The Possibility and Consequences of Climatic Change

by STEPHEN SCHNEIDER

How does climate relate to the world predicament? I think the most obvious way is through its effect on the food supply.

In the very short time scale, climatic fluctuations take food production along with them, and globally that means that food production varies up to 5 percent per year. In 1972, after an almost unprecedented decade in which world food production was increasing faster than population (3 percent as against 2 percent), production dropped by about 1 percent over the previous year. Since we needed a 2 percent increase to keep even with population, and 1 percent to stay up with the added affluence (which primarily meant feeding grain to animals for the New Rich), this was really a loss of almost 4 percent.

That loss created shock waves in the form of price fluctuations, and people started talking again about famine. In the winter of 1972 India declared itself self-sufficient in grain, based on a very short number of years of experience with the Green Revolution, during which time there were also very good monsoons. But a monsoon failure in the following summer and another in 1974 made us aware that food production can still fluctuate globally on the order of 5 percent.

How do we deal with that? I think the way is through reserves. That doesn't just mean stockpiling enough grain in the world; it also implies a *distribution system.* The situation is analogous to being out in a beautiful but snake-infested region, where you know there are dangerous cobras, and so you bring your anti-venom serum along with you. But the day you go out on a hike and happen to get bitten is the day you have left your kit back in the tent. By the time you get back there for an injection, you're dead.

So the important point with reserves is not just to make sure that there are enough stockpiles in the world, but that they are where we need them at the time. This isn't so much a technical problem as a political one, of working out who has control of the local stocks and how they distribute them.

In my view, the middle-term time scale involves the rates of development, particularly the rates of energy development. If the decrease in birth rate that follows increasing quality of life is related to per capita energy consumption, we have to say that the rate of energy development may be an important component in bringing about a stable transition to a stable global population. If that's the case, can we bring the resources to bear in time to prevent those terrible catastrophes that many people see, such as times of famine?

The problem is that, in the process of bringing those resources to bear, one may get catastrophic side effects—an environmental one, perhaps. And therefore we have to ask: What are the climatic consequences of rapid technological development that involves pollutants? Climate change is only one of a variety of environmental possibilities from such developments, of course. For example, there can be local climatic effects from deforestation, or desertification could result from overgrazing marginal lands, particularly when there is extensive well-digging. There are also global issues such as potential climatic modification from carbon dioxide and other pollutants that are frequently by-products of energy development.

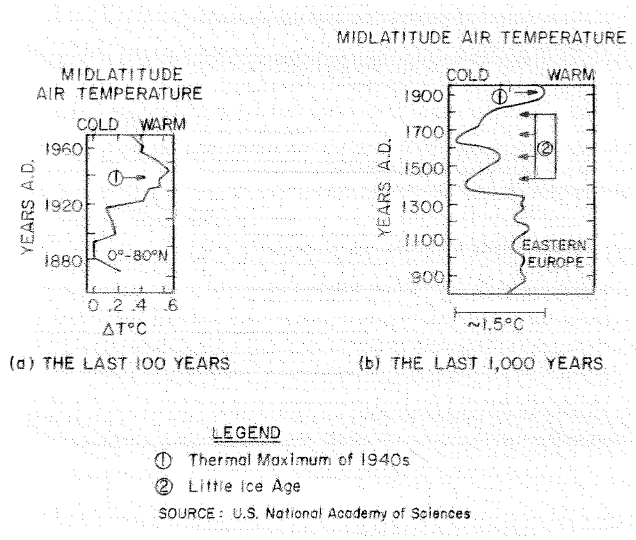
In the long run we want to have a sustainable steady-state population, with most people having a decent standard of living. But, since quality of life may be proportional to per capita consumption of something like energy, then the total population has to be small enough so that we can have a per capita standard that doesn't damage our environmental systems too badly. However, we have to start working toward that goal *before* we have too many people to have environmentally safe applications of high per capita technology. That time, of course, is now. And carbon dioxide pollution from fossil fuel energy is a prime example.

RECENT CLIMATIC TRENDS

The chart on the next page shows air temperature in the northern hemisphere, based upon the existing network of thermometers. In the short term (left) the temperature has risen by about ½ degree Celsius since the 1880s, and from the middle 1940s to the middle 1960s it dropped about ¼ degree. What's wrong with this picture is that there should be large error bars on it, because there are still vast regions of oceans not covered by thermometers. But the main point is that the range of variation is only on the order of ½ degree, and that's probably been significant enough to cause important local changes.

Taking a longer perspective (right), a record from eastern Europe over a 1000-year period shows a cold event that was called the "little ice age," when maybe it was only about 1½ degrees colder. In fact, I'm sure that no ice age has been much more than 5 degrees colder than today, on a global average. Long-term changes on the order of more than a few tenths of a degree in global temperature really start to become large. Locally, even over the long term, or globally, from one year to the next, the changes can be much larger, but globally and in the long run, ½ degree is a big change.

The little ice age is historically chronicled, and there is a quote I enjoy, from the French climate historian Leroy Ladurie, discussing what happened in France in the middle 1700s in a number of climate-induced local famines: "The price of wheat in Liège in 1740 went up . . . to astronomical heights. . . . The poor people of the town menaced the canons and others



Air temperature in the northern hemisphere—in the short term (left) and the long (right).

who had well-rounded bellies, threatening to ring their carillons to a tune they would not find at all to their taste. Prince George Louis, the governor, told the more prosperous citizens to 'fire into the middle of them. That's the only way to disperse this riff-raff who want nothing but bread and loot'."

One can find dozens of such stories. They make two points: (1) that climate-related famine situations have not only geophysical or health overtones, but also political ones; and (2) that a factor (which is not clear from these records) now becoming identifiable is the role of technology in changing our vulnerability to climatic fluctuations.

VULNERABILITY TO CLIMATIC CHANGE

In the past, Europe had more of a peasant village culture, and local villages depended to a large extent on local produce. The village, though basically self-sufficient, was probably living fairly close to the vest, with narrow margins of supply and demand. If there was a local problem with the harvests, it would generally lead to local pressures on nutrition, and perhaps to starvation.

After 1740 we don't hear of very many instances in Europe of local climate-induced famines. Possibly the climate got better, but I think the overwhelming factor was improvements in the technologies of storage and transport of food. The fact is that one can mitigate local fluctuations by buying food from a neighbor. It may cost you your hard-earned money, but you can get it. Then if you save up over a period of time, you can trade around.

I think that, through technologies, we've finally minimized our vulnerability to small local fluctuations. But I also think we're not invulnerable to climatic fluctuations; we've just changed the character of our vulnerability. In the past we had high-frequency, low-amplitude vulnerability—very frequent small failures in local regions of near self-sufficiency. Now we have what I would characterize as low-frequency, high-amplitude vulnerability. This is because there are two, three, or at most four major world granaries, producing much of the food for people other than those who grow it. We now face the situation where simultaneous shortages in, say, the United States, India, and the Soviet Union would mean numbers on the order of 40 million starving per year. I think you could increase that by a factor of five under the worst climate scenario I could conceive of, with tens of millions of people being threatened by the elimination of the surpluses in North America, or shortfalls in the USSR, or India.

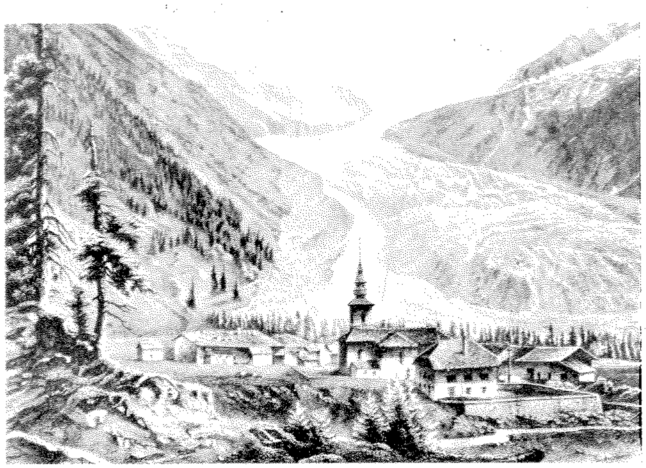
Fortunately we can put a buffer in the system, if we put aside adequate reserves. I've just written a book called *The Genesis Strategy,* pointing out that it isn't any new-fangled thinking to suggest that we have to have large margins of food safety as a buffer against fluctuations in the geophysical environment. In the book of Genesis, Joseph warns the Pharaoh of the seven fat years to be followed by seven lean years and suggests the storage of grain in the good years against the inevitability of the bad ones. Unfortunately, our Pharaoh during most of the last several years was Earl Butz, and it was very difficult to convince him of that wisdom, so that we had wildly fluctuating food prices and famines from 1972 through 1975. The Genesis strategy these days certainly is more than just saving food, and it's more than a food distribution system. It involves safety margins in a whole variety of technological and management systems that contribute to our basic survival commodities.

One more point I want to make about the ½-degree temperature change is shown in the pictures below of a glacier in the French Alps near the town of Argentière. One is a photograph taken in 1966, the other an etching made of the same scene 100 years earlier, when the hemisphere temperature was perhaps only ½ degree or so colder. A hundred years ago the glacier was right down to the plain of the town; in fact, that's probably why the town was put there. This area of the French Alps is a "marginal" environment, and I think that's the main point of almost all climatic changes. It's at the limit, where a slight change in temperature or precipitation can cause a large change of something else—in this case a glacier.

One other thing about this town—I can never resist noticing how unchanged it is, 100 years later, and I wonder how these people managed to stave off modernity. Don't you think it would look better with one of the old houses replaced by a Safeway or K-mart?

The real point here is that when we talk about fluctuations in climate we are not talking about the end of the world. I don't see that climate changes could bring an evolutionary end to the human race. I don't think they could even threaten more than 10 percent of the world's population in a direct sense; and that would be without reserves under the worst kind of fluctuations I can conceive. Does that make climatic change a crisis? Well, if you take a completely evolutionary perspective, I don't see it as a crisis at all.

I'm sure if we went back into human history, we would find many examples of famines or pestilence causing fluctuations in global population far greater than the 5 percent or so I see as possible from climatic fluctuations now. But with the world's current population, if only 1 percent were threatened (and I think that's quite realistic, even this year, if we had a major failure of the Indian monsoon), that would be 1 percent of 4 billion people or 40 million people. And 5 percent of course is 200 million. This is the level at which I see direct threats to people. We have to also ask the question whether a threat to "only" a few percent of humans by climate-induced famine can occur without leading to some other kind of desperate response that



A glacier in the French Alps near the town of Argentière—as shown in an etching made in 1866 (left) and in a photograph taken 100 years later. In 1866 the hemisphere temperature was perhaps only ½ degree or so colder.

leads to more general conflagration. Do we want, in fact, to risk that experiment (leaving aside the question of the moral compunction to prevent starvation)?

With that kind of perspective in mind we can see that climate change is certainly not going to eliminate the human race. It is not the small changes everywhere that concern me, but rather the large changes that could occur in marginal areas. Places that have just the right growing season may lose it, or those with just the minimum amount of water for agriculture might lose it. I don't see a 1-degree temperature change, for example, as being significant for most places in the world. What the 1-degree change represents would probably be a shift in the established position of major atmospheric circulation systems, so those people living at the margins of such circulation systems (like the southern end of the mid-latitude storm belt or the northern end of the Indian monsoon belt) could find that they've had a drastic change. Those people constitute the threatened 5 percent, and they could experience those radical changes. The rest would hardly notice anything —except by social, economic, or political connections to those directly affected. There would be compensation in other parts of the world also. The immediate problem is that farmers plant their crops to pre-existing expectations, and it may take them 25 years to catch up with a new climate.

Some people are talking now about warming and cooling trends. I don't know if the earth has been warming or cooling for the last seven years or so, because all we have are quick partial indications. We have millions of bits of temperature and other kinds of meteorological information, but they remain either unanalyzed or sitting on computer tapes, and there are only a handful of people around the world who analyze these things. So, ironically, we know the least about the ten years we've just lived through.

THE CASE OF THE COLORADO RIVER

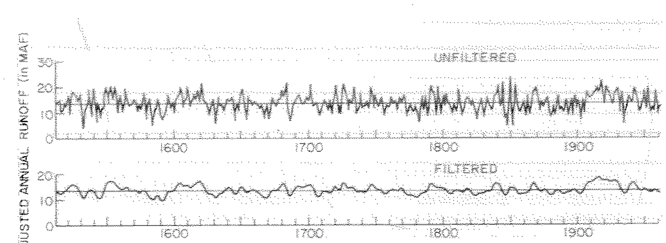
The chart at the right shows the adjusted annual runoff in MAF (millions of acre feet) for the Colorado River at Lee's Ferry in northern Arizona. The MAF measurement is a rough indication of what the Colorado River runoff is from the upper basin states—Colorado, Utah, and Wyoming.

When the Colorado River compact was drawn up in the middle 1920s, it was agreed that the upper basin states had to release half of the river's water to the lower basin states—primarily California, Arizona, and New Mexico, and to some extent Mexico. And the amount of water apportioned was based on people's concepts of "normal" flow. The runoff figures on the chart go back to the year 1500. Obviously no one was back there taking measurements, to our knowledge, so the early years are a reconstruction—by tree rings in this case, which measure climate and give a rough indication of whether it was a wet or dry year. We calibrate the long-term part by the recent record, where we know the stream flow.

Our reservoir capacity may not be capable of dealing with some of the periods, such as 1900 to 1930, which is about 25 percent above normal. Ironically, the Colorado River compact was drawn up at the end of this high-flow period, and, as a consequence, it was decided that the upper basin states should give 7½ million acre feet of water to the lower, annually. This amount was selected because 7½ million was assumed to be about half of the "normal," which recent experience (at that time) indicated was 15 million acre feet, as opposed to what we know now to be more realistically "normal"—13 million acre feet.

I said before a Senate subcommittee in March 1977 that we might want to renegotiate the Colorado River compact. (As a physical scientist I have to be careful what I say, because this is a value issue over which I have no "expert" credentials.) That's something I'm sure Californians don't want to hear. But the fact is that the Colorado had a long stretch of abnormally high runoff in the first quarter of the century, and the wrong numbers were apportioned. Nobody was evil back then; they just didn't have the right kind of records, and they apportioned a fixed *amount* of water, not a fixed *percentage,* as the upper basin states' obligation.

In the context of the next 80 years, the point is that whenever we depend upon a fluctuating physical



Adjusted annual runoff in millions of acre feet (MAF) for the Colorado River at Lee's Ferry in northern Arizona. The MAF measurement is a rough indication of what the runoff is from the upper basin states—Colorado, Utah, and Wyoming.

system, such as climate, we'd better leave large margins of safety, because the real catastrophes that are coming up in the Colorado River Basin stem from the fact that we have come to depend on every last drop of the 15 million acre feet we don't necessarily have. If we leave in large reserve capacities for extra flexibilities and we do our reservoir design for low flow, then someone will accuse us in the "good years" of wasting resources and slowing down development. Of course, the consequence of using the reserve is that we'll proceed with developments and then get the kind of shortages that lead to collapse.

Suppose, then, we are entering a 20-year period of 20-percent-below-normal rainfall, or even a 15- or 10-year period? If we let go of the remaining reservoir water and send it downstream to quell political pressure, that will be politically palatable this year, but during one of these long droughty periods we could have a very severe problem. If we don't let the water go and it turns out that next year is a good one, then we will be accused of all kinds of waste of resources, and we would have to pay for it politically at the polls. The point is that we do not know from theory whether to expect a protracted drought period or even if the long-term climate could be changing altogether, thus changing the mean runoff. Therefore, the best prudence in my opinion is to maintain, to the extent that we can, a reserve capacity based on the known frequencies and amplitudes of fluctuation. That generally means hedging, and hedging means insurance, and insurance means premiums, and premiums cost money. I think that has to be recognized as the price for hedging.

There is one more important consequence for the next 80 years, and that is that there are several ways to "cure" this water problem, and I think it applies to food also. One way is to build dams or diversion projects to increase reservoir capacity.

I'm very pleased to see that President Carter raised the red flag of question on some of those projects, and he did it in spite of some people screaming, "How could he have done it *now* when we need the water even more?" Well, many of them aren't going to bring water in tomorrow; we're talking about projects whose effectiveness is probably more than a decade away. Furthermore, there is more than one method to balance water supply and demand, and one can also talk about demand conservation as well as supply augmentation. We can reexamine where we waste water and ask whether we might be better off by curbing wasteful demand rather than building in more supply. We must recognize that building supply has some risks involving plain cost, risks that are environmental, and, in the case of dams, risk of safety.

A dam may well be the least safe of any energy alternative, unless we don't let people live in the flood plains. That's another issue of development, and the consequence for the next 20 years of this sort of issue is: If we are going to ultimately decide that we still need to augment the supply in order to provide a Genesis strategy—a reserve capacity—then we have to make sure that the price we're paying for the additional supply does exactly that.

This may mean that we will have to have some sort of statutory requirement that says a project built ostensibly for reserve capacity must be kept for reserve capacity. This involves things such as national land-use planning. There may even be constitutional questions in that kind of development-related growth situation.

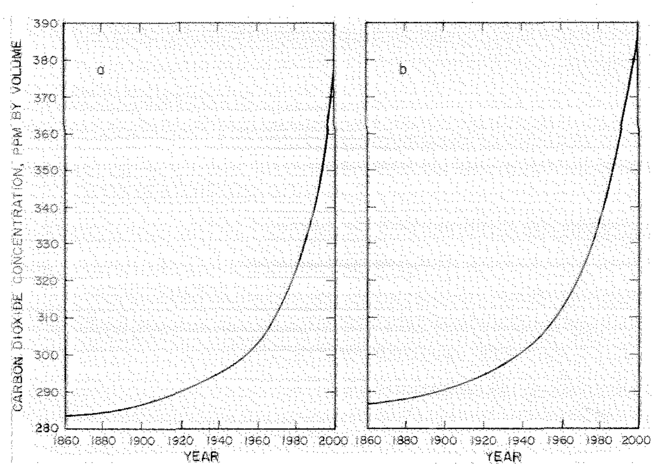
Moreover, there's an implication for energy in these reservoirs as such. That is, if we are going to turn to oil shales and coal in the West, which call for a stable supply of water, then we must ask: Where is it going to come from? After all, we are even now having trouble providing enough water for present users. The water issue has to be looked at very carefully, not only in the western United States, but in many other places in the world.

THE CO_2 PROBLEM

A word more about the carbon dioxide problem. We know that CO_2 is emitted from the burning of fossil fuels, and we have pretty good records of how much that is. We know that carbon dioxide interferes with the transfer of terrestrial (or infrared) radiation much more actively than it interferes with solar energy. That's the "greenhouse effect." In other words, if we increase the carbon dioxide content of the atmosphere, we're still letting much of the sunlight in, but we're trapping much of the outgoing infrared heat. The analogy to the glass in a greenhouse is inexact, but we believe that CO_2 increases in the atmosphere will lead to warming. How much? First, we have to ask how much CO_2 we'll have.

Based on 20 years of measurements we know that the carbon dioxide has been increasing roughly so that half the amount of CO_2 released to the air from burning fossil fuel can be accounted for as an increase in CO_2 concentration in the atmosphere, and the other half must, thus, be going somewhere else. The major "somewheres" that people have postulated are either into the oceans or the biosphere, and this has led to a grand debate. A number of biologists, most notably George Woodwell from Woods Hole, have argued that the biosphere can't be expanding; if anything, it's shrinking. He argues that the deforestation rates in the world, particularly in tropical forests, are perhaps on the order of 1 percent per year. If that's true, since the tropical forests have about the same magnitude of CO_2 tied up in the wood as there is in the atmosphere, it means that the destruction of 1 percent of the forests should be putting just about as much CO_2 into the atmosphere each year as industrial processes. And if that's the case, we don't know where it's going because it should have been building up at a faster rate in the atmosphere, since the ocean chemists can't imagine that more than about half of the *fossil fuel* CO_2 emissions could be taken up by the oceans.

So there are still large uncertainties in these projections. However, it is interesting to look at Lester Machta's 1971 projection for CO_2 increase (left, below), which shows about a 15 percent increase, to 375 parts per million, by the year 2000 over the roughly 320 parts per million observation of CO_2 in 1970. This has been criticized as being based on little data, and thus it could be wrong. We obviously can't base a strategy of industrial development on this kind of sloppy model, it has been argued. Yet, when more data were added (right, below), his projection



Projections of atmospheric carbon dioxide concentration from fossil fuels. The 1971 estimate on the left shows 375 parts per million (ppm) by the year 2000, while the updated 1974 model on the right predicts a CO_2 concentration of almost 390 ppm—proving that not all "doomsday" predictions are overestimates.

increased from 375 to nearly 390 parts per million! Uncertainty doesn't mean one has overestimated a possible effect.

How much stock are we going to put in such a projection? Are we going to redirect our energy policy to phase out fossil fuels? Are we going to change the derivatives of industrial growth based on such a model? This is where value judgments come in, because if we turn these models over to a panel of climatologists for a decision, they'll probably say, "Oh God! All these uncertainties! We don't want society to make a mistake because of us." But whether the mistake is paying too much or too little attention to projections with large uncertainties has to be based on your own value judgments about how you view the quality of life.

I could see those judgments being very different in a country with an inelastic income from one with an elastic income. We in the United States might consider our present energy use sufficient so as not to take the chance of dealing with the CO_2 scenario coming from models like Machta's. On the other hand, a poor nation like India might consider that since energy is a major source of scarce food, then it's worth it to them to risk the CO_2 problem. I think the troublesome issue is that it may well take the physical scientists as long to provide some reasonable certainty to the political system over these climatic problems as it would take the real world to "perform the experiment" of telling us whether our present theories provide projections that are too high or low.

I'm fully convinced that we face this dilemma with CO_2, because the CO_2 effect on climate should jump up out of the climatic noise level in the next decade or two, according to our climate models, and time will tell us whether the models are right if it happens. Will that event move the grain belt three or four hundred miles north, possibly drying out parts of the high plains or the California mountains? I don't know—but it is quite possible. We think a warming might improve the monsoons if it happened, and a grain belt displaced to the north would open agriculture at the northern end. But will there be fluctuations along the way?

These are the kinds of questions we have to address, recognizing that the people who are threatened are those at the margins of the circulation systems, and those at the margins of the nutritional requirements—for whom any further stress is fatal. I think that really is the outline of the climate message. □