Chapter One

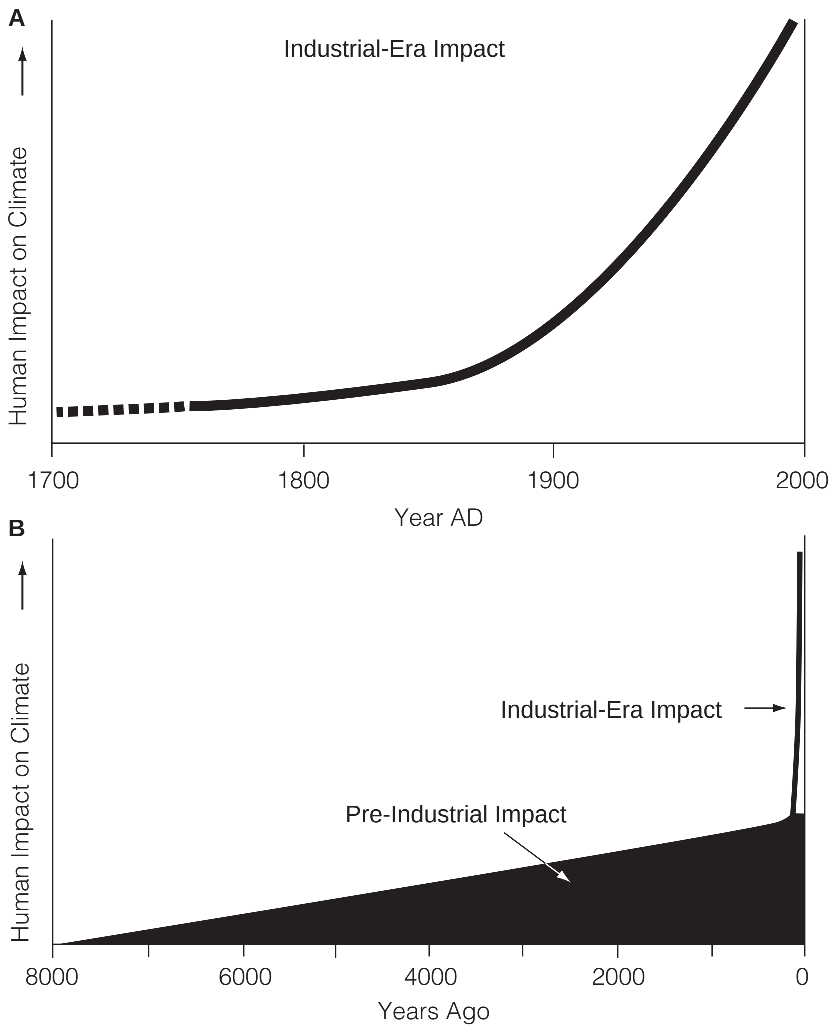
CLIMATE AND HUMAN HISTORY

Most scientists accept the view that human effects on global climate began during the 1800s and have grown steadily since that time. The evidence supporting this view looks quite solid: two greenhouse gases (carbon dioxide, or CO_2, and methane, or CH_4) that are produced both in nature and by humans began unusual rises like the pattern shown in figure 1.1A. Both the rate of change and the high levels attained in the last 100 to 200 years exceed anything observed in the earlier record of changes from ancient air bubbles preserved in ice cores. Because greenhouse gases cause Earth's climate to warm, these abrupt increases must have produced a warming.

But one aspect of the evidence shown in figure 1.1A is deceptive. Magicians use a form of misdirection in which flashy movements with one hand are used to divert attention from the other hand, the one slowly performing the magic trick. In a sense, the dramatic change since 1850 is exactly this kind of misdirection. It distracts attention from an important rise in gas concentrations that was occurring during the centuries before the 1800s. This more subtle change, happening at a much slower rate but extending very far back in time, turns out to be comparably important in the story of humanity's effects on climate.

I propose that the real story is more like the one shown in figure 1.1B. Slower but steadily accumulating changes had been underway for thousands of years, and the total effect of these earlier changes nearly matched the explosive industrial-era increases of the last century or two. Think of this as like the fable of the tortoise and hare: the hare ran very fast but started so late that it had trouble catching the tortoise. The tortoise moved at a slow crawl but had started early enough to cover a lot of ground.

The tortoise in this analogy is agriculture. Carbon dioxide concentrations began their slow rise 8,000 years ago when humans began to cut and burn forests in China, India, and Europe to make clearings for croplands and pastures. Methane concentrations began a similar rise 5,000 years ago when humans began to irrigate for rice farming and tend livestock in unprecedented numbers. Both of these changes started at negligible levels, but their impact grew steadily, and they had a significant and growing impact on Earth's climate throughout the long interval within which civilizations arose and spread across the globe.



1.1. Two views of the history of human impacts on Earth's climate and environment. A: Major impacts began during the industrial era (the last 200 years). B: The changes of the industrial era were preceded by a much longer interval of slower, but comparably important, impacts.

For most people (including many scientists), the natural first reaction to this claim of a very early human impact on climate is disbelief. How could so few people with such primitive technologies have altered Earth's climate so long ago? How do we know that the "tortoise" version shown in figure 1.1B is correct? Convergent evidence from two areas of scientific research in which major revolutions of knowledge have occurred in the last half century—climatic history and early human history—provides the answer to these questions and the demonstration of an early human impact on climate.

When I started my graduate student career in the field of climate science almost 40 years ago, it really was not a "field" as such. Scattered around the universities and laboratories of the world were people studying pollen grains, shells of marine plankton, records of ocean temperature and salinity, the flow of ice sheets, and many other parts of the climate system, both in their modern form and in their past manifestations as suggested by evidence from the geologic record. A half-century before, only a few dozen people were doing this kind of work, mostly university-based or self-taught "gentleman" geologists and geographers in Western Europe and the eastern United States. Now and then, someone would organize a conference to bring together 100 or so colleagues and compare new findings across different disciplines.

Today, this field has changed beyond recognition. Thousands of researchers across the world explore many aspects of the climate system, using aircraft, ships, satellites, innovative chemical and biological techniques, and high-powered computers. Geologists measure a huge range of processes on land and in the ocean. Geochemists trace the movement of materials and measure rates of change in the climate system. Meteorologists use numerical models to simulate the circulation of the atmosphere and its interaction with the ocean. Glaciologists analyze how ice sheets flow. Ecologists and biological oceanographers investigate the roles of vegetation on land and plankton in the ocean. Climatologists track trends in climate over recent decades. Hundreds of groups with shorthand acronyms for their longer names hold meetings every year on one or another aspect of climate. I am certain there are now more groups with acronyms in the field of climate science than there were people when I began.

Studies of Earth's climatic history utilize any material that contains a record of past climate: deep-ocean cores collected from sea-going research vessels, ice cores drilled by fossil-fuel machine power in the Antarctic or Greenland ice sheets or by hand or solar power in mountain glaciers; soft-sediment cores hand-driven into lake muds; hand-augered drills that extract thin wood cores from trees; coral samples drilled from tropical reefs. The intervals investigated vary from the geological past many tens of millions of years ago to the recent historical past and changes occurring today.

These wide-ranging investigations have, over the last half-century or so, produced enormous progress in understanding climate change on every scale. For intervals lying in the much more distant past, tens or hundreds of millions of years ago, changes in global temperature, regional precipitation, and the size of Earth's ice sheets have been linked to plate-tectonic reorganizations of Earth's surface such as movements of continents, uplift and erosion of mountains and plateaus, and opening and closing of isthmus connections between continents. Over somewhat shorter intervals, cyclic changes in temperature, precipitation, and ice sheets over tens of thousands of years have been linked to subtle changes in Earth's orbit around the Sun, such as the tilt of its axis and the shape of the orbit. At still finer resolution, changes in climate over centuries or decades have been tied to large volcanic explosions and small changes in the strength of the Sun.

Some scientists regard the results of this ongoing study of climate history as the most recent of four great revolutions in earth science, although advances in understanding climate have come about gradually, as in most of the earlier revolutions. In the 1700s James Hutton concluded that Earth is an ancient planet with a long history of gradually accumulated changes produced mainly by processes working at very slow rates. Only after a century or more did Hutton's concept of an ancient planet displace the careful calculations of an archbishop in England who had added up the life spans of the patriarchs in the Bible and calculated that Earth was formed on October 26 in 4004 B.C. Today chemistry, physics, biology, and astronomy have all provided critical evidence in support of the geology-based conclusion that our Earth is very old indeed, in fact several *billions* of years old.

In 1859 Charles Darwin published his theory of natural selection, based in part on earlier work showing that organisms have appeared and disappeared in an ever-changing but well-identified sequence throughout the immense interval of time for which we have the best fossil record (about 600 million years). Darwin proposed that new species evolve as a result of slow natural selection for attributes that promote reproduction and survival. Although widely accepted in its basic outline, Darwin's theory is still being challenged and enlarged by new insights. For example, only recently has it become clear that very rare collisions of giant meteorites with Earth's surface also play a role in evolution by causing massive extinctions of most living organisms every few hundred million years or so. Each of these catastrophes opens up a wide range of environmental niches into which the surviving species can evolve with little or no competition from other organisms (for a while).

The third great revolution, the one that eventually led to the theory of plate tectonics, began in 1912 when Alfred Wegener proposed the concept of continental drift. Although this idea attracted attention, it was widely rejected in North America and parts of Europe for over 50 years. Finally, in the late 1960s, several groups of scientists realized that marine geophysical data that had been collected for decades showed that a dozen or so chunks of Earth's crust and outer mantle, called "plates," must have been slowly moving across Earth's surface for at least the last 100 million years. Within 3 or 4 years, the power of the plate tectonic theory to explain this wide range of data had convinced all but the usual handful of reflex contrarians that the theory was basically correct. This revolution in understanding is not finished; the mechanisms that drive the motions of the plates remain unclear.

As with the three earlier revolutions, the one in climate science has come on slowly and in fact is still under way. Its oldest roots lie in field studies dating from the late 1700s and explanatory hypotheses dating from the late 1800s and early 1900s. Major advances in this field began in the late 1900s, continue today, and seem destined to go on for decades.

Research into the history of humans is not nearly as large a field as climate science, but it attracts a nearly comparable amount of public interest. This field, too, has expanded far beyond its intellectual boundaries of a half-century ago. At that time, the fossil record of our distant precursors was still extremely meager. Humans and our precursors have always lived near sources of water, and watery soils contain acids that dissolve most of the bones overlooked by scavenging animals. The chance of preservation of useful remains of our few ancestors living millions of years ago is tiny. When those opposed to the initial Darwinian hypothesis of an evolutionary descent from apes to humans cited "missing links" as a counterargument, their criticisms were at times difficult to refute. The gaps in the known record were indeed immense. Now the missing links in the record of human evolution are at most missing minilinks. Gaps that were as much as a million years in length are generally now less than one-tenth that long, filled in by a relatively small number of anthropologists and their assistants doggedly exploring outcrops in Africa and occasionally stumbling upon fossil skeletal remains.

Suppose that skeletal remains are found in ancient lake sediments sandwiched between two layers of lava that have long since turned into solid rock (basalt). The basalt layers can be dated by the radioactive decay of key types of minerals enclosed within. If the dating shows that the two layers were deposited at 2.5 and 2.3 million years ago, respectively, then the creatures whose remains were found in the lake sediments sandwiched in between must have lived within that time range. With dozens of such dated skeletal remains found over the last half-century, the story of how our remote precursors changed through time has slowly come into focus.

Even though the details of the pathway from apes to modern humans still need to be worked out, the basic trend is clear, and no credible scientist that I know of has any major doubts about the general sequence. Creatures intermediate between humans and apes (australopithecines, or "southern apes") lived from 4.5 to 2.5 million years ago, around which time they gave way to beings (the genus *Homo*, for "man") that we would consider marginally human, but not fully so. Today anthropologists refer to everything that has followed since 2.5 million years ago as the hominid (or hominine) line. By 100,000 years ago, or slightly earlier, fully modern humans existed. This long passage was marked by major growth in brain size; progressively greater use of stone tools for cutting, crushing, and digging; and later by control of fire.

Knowledge of the more recent history of humans has increased even more remarkably. Decades ago the field of archeology was focused mainly on large cities and buildings and on the cultural artifacts found in the tombs of the very wealthy; today this field encompasses or interacts with disciplines such as historical ecology and environmental geology that explore past human activities across the much larger fraction of Earth's surface situated well away from urban areas. Radiocarbon dating (also based on radioactive decay) has made it possible to place even tiny organic fragments with a time framework. The development of cultivated cereals in the Near East nearly 12,000 years ago and their spread into previously forested regions of Europe from 8,000 to 5,500 years ago can be dated from trace amounts of crops found in lake sediments. On other research fronts, archeologists unearthing mud-brick and stone foundations of houses have been able to estimate population densities thousands of years ago. Others examining photos taken from the air in early morning at low sun angles find distinct patterns of field cultivation created by farmers centuries before the present. Geochemists can tell from the kind of carbon preserved in the teeth and bones of humans and other animals the mixture of plants and animals they ate. From these and other explorations, the developing pattern of human history over the last 12,000 years has come into much sharper focus.

Because both of these research fields—climatic and human history—concentrate on the past, they have much in common with the field of crime solving. Imagine that a breaking and entering and a murder have been committed. The detectives arrive and examine the crime scene, searching for evidence that will point to the guilty person. How and when did the criminal enter the house? Was anything stolen? Were muddy footprints or fibers or other evidence left behind? Based on all the evidence, and the modus operandi of the possible perpetrators, the detectives gradually zero in on the identity of the criminal. Was the crime the work of a family member, an outsider who knew the family, or a complete stranger? A list of possible suspects emerges, the detectives check out where they were at the time of the murder, and a primary suspect is identified.

By analogy, students of climate and human history also arrive on the scene after the event has occurred, but in this case hundreds, thousands, or even many millions of years later. And, as in the crime scene, the first thing these scientists encounter is evidence that something of importance has happened. Twenty thousand years ago, an ice sheet more than a mile high covered the area of the present-day city of Toronto. Ten thousand years ago, grasslands with streams and abundant wildlife existed in regions now covered by blowing sand in the southern Sahara Desert.

Natural curiosity drives scientists to wonder how such striking changes could have happened, and for some scientists this process of wondering leads to hypotheses that are first attempts at explanations. Soon after a major discovery is made, other scientists challenge the initial hypothesis or propose competing explanations. Over many years and even decades, these ideas are evaluated and tested by a large community of scientists. Some of the hypotheses are found to be inadequate or simply wrong, most often because additional evidence turns out to be inconsistent with specific predictions made in the initial hypotheses. If any hypothesis survives years of challenges and can explain a large amount of old and new evidence, it may become recognized as a theory. Some theories become so familiar that they are invoked almost without conscious thought and called paradigms. But even the great paradigms are not immune from continual testing. Science takes nothing for granted and draws no protective shield around even its time-honored "successes."

Only rarely do scientists studying climate history manage to isolate one causal explanation for any specific piece of evidence. By analogy to a crime scene, the detectives might be lucky enough to find totally diagnostic and incriminating evidence near the murder victim or at the point of the break-in, such as high-quality fingerprints or blood samples with DNA that match evidence from a suspect. If so, the perpetrator of the crime is convicted (unless the prosecutors are totally incompetent). In climate science, the explanation for an observation (the presence of ice sheets where none exist today, or of ancient streambeds in modern-day deserts) more commonly ends up with several contributing factors in plausible contention.

But sometimes nature can be more cooperative in revealing cause-and-effect connections. The changes in Earth's orbit mentioned earlier occur at regular cycles of tens of thousands of years. These same cycles have occurred during many of Earth's major climatic responses, including changes in the size of its ice sheets and in the intensity of its tropical monsoons. Because "cycles" are by definition regular in both length (duration in time) and size (amplitude), they are inherently predictable. This gives climate scientists like me a major opportunity. We can look at past records of climate and see where and when the natural cycles were behaving "normally," but if we then find a trend developing that doesn't fit into the long-term "rules" set by the natural system, we are justified in concluding that the explanation for this departure from the norm cannot be natural.

Several years ago, just before I retired from university life, I noticed something that didn't seem to fit into what I knew about the climate system. What bothered me was this: the amount of methane in the atmosphere began going up around 5,000 years ago, even though everything I had learned about the natural cycles told me it should have kept going down. It has occurred to me since then that this was like an early scene in every episode of Peter Falk's *Columbo* television series when he has just begun to investigate a recently committed crime. After he finishes an initial talk with the person whom he will eventually accuse of the crime, he starts to leave. Halfway out of the room, he stops, turns back, scratches his head, and says: "There's just this *one* thing that's bothering me . . . ." That's how it all started, with just this one thing that bothered me—a trend that went up instead of down.

During the rest of the every *Columbo* show, Falk gradually pieces the story together and figures out what really happened. And that's how this new hypothesis came about. Having noticed the mystery of the wrong-way methane trend, I wondered what might explain it and eventually found an answer in the literature of early human history that convinced me. Just about the time the methane trend began its anomalous rise, humans began to irrigate for rice in Southeast Asia. I concluded that the irrigation created unnatural wetlands that emitted methane and explained the anomaly.

That first "Columbo moment" and the subsequent investigation has been followed by other, similar mysteries: the cause of a similarly anomalous rise in atmospheric CO_2 in the last 8,000 years, the reason why new ice sheets have failed to appear in northeast Canada when the natural cycles of Earth's orbit predict that they should have, and the origin of brief drops in CO_2 that again cannot be easily explained by natural processes but that appear to correlate with the greatest pandemics in human history. But before these "Columbo moments" can be explored, we need to go back in time to see where humans came from, and to find out how and why climate has changed during our time on Earth.