Global Change and Climate Change

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A tale of one city

In the early spring of 1889, we learned an important lesson—our first lesson—in what are now known to economists as'ecosystem services'. Johnstown, Pennsylvania was a prosperous, pretty town of 10,000 on the Conemaugh River. A little after three o'clock on a rainy May afternoon, 20 million tons of water, a wall 40 feet high, swept down the river and quite literally erased Johnstown from the map. In what must have been a harrowing few minutes, 2,209 people lost their lives. It is the anatomy of this disaster that gives us our grim lesson.

Fourteen miles upstream from Johnstown lay Lake Conemaugh, private lake of the South Fork Fishing and Hunting Club, whose membership included Andrew Carnegie and Henry Clay Frick. After the Civil War, much of the 657-square-mile watershed feeding the lake had been logged, removing trees that buffered the stream from rainfall. Unabated, water swelled the lake to a level that South Fork Dam could not resist; the waters of Lake Conemaugh rolled forth.

Forests were the critical element in this disaster. Trees cycle water by taking it up through the roots and spraying it out into the air through tiny holes in their leaves. Most of the rainfall in a forested watershed would move into the ground through loose forest soil and be released slowly into the drainage. Much of it would be put back into the atmosphere before it ever reached the river. When the forest was cleared, however, water flowed in sheets across the landscape, much like it flows into the storm sewers in a large parking lot, with the deadly results stated above. It was the realization that we are tied to the environment, and that our changes to it can pay us back with dire consequences, that led to the formation of the US Forest Service.

Over the next 100 years we realized that the water cycle was just one of many natural chemical cycles. One of the greatest advances in science has been to model the movements of elements and molecules—important ones like carbon, oxygen, water, and nitrogen—throughout the entire globe. This is done by dividing the world up into compartments—often enormously large compartments—and then examining the movement of the compounds among them. Take water, for example. We saw earlier that trees can modify water flow across the landscape. But there is a simpler question: why do we have fresh water? At once silly and dearly important, the answer illustrates of the power of biogeochemistry.

Water cycles between three compartments, ocean (by far the largest), the atmosphere, and land. The quantities of water that move around the globe are staggering, and the units of measurement used in biogeochemistry dwarf even those we use to talk about computers. The oceans are a reservoir of about 1.35 billion cubic kilometers (322 million cubic miles) of water. From this immense salty reservoir, about 425,000 cubic kilometers of water evaporate and are transferred to the atmosphere as fresh water each year. The atmosphere only transfers 385,000 cubic kilometers of water back to the ocean as rainfall each year, leaving 40,000 cubic kilometers extra that falls onto land. It is this relatively small portion of the total amount of water cycling from the ocean to the atmosphere and back again that gives us all of our fresh water. The subject of much scientific investigation and acrimonious political debate, global change, including the global warming, can be thought of in the same terms of pools and fluxes.

A perspective on global change

Global change? Change is the rule of the earth in nearly all areas—fauna, flora, geology, and climate. The scale varies, but change is the rule. The average temperature of the earth has been falling steadily for the past 24 million years. We know this with some certainty because little sea-creatures called foraminifera are highly selective chemical machines, discriminating very carefully between the heavy and light varieties of oxygen isotopes in water when making their shells. The discrimination depends on temperature, and when this ratio is assembled with the past positions of continents, we get a pretty clear picture of how changes in ocean currents and large episodes of mountain building combined to change the way heat circulates around the planet, and how much is trapped by the atmosphere. And this is only one example of what we know about the past. For example, about 5.5 million years ago, sea-level dropped below the level of the Straits of Gibraltar. The Mediterranean Sea, cut off from the rest of the world's oceans, dried up completely. Fluctuations in sea level over the next million years caused it to fill and dry up several times. Mind-bending changes in temperature, sea level, mass extinctions, extraterrestrial impacts, and volcanic eruptions are all inherent features of the earth.

Most of these changes, however, occur over time scales that are outside the realm of human understanding. Their magnitudes defy comprehension simply because we have nothing in our experience we can relate them to. Can you really imagine New York City under a kilometer of ice? Sea level 400 feet lower than today, making the Bahamas the single largest Caribbean island? A sprawling spruce-fir forest extending 20 miles east of Cape Hatteras? Eighteen thousand years ago, and indeed for 80 percent of the past two million years, this was the climate of the eastern U.S. There is no dispute among scientists about this. We have samples of ancient vegetation, animals, sediments, and even the ancient air itself locked up in polar ice caps to tell us about the past climate. What is causing considerable debate today is the realization that humans are changing the climate, and that we face an uncertain future because of it. From my point of view, the debate isn't so much over the scientific validity of the trends, but rather manifests our utter lack of preparation to deal with the realization that, because of our population size, standard of living, and energy consumption, we now must manage the entire globe as if it were a giant park, including the very air we breathe.

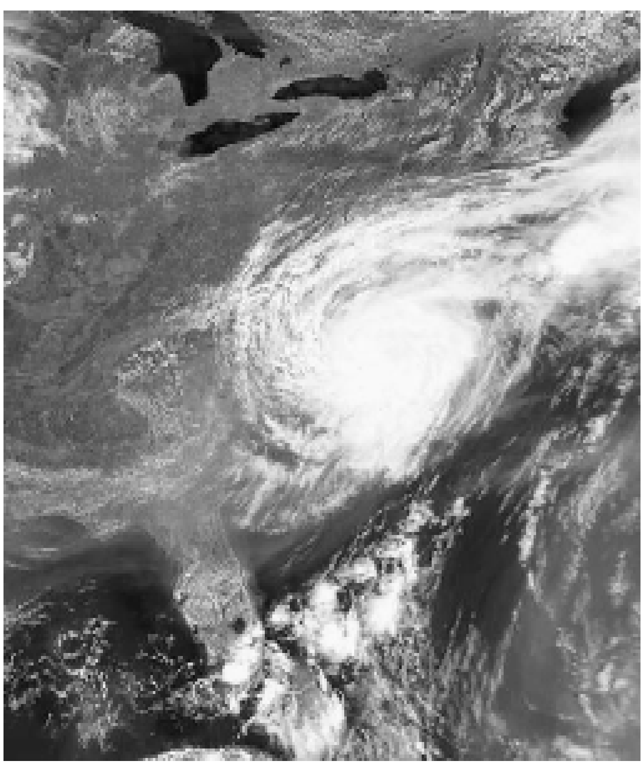
My goal in this essay is not to go over the science behind global change in excruciating detail (though we will cover the basics), but, in keeping with the theme of this book, to show how our awareness of this problem has increased due to scientific advances. The changes we've caused in our environment are portentous, and they lay on our doorstep at this the end of the millennium.

The science of global warming

Much of the emphasis on global change is on global warming, and the basic question is simple: are humans making the earth warmer? The debate, however, has been bewildering. Science seems to contradict itself at every step. What I will attempt in the next few paragraphs is show the mechanism of global warming (it is surprisingly simple to understand), the long term trend in temperature, and what is predicted to happen in the future, at least where the weight of the evidence lies. I won't leave you in suspense: humans are indeed increasing the temperature of the planet.

Mechanism: In and Out

I hope you won't be disappointed, but the entire fracas about global warming boils down to this question: are we decreasing the rate at which earth radiates heat to space? Our temperature is set by two things: the amount of energy the earth absorbs from sunlight, and the rate at which that energy is radiated back to space. We can use this idea of a balance between energy in from the sun and energy out from the earth to understand what sets the temperature at the earth's surface. If you calculated what the temperature of the earth should be using the values from a physics textbook for solar radiation and the radiative properties of a water-covered rock, its average temperature should be about negative 18ºC (-0.4ºF). The real average temperature at the surface of the earth, over the entire year and all the continents and oceans, is about 15ºC (59ºF). Why the 33ºC discrepancy? The atmosphere slows the rate at which the sun's energy is radiated back to space by absorbing it and emitting it again. This doesn't stop energy from going back to space, it just slows it down, which has the effect of raising the total amount of energy earth has at any one time. Say you had a bucket of water with a bunch of holes in the side. If you put a hose in the bucket to fill it, the water level would increase until the rate it was going out of the bucket exactly matched the rate at which it was coming in. If you made all the holes bigger, more water would run out, and the water level would drop until it reached a new equilibrium. Conversely, if you made the holes smaller—if you slowed the rate at which water could leave the bucket—the water level would rise to a new equilibrium. So it is with energy escaping the earth's atmosphere. An increase in heat trapping slows the rate at which it can be radiated back to space, raising temperatures. We now know that the earth's energy balance is in disequilibrium: glaciers have been retreating and sea ice and continental ice caps have been melting this century at unprecedented rates.



The compounds in the atmosphere that trap the energy are the infamous greenhouse gases, and principal among them are water vapor, carbon dioxide, methane, the nitrogen oxides (laughing gas and its relatives) and chlorofluorocarbons, such as freon. Of the greenhouse gasses, carbon dioxide and methane are the principal culprits in human-caused global warming because we are increasing their concentrations well above that of the natural cycles of the earth. For all its notoriety, it may be disappointing to hear that CO_2 makes up a very small percentage of the atmosphere—a mere 0.04 percent. Methane is even rarer, found about twice in every million molecules sampled. Yet, because these molecules have the property of absorbing radiation in nearly the same wavelength that the earth uses to return energy back to space, small changes in the amounts of these molecules can cause large changes in the rate at which heat is lost from the planet.

The temperature of the earth is set by the balance between the rate of energy in and energy out. While discussion often focuses on compounds that trap heat, just as important are particles in the atmosphere and surfaces of the earth that reflect solar radiation back to space in wavelengths that the greenhouse gasses don't absorb. It works just like a car in a summer parking lot—white seats reflect much more sunlight than black seats, and so stay cooler. Dark surfaces on the earth—oceans and forests—absorb heat, while light surfaces (deserts and ice) reflect it. The more of the earth's surface is ice, the more heat that gets reflected to space. Dust from arid regions, ash and sulfur compounds from volcanic eruptions, and clouds are the main atmospheric reflectors of solar radiation. Each of these decreases incoming solar radiation by reflecting it back to space. They are impartial reflectors, however, and also prevent radiation reflected from the earth's surface from returning directly to space, making their effects dependent on the albedo (or reflectance) of the surface below it. Dust warms temperatures over land because much of the sun's energy is reflected off the light surface, but cools temperatures over oceans due to their dark color and low reflectance. Volcanoes too can have mixed effects, but generally cool the earth when large amounts of ash and sulfur dioxide are injected into the upper portions of the atmosphere. It turns out that the upper atmosphere mixes with the lower atmosphere every 1.3 years, taking half of the volcanic discharge out every year. In a period of four years, only 1/20th of the material would still be aloft. Our most recent large volcanic eruption was Mt. Pinatubo in the Philippines in 1991. The 20 million tons of sulfur dioxide it ejected into the atmosphere dropped the average global temperature about 1.5 ºF over the next year, with the temperature effect remaining for three years.

Trends in earth's temperature

Global changes in temperature are the rule, not the exception. In this section, I present the recent trends in temperature, starting back a mere 60 million years ago.

The earth was considerably warmer 60 million years ago than it is today. Then, 30 million years ago, the Indian sub-continent slammed into Asia, raising the Himalayas. About the same time, South America became fully separated from Antarctica. Both of these events conspired to cause a steady decline in earth's temperature that started around 24 million years ago, and continues to today. The new Himalayas removed carbon from the biosphere in two ways, both of which dropped temperatures. The long-term balance of carbon on earth is a balance between the atmosphere (CO_2), silicate rocks (SiO_2) and carbonate rocks. Carbon dioxide in the atmosphere mixes with water to form carbonic acid—the same stuff that causes gargoyles and grave markers to erode. The acid weathers silicate rocks, forming bicarbonate ions, which flow to the ocean and are taken up by marine organisms to make their carbonate shells. These organisms die and sink to the ocean floor, where they move slowly along, forming limestone, until they are pushed under a continental plate via subduction. The intense heat and pressure causes carbonate rocks to release gaseous CO_2 and convert back to silicate rock. Much of the gas in volcanic eruptions is CO_2, returning the gas to the atmosphere and completing the cycle in a period of about 250 million years. You might remember a particularly gruesome illustration of this cycle from a decade ago. A volcano beneath a lake in the African nation of Chad burped a tremendous cloud of CO_2, which, being heavier than the other components of air, flowed down the mountainside and settled in a valley, suffocating thousands in their sleep.

The Himalayas exposed large amounts of silicates, causing bicarbonates to flow into the oceans and be deposited in continental sediments. Also, the intense erosion of the rapidly growing Himalayas buried immense amounts of organic material, further removing carbon from the biosphere. The net result was that the atmosphere lost enough of the greenhouse gas, CO_2, to force the global climate to cool.

Nearly simultaneously, South America separated from Antarctica, then a relatively temperate, lush continent. Up to this point, a warm ocean current transported equatorial heat all the way south to Antarctica, much like the modern-day Gulf Stream transports heat to northern Europe, keeping it habitable. The newly opened seaway between South America and Antarctica changed the circulation in the ocean, starting a circumpolar current that keeps warm water from transferring heat south. Robbed of its source of warmth, Antarctica began to disappear beneath ice, dropping sea levels and cooling the earth even further.

Though temperatures were dropping steadily, it wasn't until about 3 million years ago that temperatures really started to get cold. Central America and the Antilles, sliding eastward, reconnected South America and North America after 140 million years of separation. Biologically, this ended one of the most interesting natural experiments ever. South America broke away from North America and Africa while the dinosaurs still ruled the earth and mammals were small relatives of the opossum. Connected to Antarctica and Australia for millions of years, and then an island continent, South America developed a bizarre parallel series of mammals from marsupial stock—one that makes Australia's current kangaroos and koalas seem tame and relatively bland.

The event that ended what the paleontologist George Gaylord Simpson called "splendid isolation" in a book by the same name also precipitated the ice age in which we are currently living. The rise of the Isthmus of Panama divided the Pacific and Atlantic and forced warm equatorial water northwards. While this carried heat to northern Europe, it also carried moisture to the colder portions of the high latitudes, greatly increasing snowfall. Over the last three million years, this snow has formed glaciers and locked the northern part of the world under ice no less than 30 times, with five major events in the last half million years.

Glaciation: The Current Ice Age

Ice ages have been occurring from time to time in the earth's history for at least the past billion years. The mechanism of this ice formation is interesting. Glaciation occurs not when winters are unusually cold, but rather when summer temperatures are not warm enough to melt winter snow. Surprisingly, during the periods of the greatest glaciation the winter temperatures were actually warmer than they are today. Summer and winter temperatures are set by the earth's orbit around the sun. In our winter, the earth's axis tilts the northern hemisphere away from the sun; in the summer, the earth's tilt points the northern hemisphere towards the sun and the southern hemisphere away. The changes in day length cause the heat balance of different areas of the earth to change. Superimposed on this is the fact that the earth's path around the sun is not quite circular, pointing the southern hemisphere away from the sun when the earth is farthest from it. It is no wonder that the coldest recorded temperatures are from Antarctica.

The orbit is not fixed, however. On a cycle of about 100,000 years, the earth's path around the sun goes from a more elongated to a less elongated ellipse. The tilt of the earth varies between about 22 degrees and 25 degrees every 41,000 years, making the seasons less pronounced when the angle is shallow and more pronounced when the angle is large. And, though the solstices now correspond to when the earth is closest and farthest from the sun, they proceed through the months, so that in a few thousand years the earth will be closest to the sun in February, then March, finally returning to January 21 again after 23,000 years. These three processes are called the Milankovitch cycle after the Serbian astronomer who discovered it.

Just like notes struck together form a chord much richer than the original tones, the three Milankovitch cycles predict that solar radiation varies on the earth's surface in a complex pattern. When a musical chord is struck, one can use a relatively simple mathematical technique to reduce the complex chord back into the original notes and overtones that formed it. We now have many independent records of temperature change, from deep-sea samples of foraminifera to the microscopic air bubbles trapped inside the ice caps in Greenland, and all show the complex pattern of temperature changes. Using the variation in temperature like variation in sound waves that form music, scientists have extracted the"notes"from the climatic record, and the tones come out at 100,000 years, 41,000 years, and 23,000 years, precisely those that comprise the Milankovitch orbital cycle.

So why was New York City under a kilometer of ice 18,000 years ago, while summer days can be unbearably hot in Manhattan nowadays? The answer lies in the orbital cycle of the earth around the sun, forcing the climate to shift. The pattern or temperature variation over the past 2.5 million years has been glacial advances lasting 60,000-90,000 years, and interglacial periods lasting about 10,000-40,000 years. As the last ice age ended about 10,000 years, we are about a third of the way through an interglacial, assuming the pattern holds.

What this means—and it is surprising—is that we are living in the warmest part of the climate cycle that has dominated the past 2.5 million years. Civilization—agriculture, society, culture—is a product of this relatively rare interglacial warming, made possible by global patterns of rainfall and climatic stability that allowed primitive humans to remain in one place long enough to domesticate wild plants and animals.

The debate

The discovery of the glacial-interglacial cycle led to the exaggerated press reports of the 1960s that the world was headed for another ice age. What the scientists didn't know at that time is that we were creating the conditions for global warming. The issue of global warming was first raised because scientists saw a striking trend of increasing CO_2 in the atmosphere. There was not a conspiracy to find evidence for warming. Rather, ecologists and physiologists are interested in CO_2 because it is what plants use to make sugar (it is worth remembering that every bit of energy you eat is just sunlight, CO_2, and water rearranged by a plant, and perhaps processed through an animal).

A wand sticking up on the top of the Mauna Loa Observatory in Hawaii has been recording the concentration of CO_2 in the atmosphere since 1958. The results have become an icon in the discussion of global warming. What they show is an overall increasing trend for CO_2 in the atmosphere. Yearly zig-zags are due to trees in the northern hemisphere drawing down CO_2 in the summer to make leaves, and then the CO_2 increasing again in the winter as the trees respire and their lost leaves decompose: a global breathing in and out.

Scientists immediately wanted to know if this was a real long-term trend or a shorter-term anomaly. Researchers working on cores taken from the ice caps in both Greenland and Antarctica have analyzed the composition of air trapped in bubbles in the ice. What they have found is that, for the past several thousand years, CO_2 concentrations in the atmosphere have been nearly constant at 280 parts per million, or about 0.03 percent. Since the beginning of the Industrial Revolution in the mid-1800's, the CO_2 concentration of the atmosphere has been increasing. In about 100 years we have increased the CO_2 concentration of the atmosphere to its current level of 360 parts per million, and it is now increasing about 1 part per million per year. It is expected to accelerate and double by the end of the next century to around 700 parts per million. Looking back over the past 200 thousand years or so, we can see that we are changing CO_2 levels at an unprecedented rate, and they are reaching levels unknown during the last 3 million years of glacial cycles. Methane concentrations have doubled in the same period. Overall, the concentrations of greenhouse gasses are increasing about 1 percent per year.

One of the first questions asked was if the increase in CO_2 was due to human activity. Though the correlation with the onset of the Industrial Revolution and the burning of fossil fuels was tantalizing, proof came through a clever use of the carbon 14 isotope, something we are more familiar with in its use in archaeological dating. We use carbon 14 in dating because it is formed at a constant rate in the atmosphere and decays relatively rapidly at an absolutely constant rate. That means that when an organism dies, we can look at the ratio of carbon 14 to the more common carbon 12 in its tissues and compare that to the ratio found in a living organism. The change tells us how much of the carbon 14 has decayed, and, because of the constant decay rate, how much time has passed since new carbon 14 was incorporated into the organism from the atmosphere. What scientists realized is that, because the carbon in fossil fuels is millions of years old, all of the carbon 14 has decayed—it is nearly pure carbon 12. When fossil fuels are burned, it puts CO_2 in the atmosphere containing only carbon 12, diluting the atmospheric carbon 14 to carbon 12 ratio. Just as tea weakens in the summer when the ratio of tea to water changes as the ice cubes melt, scientists detected the dilution of carbon 14 CO_2 and conclusively proved it came from humans burning fossil fuels. Similarly, increases in the other greenhouse gasses have been traced to human sources.

Effects on Global Temperature

Over the past 160,000 years, temperature and atmospheric CO_2 concentrations have been closely correlated. There is a dynamic interplay between temperature and CO_2—increased CO_2 can cause an increase in temperature, but also increases in temperature can change the concentration of CO_2. Recent studies have shown that the increased CO_2 does drive warming, however. Given this fact, scientists have set about modeling the effects of increased CO_2 on global temperature and climate. While any kinds of predictions are subject to uncertainty, and uncertainty is subject to debate, numerous research programs have come to the conclusion that human beings are increasing the temperature of the planet through human-caused increases in greenhouse gas concentrations. Data from many sources—climate records, tree rings, ice cores, weather stations—all show the same thing: the average temperature of the earth has increased, by about 1 degree Celsius, over the past century. This doesn't seem like much, but remember this is an average. The temperature was only a few degrees higher 3.5 million years ago when relatively balmy conditions stretched from the equator to the arctic circle, or even a little further back when crocodiles were found near what is now the province of seals, polar bears, and Eskimos in northern Canada. Other records show that the 1990s were the warmest decade in the past 1,200 years, and that deviations from the long-term climate average were most extreme in this decade. Still, if you have a natural skepticism of science, put your faith in true climate experts, ones that rely on accurate climatic predictions for their very persistence. I am talking, of course, about plants, birds, and frogs, all of whom have shifted their breeding or flowering about a week earlier in the spring in response to warming temperatures.

At this point you may be wondering why there is so much controversy about global warming. The mechanisms are plausible, easy to understand, and the evidence it is happening is strong. There are two reasons. First, although the basic scientific principles of global warming are easy to understand, there are many devils in the details. The earth is a linked system with feedbacks that make interpretations of data and determinations of causality difficult. Never mind predictions—carbon is locked up in living trees, wood products, paper, etc. It is also found in great quantities in the ocean, dissolving into the great mass of water when atmospheric concentrations increase just like increased CO_2 puts the fizz in soda pop. It is also taken up in great quantities by tiny, planktonic marine plants. Increasing global temperatures increase water vapor in the atmosphere, which makes more clouds, which in turn both reflect sunlight back to space (from above), but also prevent heat from being radiated to space from below. And, in turn, the effects of clouds change with the type of surface below them, depending on how much heat is being radiated from them. Atmospheric aerosols like sulfur dioxide, dust, etc., also have these combined effects and must be taken into account. As if those weren't enough difficulties, the sun itself varies in brightness, and that affects the amount of energy the earth receives which, in turn, causes earth's temperature to vary. Scientists have worked to understand these factors and parse out their effects. The conclusion? Human activities are significantly warming the earth.

The Future

The critical question in global warming is what will be the impact? Few people mind their daffodils coming up a week earlier in the spring, but wholesale coastal flooding, increased storm intensities, and killer heat waves would be more worrisome. Predictions of future climate simplify the earth by taking the surface of the globe and breaking it up into a grid. Then, at each grid-cell, they take the column of atmosphere and break it vertically into compartments. Finally, all the feedbacks and reactions are modeled at every compartment at every point on the globe, taking into account the actions of all the neighboring compartments. The result resembles a giant Rubik's Cube covering the surface of the earth, but even more difficult to solve. Only recently have we had the computing power and understanding of global mechanisms to make accurate general circulation models. The result? When projected into the future, the model predicts the earth will warm somewhere between 1.5 and 3.5 ºC over the next century.

The impacts of global warming

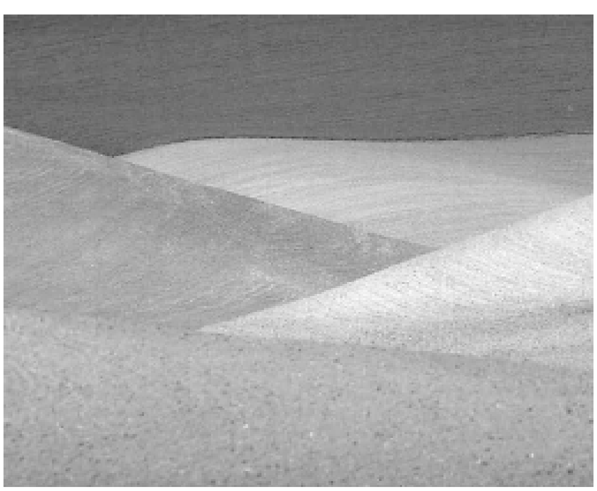
The second area of controversy is the impact of global warming and climate change. So what if the earth warms a few degrees? You hear some people saying that it will make more of the earth better for agriculture. Unfortunately, it is not that simple. Increased temperatures will cause the soil moisture level in the soil to drop over much of the U.S., changing patterns of crop production and natural vegetation, and making current water shortages even more severe. Increasing temperature 1-4 ºC will also increase the amount of water that evaporates off the oceans and land, in turn increasing the amount of water vapor in the atmosphere. Water vapor is the main carrier of energy in the atmosphere, and more, warmer water vapor means more violent storms. Already there is a significant increase in the number of heavy rainfalls that we see during a year. The total rainfall hasn't increased, but rather the precipitation is coming in fewer, stronger storms. The infamous El Niño/La Niña phenomenon is another example of a climate system that is thought to be influenced by global warming. The phenomena are changes in the temperature of the surface waters of the tropical Pacific, warmer than average during El Niño, cooler during La Niña. The reason it affects weather is that it influences the amount of water vapor and energy in the atmosphere above the water, and these effects cascade around the globe. In the Southeast, we experience wetter than normal winters, and drier summers, during El Niño events. South America bears the brunt of the change in weather, with coastal deserts experiencing devastating flooding.

Sea level has risen about 5 inches in the last century. This is due both to increases in glacial melting and the fact that water expands when it is heated, just like the mercury in a thermometer. This thermal expansion is a significant source of sea level rise, and when combined with the additional water contributed by melting glaciers, is predicted to raise the level of the oceans another one to three feet over the next 100 years. Even if temperature stopped increasing at the end of the twenty-first century, the oceans will continue to absorb heat from the atmosphere and sea level will rise for the next 400 years. Anyone who is familiar with the coast knows the devastation that a three-foot increase in sea level will cause. I am not by nature a doomsayer, but one fact bothers me in particular. The last time the earth was 3.5 ºC warmer (3.5 million years ago), sea level was about 70 feet higher. Three-quarters of the world's population lives within 70 feet of sea level. The consequences of a large rise in sea level would be unthinkable. I hasten to add that this is not a near-future prediction, but it has happened before.

It will also be hotter. Summers that are currently only barely tolerable will become even less so. And this will have particularly bad consequences for older people. The 1995 heatwave in Chicago killed 830 people, mainly elderly, not because the daytime temperatures were so high, but rather because it did not get cool at night. Unfortunately, most of the temperature increases predicted by global warming, and those that have occurred to date, have been at night. This makes perfect sense when you think of the mechanisms of global warming: increasing the concentrations of greenhouse gasses slows the rate at which heat is lost from the earth. This happens mainly at night when the ground, warmed by the sun during the day, radiates heat to the cold night sky.

Stopping global warming

Global temperatures will rise. Even drastic cuts in the current rate of CO_2 emission will still result in a much higher level of CO_2 in the atmosphere, raising temperatures. Reducing CO_2 emissions to 1990 levels by early next century is required to level off global warming by 2100. If we do not reduce emissions, the temperature will continue to increase, and the consequences will be considerably worse. An example that hits close to home: with a four-fold increase in CO_2 levels, the Southeastern U.S. is expected to be 15-20 ºF warmer on average.



Global warming is a relatively new area of scientific investigation, and like any new field, it is progressing through series of experiments and analyses, each set suggesting new directions and inviting new hypotheses and interpretations. Some of the points that pseudo-scientists have seized upon are valid and scientifically interesting twists in our understanding of the global climate and how it is determined.

Dramatically, though we take the rising and the setting of the sun as a constant, the light that comes from it is not. Sunlight varies in intensity over many different time scales. Indeed, when dinosaurs roamed the earth, the sun was brighter, and has been decreasing in intensity ever since. On shorter time scales, the sun's energy output varies. One of the most familiar examples is the 11-year sunspot cycle that plays havoc with radio and satellite transmissions. Currently, the sun is increasing its energy output and, consequently, the earth is warming. It is not, however, the cause of all the warming. Human-caused warming exceeds the warming from the sun. Another interesting fact is that the most abundant greenhouse gas in the atmosphere is not CO_2, but rather water vapor. This has been seized upon as the trump card of the global warming debate by those who oppose significant CO_2 reduction measures. The assertion of several global warming opponents is that even if all the CO_2 in the atmosphere were removed, the greenhouse effect would be 98 percent as strong as it is currently. Unfortunately, though abundant, water vapor is responding to temperature and CO_2 in the atmosphere, not driving it. Removing all the CO_2 and other trace greenhouse gasses and keeping water vapor fixed would decrease the temperature of the earth from 5-10 ºC. Removing $CO_2$and other greenhouse gasses and letting water vapor respond would nearly eliminate the greenhouse effect, making the earth unhabitable. The key thing to remember in the global warming debate—indeed, in any argument—is the central issue. Sidelights might incite more controversy and thus be more interesting to argue, but the central issues are what impact our lives in the long term. In the case of global warming, humans are altering the carbon cycle of the earth by increasing the amount of CO_2 and other greenhouse gasses in the atmosphere, primarily through the use of fossil fuels. Increasing the heat-trapping capacity of the atmosphere changes the input-output ratio of energy, and has caused the earth to warm. Finally, these increases in temperature have consequences for long-term weather patterns, or climate, that are less predictable, but worrisome.

Global warming is the least immediate issue in global change

Climate change is only a small component of the larger issue of global change. And, of the many facets of global change, climate change, though most talked about, is among the least urgent, most easily reversible, and least well known. That is, when we look at all the factors that will affect our lives, and the factors that will change the

planet forever, global warming is down near the bottom of the list. To change the factors influencing global warming, all we need is the will to change our patterns of energy production and consumption—nothing more. If we radically reduce the emissions of greenhouse gasses, over time, the climate will stabilize.

The critical and unappreciated fact is that humans are having other effects on our globe that are much more important, urgent, and permanent. What's more, these other aspects of human-induced global change are really beyond any serious scientific dispute. Even scientists—curmudgeonly people who must be right at least 19 times out of 20—agree on them. There are no rough edges for pseudo-science to seize upon. And I would say this is why you rarely hear about issues like habitat fragmentation, land cover change, and changes in other global biogeochemical cycles. There is little controversy.

Humans now directly use, or have substantially altered through their use, between one-third and one-half of the ice-free land surface of the world. And, of all the earth's terrestrial productivity—the amount of new vegetable matter growing every year—humans directly use 4 percent, 27 percent takes place in wholly human-dominated systems, and 12 percent is lost due to human activities. We have come to control a little over 40 percent of the earth's productive capacity on land. The other 3 million-30 million species that share the earth with us must now get along with us, or get along on the rapidly declining habitat left over. From what we know about extinctions in places like Trinidad, which was once a part of South America before becoming isolated, species diversity declines predictably with decreasing area. The same number of species simply can't be maintained as the area of habitat decreases. At our current rate of habitat destruction, the species loss we are incurring now will show up in the fossil record as drastic as the one that killed off the dinosaurs.

Humans have also taken over the nitrogen cycle of the earth. Just like water moves from ocean to atmosphere and back again, the nitrogen that we use—and it is in every cell in every living creature—cycles between the atmosphere and plants. Though nitrogen is the most abundant element in the atmosphere, it must be made biologically available by microorganisms that live in the soil and certain plants. That is why, though incredibly abundant, you add nitrogen fertilizer to your houseplants and garden. Indeed, nitrogen has been limiting plant growth in most places for the entire history of the earth—until now. Since the 1960s, we have been making enormous quantities of nitrogen fertilizer—so much that humans now make more biologically available nitrogen than all the natural processes on the planet combined. On the face of it, fertilizing the entire planet sounds good. Unfortunately, some plants do better than others when nitrogen levels increase, driving others to exclusion. Also, agricultural pests can increase on the more nutritious, nitrogen-rich tissue. The fact is, we have no idea what will come of the experiment we have embarked upon.

My goal in this essay was not to make the reader feel bad, but simply to point out that, controversy-loving media reports to the side, humans are changing the earth and it does have measurable impacts. Some we understand well, some we don't. What we now must face is not the decision about whether they are actually occurring, but rather what to do about them. It is puzzling to see the great hullabaloo caused by the realization that, every once in a great while, an asteroid impacts the earth with serious consequences. News reports, television specials, and even movies reflect our preoccupation with it. Yet, we have potentially strung our own sword of Damocles in terms of global change and sit content in our seats below it. We argue about climate change from the point of view of short-term economic gains. If tree with a large limb were hanging over one of our children's rooms, we wouldn't hesitate to remove it. Trees are strong, and the limb probably wouldn't fall, but the consequences aren't worth the risk.

Postscript: unnatural disasters

The great hurricane of 1846 that drowned 6,000 people in Galveston, Texas, was a natural disaster, the Johnstown flood was not. Nor were the recent floods of the Mississippi and Missouri rivers in 1993 or the devastating floods of the Yangtze in China that killed thousands. More subtly, we know that human-caused global warming is happening. The data are very reliable. One of the biggest effects of global warming is the amount of energy that we are putting into the atmosphere, which means that storms of the future will be more frequent, and more violent, leading us to question whether the next great hurricane will really be a natural disaster. At the close of the millennium, we are the first generation in history to have the technology to understand the full scope of how we are changing the world. We need to decide what we are going to do about it.

Suggested Websites

http://www.giss.nasa.gov/edu/gwdebate/
http://gcrio.org:80/gwcc/toc.html
http://www.ngdc.noaa.gov/paleo/primer_history.html
http://www.whitehouse.gov/Initiatives/Climate/content.html