Chapter 1: Introduction to Global Climate Change

“Everybody talks about the weather, but nobody does anything about it.” This comment, attributed to Mark Twain in 1897, is no longer valid. Today human activities influence climate on both a local and global scale. Average temperatures are rising. Storms and forest fires seem to be increasing in severity (Figure 1.1). The vagaries of weather may obscure specific cause and effect relationships, but humans are definitely part of the equation.

Humans are also part of the solution. To diminish the potential damage from climate change, governments have implemented policies that range from limiting carbon emissions to reinforcing levees. As the public has become more aware about this issue, consumer behavior including vehicle purchases and recycling of materials increasingly reflects their concerns.

On contentious issues such as global climate change, a broad understanding generally contributes to the quality of debate. This book considers the factors responsible for climate change and the geophysical, biological, economic, legal, and cultural consequences of such change as well as various mitigation strategies. It highlights the complexity of decision-making using uncertain information and compares the methods that various disciplines employ to evaluate past and future conditions.

Most textbooks concentrate on a single discipline (e.g., Geophysics, Biology, or Economics) or sub-discipline (e.g., Glaciology, Plant Physiology, or Macroeconomics); they introduce the major concepts and then apply them to several examples. This book, by contrast,

Figure 1.1  Hurricane Katrina extends across the Gulf of Mexico as it approaches New Orleans on August 28, 2005. Imagery from the GOES-12 weather satellite. [http://www.nvlnoaa.gov/curseas2005/Katrina1545zD-050828-1kg12.jpg](http://www.nvlnoaa.gov/curseas2005/Katrina1545zD-050828-1kg12.jpg)
focuses on a single application—Global Climate Change—and relates concepts from a number of natural and social sciences to it. Lacking expertise over such a wide spectrum, everyone will find certain topics challenging; nonetheless, stretching to maintain flexibility becomes critical as one matures.

Articles on environmental issues frequently evoke Fear, Uncertainty, and Doubt (FUD) that further exploitation of natural resources might cause irrevocable damage. Excessive use of FUD, however, inures the public to such issues (“crying wolf”) or, worse, elicits fatalistic despair. This book will deserve the subtitle Doom & Gloom with Bloom (Figure 1.2) if it fails to present a more balanced perspective and occasionally unbridled optimism.

The present chapter recalls the last 70 years of research on global climate change. The next three chapters constitute a geophysical section that examines the past, present, and future of Earth’s climate: Chapter 2 presents historical reconstructions of temperature and a few other climatic parameters, Chapter 3 details the factors that influence climate, and Chapter 4 describes global climate models and what they predict about changes during the next century. Subsequent sections of the book introduce direct and indirect effects of climate change on organisms, mitigation strategies and the economics thereof, international cooperation and accords, and finally the interplay of culture and political action.

**Climate**

The weather page in your local newspaper includes information on the daily (a) maximum and minimum temperatures, (b) humidity, (c) precipitation, and (d) wind speed and direction. Long-term averages of these parameters define the climate in your area. For example, in Davis, California, over 80% of the rainfall occurs during the winter months (Figure 1.3) and, thus, Davis is considered to have a Mediterranean climate.

“Climate is what we expect; weather is what we get,” another statement attributed to Mark Twain. In other words, weather parameters are highly variable from day-to-day or year-to-year. Over an eleven-year period, total precipitation during the month of December
in Davis ranged from 0 to 250 mm (Figure 1.3). Consequently, predicting daily weather from climatic trends is seldom worthwhile. Moreover, subtle changes in climate over several decades are difficult to discern against a fluctuating background.

The first to discover the recent warming trend in Earth’s climate and associate it with fossil fuel emissions was Guy Stewart Callendar (1898-1964). Callendar’s father, Hugh Longbourne Callendar, was a professor of physics at the Imperial College of Science, London, who developed the platinum resistance thermometer, an instrument which permitted continuous recording of temperatures with unprecedented accuracy. Guy Stewart Callendar, although he had a career as a steam engineer for the British Electrical and Allied Industries Research Association, inherited his father’s interest in temperature measurement and, as a hobby, scrutinized weather records from around the world.

Guy Stewart Callendar grouped together data from the most reliable weather stations in a given region of the world and weighted each group according to the area represented by its stations (Callendar 1938). He calculated ten-year moving averages (the average of the values 5 years before and 5 years after a given date) to smooth out year-to-year variation (Figure 1.4). This analysis suggested that world temperatures had increased more than 0.2°C between 1890 and 1935. Based on crude measurements of carbon dioxide (CO₂) concentrations in the atmosphere and a simplistic model, Callendar proposed that rising CO₂ levels were responsible for over half of this warming.

The ideas of Callendar, an amateur encroaching on a discipline with licensed profes-
Most climatologists of the day believed that temperature data were so random that one could statistically manipulate these data to support nearly any conclusion. For example, Helmut E. Landsberg (1906-1985), perhaps the most renowned climatologist of the 20th century (Baer 1992), declared, “There is no scientific reason to believe that our climate will change radically in the next few decades, hence we can safely accept the past performance as an adequate guide for the future.” (Landsberg 1946)

The scientific establishment also doubted whether atmospheric CO₂ concentrations had changed significantly (Weart 2003). Readings of CO₂ concentrations would shift with the winds because local sources that release CO₂ such as nearby factories and sinks that absorb CO₂ such as nearby forests influenced every sample. The consensus was that nearly all the CO₂ released from fossil fuel burning would dissolve in the immense volume of Earth’s oceans, and thus atmospheric changes would be negligible.

With the dawn of the nuclear age at the end of World War II, atmospheric and oceanic scientists became preoccupied with other products of human ingenuity, namely radioactive wastes. In 1954, fallout from an American nuclear bomb test injured the crew of a Japanese fishing vessel, and later that year came the release of Gojira, the first in a long series of horror movies to feature Godzilla, a monster created by an American nuclear bomb test. Anxiety was escalating. Would radioactive carbon dioxide (^14CO₂), which was generated in the atmosphere during nuclear explosions, dissolve in the oceans and widely contaminate sea life and seafood?

Roger Revelle (1909-1991) and Hans Suess (1909-1993) of the Scripps Institution of Oceanography in San Diego, California, analyzed the exchange of ^14CO₂ between the atmosphere and the oceans. They published a seminal work in 1957 showing that only a thin, upper layer of seawater rapidly exchanged materials with the atmosphere (Revelle and Suess 1957). These results had broad implications. On the positive side, contamination of sea life from nuclear testing would be highly localized; but on the negative side, the oceans would remove only a small portion of the CO₂ being released into the atmosphere.

Technological advances by the mid-1950s had increased the precision of CO₂ measurements ten-fold. C. D. (Dave) Keeling (1928-2005) also of Scripps garnered funds from the International Geophysical Year in 1956 to establish two atmospheric CO₂ monitoring sta-
tions. To minimize the influence of local disturbances, he chose sites that were remote from industrial and biological sources of CO$_2$ and were subject to strong prevailing winds (Figure 1.5). One site was at the South Pole and the other was on the Island of Hawaii at the Mauna Loa Observatory atop the northern flank of the Mauna Loa volcano at an elevation of 3397 meters (Figures 1.6).

Monitoring at the South Pole began in September, 1957, and at Mauna Loa six months later. Concentrations of CO$_2$ at Mauna Loa, in contrast to those from the South Pole, oscillated from month to month (Figure 1.7), raising doubts about the verity of the data (Keeling 2005).

Figure 1.6A  Satellite photos of Hawaii showing the location of the Mauna Loa Observatory.

Figure 1.6B  The observatory in 1982 shown against the backdrop of the neighboring peak Mauna Kea.  
http://www.photolib.noaa.gov/corps/images/big/corp2689.jpg

Figure 1.7  Monthly average CO$_2$ concentration (parts per million; 1 ppm means that there is 1 microliter of CO$_2$ per liter of total gas) in the atmosphere at the South Pole and near the summit of Mauna Loa in Hawaii. The inset in the upper left corner shows data from the first few years on an expanded scale. Data obtained from http://www.cmdl.noaa.gov/projects/src/web/trends/co2_mm_mlo.dat
1978). Fortunately, with more observations, Keeling realized that the oscillations at Mauna Loa reflected an annual cycle of CO₂ sequestration and release by terrestrial ecosystems on nearby continents. Funding for the South Pole station ran out after about two years, during which CO₂ concentrations rose from 311 to 314 ppm (parts per million; 1 ppm = 0.0001%). The Mauna Loa station, except for when funding was suspended for three months in 1964 (Weart 2003), has provided a continuous record of atmospheric CO₂ levels that has become known as the Keeling curve (Figure 1.7).

As evidence accumulated, the scientific establishment became more receptive to the ideas of global warming and its relationship to atmospheric CO₂ levels. H. E. Landsberg, who by 1958 had become the Director of the Office of Climatology in the U. S. Weather Bureau, modified his stance,

“For nearly a half century, a general warming trend has been noted...For the moderate latitudes, 30° to 50°N in the area around the Atlantic, the natural rise can be estimated at about 2°F (1.1°C) per century (Figure 1.8)...”

“For the latest temperature change, there is an important contender as cause: atmospheric carbon dioxide. There are some interpretations of historical and current observations pointing toward a gradual increase of this atmospheric constituent...Carbon dioxide is an absorber of outgoing long-wave radiation, and hence has an influence...often referred to as the ‘greenhouse effect.’” (Landsberg 1958)

**Current State of Affairs**

Disagreements still remain about the degree to which the recent warming in global temperatures deviates from normal climatic cycles. Direct measurements of temperature have been available from weather stations around the world only since 1861. To reconstruct temperature patterns before 1861 requires the use of proxy measures, parameters strongly correlated with temperature that can be dated with accuracy. Chapter 2 on the history of Earth’s climate considers different types of proxy measures.

In 1999, Michael Mann (currently a professor at Pennsylvania State University) and co-workers reconstructed the mean annual temperatures in the Northern Hemisphere over the last 1,000 years from a variety of direct and proxy measures (Mann, Bradley, and Hughes 1999). The graph (Figure 1.9) became affectionately known as the “hockey stick” because
the “shaft” representing the first nine centuries was relatively straight, whereas the “blade” representing the current century was abruptly bent upward. They proposed (Mann, Bradley, and Hughes 1998), as did Callendar and Landsberg many decades earlier, that emissions of CO₂ and other greenhouse gases from the burning of fossil fuels were responsible for the dramatic warming trend.

Yet the political climate of the USA had changed in 2002. Fossil fuel companies assumed a larger role in governmental policies on energy, and the link between global warming and fossil fuel consumption was troubling. ExxonMobil, the largest supplier of fossil fuels, distributed over $8 million from 2000 through 2003 to organizations who promoted the message that the scientific basis for global climate change was unsound (Greenpeace 2004; McKibben, Mooney, and Gelbspan 2005). The hockey stick became even more contentious, and the U.S. Congress requested that the National Academy of Sciences of the USA, a body of prestigious scientists, verify Mann’s research.

Eight years after Mann and coworkers published their ten-page article, the committee appointed by the National Academy released a 196-page report (National Research Council 2006). This report upheld the major premise of the hockey stick: global temperatures have warmed more than 0.6°C during the last century, and such changes are without precedent during the preceding four centuries and probably much longer. In particular, the year 2006 was the hottest on record, followed in descending order by 2005, 1998, 2002, 2003, 2001, and 2004. All indications are that this warming trend will continue and perhaps even accelerate.

About 130 stations around the world now monitor atmospheric CO₂ concentrations and have affirmed the trends first found in Keeling’s data from the South Pole and Mauna Loa. Atmospheric concentrations of CO₂ have increased worldwide (Figure 1.10). Concentrations are lower in the summer when plants incorporate CO₂ into organic carbon via photosynthesis and higher in the winter when biological respiration exceeds photosynthesis and releases CO₂ from organic carbon. Seasonal variation is greater in the Northern than Southern Hemisphere because the Northern Hemisphere has substantially more land mass (Figure 3.12) and thus more terrestrial organisms that conduct rapid photosynthesis and heavy breathing.

Global temperatures and atmospheric CO₂ concentrations show a positive correlation, both in the current century (Figures 1.7 & 1.9) and during the last 650,000 years (Chapter 2). Admittedly, correlation does not necessitate causality. For example, in a parody of scientific method, Bobby Henderson—self-described as an unemployed, amateur pirate with a phys-

Figure 1.9  A graph from the publication of Mann et al. in 1999 showing the average annual temperatures (°C) of the Northern Hemisphere reconstructed from a variety of sources. The zero line corresponds to the average from 1902 to 1980. The light dotted lines surrounding the darker core represent the positive and negative uncertainty limits from a statistical test. The thick dark line represents the long-term trends after mathematical filtering (low-pass) (Mann, Bradley, and Hughes 1999).
ics degree—found a negative correlation between the number of pirates and global average temperatures (Figure 1.11) and advocates that people become pirates to stop global warming (Henderson 2006). Admittedly, this analogy seems less amusing in light of the recent rash of pirate attacks off the coast of Somalia. In another spoof, Connie M. Meskimen, a bankruptcy lawyer from Arkansas, suggested that daylight savings time exacerbates global warming by setting sunrise at an earlier hour (Figure 1.12).

Few in the scientific community have turned to piracy or turned back their clocks prematurely, but most agree that global temperatures are rising and that human emissions of CO$_2$ and other greenhouse gases are contributing to this rise. Alternative explanations for the current temperature trends conflict with a growing body of evidence. Even organizations with strong vested interests in fossil fuels have modified their message.

For instance, ExxonMobil’s “Corporate Citizenship Report” in 2005 acknowledged that “the accumulation of greenhouse gases in the Earth’s atmosphere poses risks that may prove significant for society and ecosystems. We believe that these risks justify actions now,
but the selection of actions must consider the uncertainties that remain (ExxonMobil 2005).” The report presents ExxonMobil’s view of the uncertainties, but then touts the $200 million that ExxonMobil just bequeathed to the Global Climate and Energy Project at Stanford University in California, “the largest-ever privately funded research effort in low-greenhouse-gas energy.”

Other fossil fuel companies have taken similar approaches. In June of 2006, BP (formerly British Petroleum) and Chevron announced plans to allocate $500 and $400 million, respectively, for research on biofuels. The websites of all these companies feature their efforts in developing energy resources while minimizing environmental degradation.

Tell-Tale Signs

Global warming has altered a broad range of geophysical and biological phenomena. These are the focus of several chapters in this book. Recent changes in ice cover, however, are so visually striking as to warrant a place in the first chapter.

Mount Kilimanjaro reaches 5,895 meters above sea level in equatorial Tanzania (Figure 1.12). Not only is it the highest peak in Africa, but it is the only place on the continent cov-
ered with snow year round, hence its nam e “Shining Mountain.” Satellite photographs show the mountain in February, 1993 and 2000 (Figure 1.13). A compilation of maps outlining the ice fields near the summit document the changes over the last century (Figure 1.14). Given the current rate of decline, the snows of Kilimanjaro will disappear during the next few decades (Thompson et al. 2002).

At the other end of the earth, the Arctic has experienced since 1950 an increase in average temperatures of about 2°C, more than twice that observed at lower latitudes (ACIA 2005). In response, the polar ice cap is receding around 10% per decade (Figures 1.15 & 1.16). Sometime in the not too distant future, the Arctic Ocean will have an ice-free season and realize the long-sought Northwest Passage, a sea route from the Atlantic Ocean to the Pacific Ocean through the Canadian archipelago. This may prove to be a financial windfall for Pat Broe, a Denver entrepreneur who bought the port of Churchill on Hudson Bay at

Figure 1.13  Mt. Kilimanjaro on February 17, 1993 (top) and February 21, 2000 (bottom). The images, acquired by the Landsat 5 and Landsat 7 satellites, respectively, were draped over a digital elevation model to give a better sense of the mountain’s shape. Differences in the summit’s appearance in these scenes are due in part to annual variations in snow cover. http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=10856

Figure 1.14  Outlines of the ice fields near the summit of Mt. Kilimanjaro in 1912, 1953, 1976, 1986, and 2000. The inset illustrates the near linear decrease in ice area over time (Thompson et al. 2002).
auction for $10 Canadian in 1997: an ice-free Northwest Passage could bring up to $100 million of shipping business to Churchill each year.

An appropriate ending to this introduction is the famous figure drawn by Charles Joseph Minard (Figure 1.17), a testament to climate and the fate of empires (Tufte 2001). On June 24, 1812, Napoleon invaded Russia, crossing the Niemen River with 422,000 men. Six months later after experiencing temperatures as low as –38°C, the Grande Armeé departed Russia with a mere 10,000.

Climate again played the pivotal role in the disastrous German invasion of the Soviet Union in 1941. German forces were trapped outside of Moscow during the Russian winter with inadequate shelter, clothing, fuel, and food. All in all, more than 4 million German and 8 million Soviet troops lost their lives on the Eastern Front.

Battling the elements has determined the outcome of many endeavors, and insufficient consideration of climate often has dire consequences. In 2007, both military and spy agen-
cies in the United States of America warned that anticipated changes in the world’s climate pose a serious threat to the security of nations (Mazzetti 2007). In their fourth assessment, the Intergovernmental Panel on Climate Change (IPCC), an organization established by the World Meteorological Organization and United Nations, agreed that further global warming is already unavoidable due to past human activities and an international effort is required to mitigate the impacts (Intergovernmental Panel on Climate Change 2007).

This book first outlines the causes and possible consequences of global climate change and then weighs the costs versus benefits of various strategies for addressing these consequences. Simple solutions to complex problems are always suspect, and climate change is a complex problem. This book cannot provide definitive answers to many issues, but at least readers will receive a broad context from which to draw their own conclusions.

References

Spencer Weart’s “Discovery of Global Warming” deserves special mention. It presents a fascinating account about the history of research on climate change. Dr. Weart regularly updates the version available for free on the World Wide Web (http://www.aip.org/history/climate/).


