Preface

Human activities are transforming the global environment, and these global changes have many faces: ozone depletion, tropical deforestation, acid deposition, and increased atmospheric concentrations of gases that trap heat and may warm the global climate. For many of these troubling transformations, data and analyses are fragmentary, scientific understanding is incomplete, and long-term implications are unknown. Yet, even against a continuing background of uncertainty, it is abundantly clear that human activities—burning fossil fuels, emitting pollutants from industry, and clearing forests that are the habitats for plant and animal species, for example—now match or even surpass natural processes as agents of change in the planetary environment. Understanding the nature and possible consequences of global change is an urgent challenge to the natural sciences, social sciences, and engineering, and to the world community of nations and their citizens.

Global environmental change is interwoven with a complex web of social, economic, political, and scientific implications. Recent natural fluctuations in weather and climate, while not necessarily attributable to climate change due to human activities, nevertheless illustrate the magnitude and broad scope of environmental impacts on our intricately intertwined global economy. Widespread droughts in the early 1970s set the stage for major worldwide swings in grain prices. Persistent droughts in Africa have caused unspeakable suffering for millions of people. Damage caused as pollutants travel across national boundaries and result in acid deposition has created major political tensions in North America.

The diverse faces of global environmental change are linked both scientifically and politically. Scientifically, the ability to predict future changes in the environment requires an understanding of the physical, chemical, biological, and social processes that govern the earth, and of the interaction of these processes throughout the earth system. Politically, policy options to address these problems highlight the need for coordinated international policies relating to energy, technology, land use, and economic development.

Thus difficult policy decisions must be made on the basis of judgments between dimly perceived future risks and possible economic or other consequences that may be more immediate. While these decisions must be based on the best information that science has to offer, scientists are no better qualified than other individuals to hammer out these difficult judgments. It is important that the public also become informed and involved in making these choices and shaping the necessary policy decisions.

It was with a realization of the indispensable role of an informed public that the 1989 Forum on Global Change and Our Common Future was conceived. The forum's goal was to promote and enhance understanding and dialogue on a broad range of issues related to global environmental change and the dynamic interactions among the physical, chemical, biological, and social systems that make the earth's environment so uniquely hospitable to life. The presentations and discussions during the eventful three days of the forum provided the stimulus and the basis for this book.

The forum is but one of many activities related to these
complex issues. For example, in the fall of 1988 the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine prepared recommendations on global environmental change for then President-elect George Bush. That document, which may be found in Appendix D, is the current position of the Academies and the Institute in this area. In addition, at the request of Congress, the U.S. Environmental Protection Agency commissioned a study on policy implications of greenhouse warming by the Committee on Science, Engineering, and Public Policy of the councils of the two Academies and the Institute. The report of that panel, which is expected to be available by the end of 1990, will be the next major statement of the Academies and Institute in this area. Within this context, this book is intended as a contribution to the active global dialogue that will shape the future of our species and our planet.

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The photographic images relayed to a rapt earth-bound audience in 1969, when a human first set foot on the moon, were rapidly inscribed on the human psyche. Seen from space, our planet was breathtaking in its loveliness, startling in its solitude. The image brought home as never before that our home is, after all, a planet—small, self-contained, and in some ways perhaps, fragile.

In the ensuing 20 years, that image of the earth has become a cliché, but the ramifications of those hard-won insights persist. The earth’s land masses, oceans and atmosphere, and biological communities are increasingly seen by scientists, as well as by the public, as part of a unified system. Consequently, scientists can no longer adhere to the academic definitions of the classical scientific disciplines. Scientists are turning for help to colleagues in diverse fields, and integrating their studies as they develop a science of the earth.

As the pervasive effects of human activity on the earth system become clear, the world’s scientists face an urgent challenge: Can they apply the scientific understanding and technology that
have allowed us, for instance, to venture into space, to develop
the scientific understanding necessary to address the challenges
we face in protecting the global environment on our own planet?
To understand how human-induced changes—global warming,
depletion of the protective ozone layer, acid rain, deforestation,
and possibly other changes that have not yet been detected—affect
and are affected by the earth system, scientists are studying
the interactions among processes in the atmosphere, oceans,
and land surfaces, and the plants and animals that inhabit them.

In some ways, this new push to understand the earth is
a natural outcome of those first glimpses from the moon, two
decades back. The quest to understand how the earth works
may not match the excitement of man’s footprint on the age-old
lunar dust or the thrill of a manned trip to Mars. But what
this quest lacks in glamor it makes up in importance for
the future of the earth’s environment: In one of the broadest
scientific inquiries in human history, physical and social scientists
are drawing on every resource of technology and intellect to
advance understanding of both the natural variability of
the earth’s processes and the effects of human activities on them.

This new approach to the study of our planet is referred to
as earth system science. Its practitioners strive to understand
how the world works on a global scale by describing how its
parts and their interactions evolved, how they function today,
and how they may be expected to function in both the near
and distant future. In this light, the earth system is seen as a set
of interacting subsystems characterized by processes that vary
on spatial scales from millimeters to the circumference of the
earth, and on time scales from seconds to billions of years. It has
become ever more clear that despite wide separations in distance
or time, many processes are connected, and that a change in one
component can propagate through the entire system. A 1988
report of the Earth System Sciences Committee to the NASA
Advisory Council noted, for example, that “volcanic activity
occurs widely along intersections of the earth’s crustal plates
and is driven by mantle convection on long time scales; yet the
effects of eruptions are felt locally within hours or days and then,
Human influence is superimposed on the natural earth system processes operating over these time scales. Human civilization is characterized by modification of the environment—beginning with fire and then agriculture—but until fairly recently, we did not profoundly alter the planet as a whole. Over the past few centuries, however, the sheer expansion in the number of the earth’s human inhabitants and the growth in our technological ability to modify the landscape and exploit the earth’s bounty of minerals, water, and fossil fuel have profoundly changed the entire earth system. The extent and consequences of these changes are only beginning to be understood.

With all that is known and yet to be learned, how do we synthesize the vast body of knowledge necessary to describe the interactive system that is our earth? It is not enough to simply enumerate processes that are important. Participants in the effort to develop an earth system science have devised a schematic model of the earth system—a working hypothesis of how the parts of the system work together—atmospheric and ocean circulation and dynamics, atmospheric chemistry, terrestrial ecosystems, and the global hydrologic cycle. All of these parts of the system interface continually with human activities and with changes in natural inputs from the sun, from volcanoes, and from other natural causes.

Although processes operating on all time scales influence the earth system, for this conceptual model it is the middle time scale—decades to centuries—that is most relevant to the urgent inquiry into global environmental change. Within individual scientific disciplines, the most advanced models developed for use on this time scale focus on the physics and dynamics of the atmosphere. Models of ocean dynamics and atmospheric chemistry are fairly well developed. The least developed models are those describing terrestrial ecosystems and marine biogeochemical systems, which are difficult to predict and subtle in their nature.

Francis Bretherton, director of the Space Science and Engineering Center at the University of Wisconsin at Madison, led the committee that developed the NASA report on earth system science. He explains that schematic models of this sort offer a vehicle by which scientists of different backgrounds can share, in a useful way, the knowledge that has been acquired so laboriously by the work of the world’s scientists. Models also indicate which aspects of the earth system may be the most important ones to measure and help scientists test whether their understanding of how the system works is correct.

Although the global environmental changes discussed in this book are partly due to the by-products of technologies developed during and since the Industrial Revolution, it is our technological prowess that enables scientists to measure and observe the changes and processes under way and engineers to develop sophisticated technologies that reduce the burden on the environment. Scientists are confident that within the next two decades many answers will emerge as data are acquired, cross-referenced, and interpreted. As Bretherton cautions, however, “Our vulnerability to error is greatest not from the things that we include in the model, but from prophesies we leave out entirely.”
System Interactions: Atmosphere, Oceans, Land, and Humans

Over the past several decades, scientists' understanding of the complexities of the earth system has evolved to the point where they now recognize that the components of the system—the atmosphere, oceans, land, and water—are inextricably intertwined. A change in one part of the earth system has repercussions for other parts—often in ways that are neither obvious nor immediately apparent. It is beyond the human ken, however, to study the whole, multidimensional system at once. As the following sections attest, the effort to understand the dynamics driving change in the global environment is designed along the academic lines that essentially define classical disciplines. In fact, though, researchers are ever-aware that the various sciences of the atmosphere, ocean, land, and water are connected in countless ways. The intricacies of the earth system range from the obvious links between currents in the ocean and atmosphere, to the all-encompassing global cycles of carbon and water, to the subtle, distant effect of clearing a tract of tropical forest on the amount of carbon in the atmosphere.

While each major component of the earth system holds its mysteries, the effect of human activity on the system can be the greatest wildcard of all. For the first time, the social sciences are assuming substantial weight in the study of the earth system as researchers and policymakers struggle to discern how humankind, this relatively recent, terribly powerful feature of the earth, affects the age-old forces that also dictate our planet's future.

HUMAN INTERACTIONS

The recent furor over the changes humanity has wrought in the global environment since industrialization began invites the assumption that human alteration of the earth's landscape is a fairly recent phenomenon. In fact, many of our effects on the environment did not reach their global scale until the latter half of the twentieth century. But studies of many parts of the world suggest that as we extended our natural abilities with tools and later learned to cultivate plants, we became an effective agent of environmental change.

Ecologists Robert Peters, of the World Wildlife Fund, and Thomas Lovejoy, of the Smithsonian Institution, traced the record of human activity and its effect on terrestrial plant and animal life in several regions of the world. One of the areas they studied, the Mediterranean, provides a telling example.

 Destruction of natural habitats around the Mediterranean began at least 7000 years B.C. Excavations show that by 6000 B.C., the bones of wild animals in kitchen refuse heaps were replaced by the bones of domestic sheep. In the fifth and fourth centuries B.C., forests began to dwindle as wood was harvested for fuel and construction. Around the Mediterranean, the researchers explain, humans have disrupted natural communities for so long that "it is difficult to determine which plants are natural or introduced, or what the original vegetation was like." Throughout the region, degradation of forested areas is so extreme that even if an area is protected, original vegetation often will not regenerate. Over the centuries, forests were converted to pasture, and grazing pasture was then replaced by thorny plants over enormous areas. Animal communities, displaced as their habitat disappeared, shrank in size and diversity.

Scientists have found patterns of human-induced change in other regions. Aborigines are thought to have walked into Australia from Indonesia about 40,000 years ago, when sea level was lowered during a glacial episode. Almost immediately, Australian vegetation became dominated by the fire-resistant eucalyptus tree. In Britain, habitat destruction over the last 3,000 to 4,000 years has caused 90 percent of its forest and most of its wilderness to vanish. In North America, as in Europe, marshes were drained, rivers dammed, and prairies plowed. And in Brazil's Atlantic forest, clearing began in earnest in the seventeenth century and continues today. From an original one million square kilometers, the Atlantic forest has been cleared until now, only fragments remain—less than 7 percent in any condition and less than 1 percent undisturbed.
The message in these examples is clear: With longer human occupation and greater population density, the influence of humans on other parts of the earth system grows. Now we know that human activities have become so pervasive that the effects are no longer local but are regional and even global in scale. Forest clearing is eliminating habitats where millions of species reside, acid rain is affecting lakes and streams in North America and Europe, and pollutants are changing the makeup of the atmosphere in ways that can affect climate and the protective ozone layer.

This awareness that humanity is an intrinsic part of the earth system is causing a fundamental shift in the way science is pursued. No longer is it sufficient to explore only the physical dynamics of the earth system. This effort, daunting in itself, may be dwarfed by the effort to decipher the confounding behavior of Homo sapiens, the planet's most powerful inhabitant. Thus, as physical scientists join together to study, model, and predict changes on the earth's surface and in its atmosphere, their traditional focus on the physical and biological aspects of change is shifting to include the social sciences. For the first time, scientists from disciplines ranging from geochemistry to ecology are realizing that human action is the critical element in their studies. So potent is the human impact on the earth system that knowledge of physical processes ruling terrestrial or atmospheric change will be incomplete until scientists better understand the human dimensions of that change.

While studies in fields including economics, psychology, and communication provide an invaluable research foundation, they have, for the most part, focused on what determines and controls individual behavior. Roberta Balstad Miller, director of the Division of Social and Economic Science of the National Science Foundation, stresses that the study of human aspects of global change must consider not only individual behavior but also entire institutions—national laws and regulations, profit margins, transportation patterns, agricultural markets, and tax structures—that are significant for the environment. The research must also address the history of environmental change, dealing with human and institutional activities over long periods of time. "Research on the human dimensions of global change that ignores these factors would be nearly as inadequate as research that ignores the human dimension altogether," Miller said. "Will a social science research effort on global change be expensive? No question. But we must never forget that the costs of doing nothing are even greater."

"The effort to discern the human causes of global change is complicated because the target changes over time: humans both act on and react to their environment. Using their unique capability to choose, people can perceive and assess possible future changes that they hope to encourage or avoid. According to Harvard University's William C. Clark, "Ultimately, it is certain patterns of human behavior that lead to environmental degradation, and other patterns that result in sustainable development. We need to establish how relevant human behaviors are shaped, and how they can be altered as part of efforts to manage the long-term, large-scale interactions between people and their environments."