INTRODUCTION

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Whether the weather be cold or whether the weather be hot,
We'll weather the weather whatever the weather,
Whether we like it or not.

—Anonymous

Climate is what you expect, weather is what you get.

—Mark Twain

In writing a book about climate change, it's probably a good idea to start with what we mean by *climate*. A common definition—"weather conditions prevailing over an area or over a long period"—reflects the situation of forty years ago, when climatology solely referred to a very necessary, but rather dull, study of daily temperature and rainfall statistics, and their collation into averages. This definition, however, does little justice to the expansive modern concept of a climate system that incorporates the oceans, atmosphere, biosphere, and polar regions and describes the multiple interactions between these distinct physical entities. While the weather in the atmosphere or the eddies in the ocean are quite variable and even chaotic from day to day, the average conditions in a given location are relatively stable and can be explained and understood in physically consistent ways.

Climate, then, is the average condition of all these environmental components over a period of time. The period needs to be long enough, say thirty years, to smooth out some of the variability associated with the weather day to day and year to year. However, the average condition alone is not enough to define the climate. We also need a description of the variability over the same period—the frequencies of a cold winter or strong rainstorm, or the magnitude of the seasonal cycle—which is also part of a region's climate. The climate can be thought of as all the statistics of the weather (or of the sea ice, or the ocean, or the biosphere), but not the particular sequence of events in any one season or year.

If climate is the sum of our expectations, *climate change* is an alteration in those expectations. However, climate change is not limited to alterations in the global mean temperature or rainfall. For example, global warming describes the ongoing rise in mean surface temperatures across the planet, but global climate change encompasses not only global warming but also the occurrence of drought and the shifts in ocean currents or atmospheric winds. Although climate change cannot be seen in any one particular storm, heat wave, or cold snap, it is found within the changing frequency of such events.

We take for granted the ways in which we have adapted to the current climate. After all, the climate as we know it has been relatively stable for hundreds of years. The kinds of crops that are grown, the capacity of storm drains, and the distance that we allow between a building and the shoreline all depend heavily on the expectation that patterns in rainfall, temperature, and sea level will continue as in the past. This expectation has served us well up to now. But how well will it serve us in the future?

Has the Earth's climate changed before? Yes! The planet has seen many different climate changes in the past. Some 700 million years ago, geological evidence indicates that our planet may have been completely glaciated, a condition referred to as "snowball Earth." During the extremely hot Cretaceous period 100 million years ago, dinosaurs ruled a world in which the polar regions were ice-free and heavily forested. More recently, during the last major ice age that ended only about 20,000 years ago, much of Europe and North America was covered with ice that was kilometers thick.

Why did the Earth's climate change in the past, before we humans had any measurable impact on it? Those changes were driven by slow movements of the continents that changed the ocean currents, by asteroid impacts that filled the atmosphere with smoke and dust, and by wobbles in the Earth's orbit that made the summers warmer and the winters colder. These factors (among others) led to dramatic extinctions and spurts of evolution. However, since the time agriculture was invented, animals were domesticated, and our earliest cities were built, all of human civilization has existed in the relatively stable climate of the Holocene epoch, which started around 10,000 years ago. No farmers were displaced when the now-petrified forests of Axel Heiberg Island in the high Arctic first succumbed to the ice some 50 million years ago. No human cities were drowned when sea levels rose 120 meters (400 feet) at the end of the last ice age. What makes climate change different this time is that, over hundreds of years, our modern industrial society has adapted, albeit imperfectly, to the current conditions. Our climate has influenced where we have built our cities, where we plant our crops, how we travel, what we eat, and sometimes, how we die.

Throughout our planet's 4.5 billion years of existence, Earth as a whole has been indifferent to its average temperature. Life on Earth, as it has for several billion years, will eventually adapt to any new situation. But for our particular species, with its huge investment in the status quo, that fact is probably not too comforting. The issue of climate change today is not that the current climate is somehow ideal or perfect, but that it is the one we are used to. Given enough time, we could probably adapt to almost anything. But could we adapt if the climate changed quickly? Would we have enough time?

A medical analogy is illustrative. A doctor can examine our symptoms, try to diagnose our condition, and suggest treatments if the prognosis is not favorable. The success of modern medicine shows clearly that, even when medical knowledge is not perfect, it can still be useful. This is also true for climate scientists studying the Earth—the science is imperfect, but still useful. Drawing from that analogy, we have organized this book into three parts that describe the symptoms of climate change, the diagnosis and prognosis, and suggestions for potential cures and treatments.

The symptoms of climate change can be seen on land, in the oceans, in the stratosphere, at the poles, and near the equator. They can be seen in temperatures, rainfall, winds, plant and animal behavior, and in observations at the local level as well as in images derived from satellites in orbit around the Earth. Diagnosing what the symptoms mean is a job for theorists and modelers who attempt to place these changes in a consistent physical framework. The details are not perfectly described—ambiguities will always exist. But the overall conclusions are robust: much of what is happening is clearly the result of human activity.

Since human activity is not about to cease, or even stop growing, the diagnosis that humans are impacting climate has real consequences. If we take a business-as-usual approach and change very little, those consequences are likely to be serious. Even with significant effort to reduce human impacts, we have no guarantee that dangerous interference with the climate won't occur. Given the nature of the problem and the diverse and complex sources of greenhouse gases, no one simple solution will be possible. But the set of solutions that will be most effective and efficient is still unclear.

In many ways the problem of human-induced climate change is unique: it is global, it will affect the planet for decades to centuries, and it is complex, imperfectly understood, and has the potential for truly dramatic consequences. However, human civilization may have solved one other environmental problem that shares all of these characteristics, albeit on a smaller scale: stratospheric ozone depletion. This story has both connections to, and lessons for, the climate change problem.