatic change affect them.

Conclusions

Much of the conventional wisdom about impacts of global warming would appear as yet to have little support from research. The statements that embody this view need to be treated as hypotheses for testing. In every case, it would seem straightforward to design a research effort that could support or clarify the hypothesis in question. For the present, the hypotheses might be labeled myths, because to a considerable extent they are uncritically held views. Like more traditional myths, some will turn out to be profoundly true, and others will turn out to be in defiance of facts. In either case, they should be rigorously tested and examined. In the meanwhile, individuals, enterprises and governments should think carefully in acting on the basis of much of what is being said.

I would offer the following revised statements about climatic impacts, in the hope that they will inform the decision-making process:

1. It is very important whether the climatic change is expected.
2. It is very important how fast we can acquire better information.
3. There is likely to be a complex and shifting set of winners and losers.
4. There should be an increased focus on water resources and ecosystem preservation.
5. It is important to identify thresholds and discontinuities that may matter for impacts.
6. It is important to clarify how greenhouse-induced climatic change will differ from all the climatic variations that already occur.
7. There may be a double vulnerability of LDCs, both from climatic hazards and from strategies to limit emissions that may cause those hazards.
8. The economics of hedging strategies need to be demonstrated.

It will be helpful to have a more dynamic and variegated image of the greenhouse effect that takes greater account of the human capacity for social learning and adaptation. The prevailing image may influence importantly the identification of policies and impel us to place, and perhaps to misplace, some quite large investments.

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