Kates, R. W., 1985. "Foreword", "Part I Overview", "Part II Biosphysical Impacts", "Part III Social and Economic Impacts and Adjustments", "Part IV Integrated Assessment", in Robert W. Kates, Jesse H. Ausubel and Mimi Berberian, eds. Climate Impact Assessment: Studies of the Interaction of Climate and Society, John Wiley, pp. 1-2, 103-104, 247-249, 465-467.

Preface

The decade of the 1970s was marked by a growing climate consciousness, both popular and scientific. The new interest was sparked by a series of extreme climate events and related disruptions, and by scientific speculation as to increased climate variability and possible climate change. Two sets of events during this period attracted both scientific and public interest. The first, in 1972, was the apparent simultaneous occurrence of unfavorable weather in many parts of the globe and its speculative relationship to a wide variety of socioeconomic events, including the quadrupling of various commodity prices around the world, food shortages in the Sahel of West Africa and in South Asia, a drastic fall in the anchovy fishery of the Pacific, and even changes in government in Ethiopia and Niger. The second was an emerging scientific consensus that human-induced alterations in the chemical constituents of the atmosphere could lead to large regional, and even global, changes of the atmosphere in the form of more acidic rain, greater ultraviolet radiation, and altered temperatures.

The early eighties again found persistent drought in northeast Brazil and in many countries of Africa; a warming of sea-surface Pacific temperatures leading to the most remarkable 'El Niño' event recorded to date; and the warmest years in a century of northern hemisphere temperatures. A scenario for a new and most serious set of climatic consequences following a major international exchange of nuclear weapons, the 'nuclear winter', was postulated. The science of human-induced alterations of the atmosphere became more complex with the slowing of the rate of fossil fuel use and with improved understanding of the way the many 'greenhouse' gases contribute to global warming, while at the same time reducing the net destruction of the ozone shield against ultraviolet radiation.

In sum, the diversity of novel climatic experience continues unabated, the recognition of potential sources of human-induced alteration has increased, and the pace and degree of change are questioned and debated. Nonetheless, it is widely agreed that one such change, a long-term global warming derived from the enrichment of the atmospheric content of the 'greenhouse' gases, is underway. Within the time period of the projected global average warming, measured in tens of hundreds of years, sustained variation of climate will occur in many places, and lesser periods of favorable or unfavorable climate will occur in most places—a function of normal variability. Where these changes are large—the extremes greater than what is customary—where people and places are vulnerable, or where human activity meshes poorly with natural opportunity, significant climate impacts to people, ecosystems and societies are likely to occur. How to respond to such impacts—adjusting to changing climate, coping with extremes, matching human needs to climate endowment—are issues of considerable import. The scientific study of climate and society will inform societal response. Concepts of climate impact assessment are new, the methods are still under development. This volume is an authoritative review of these methods and concepts, a contribution of the Scientific Committee on Problems of the Environment to the World Climate Program.

The World Climate Program (WCP) was initiated in February of 1979 at a meeting of 350 scientific experts held under the aegis of the World Meteorological Organization. The Program is directed at four goals:

1. improving our understanding of the physical climate system;
2. improving the accuracy and availability of climate data;
3. expanding the application of current climate knowledge to human betterment; and
4. advancing our understanding of the relation between climate and human activities.

Organized to address the fourth goal was the World Climate Impact Program (WCIP), of which this study is an initial effort. WCIP's purpose was well-stated in its founding document:

> ... the ultimate objective of the Impact Study Programme within the World Climate Programme will be to insert climatic considerations into the formulation of rational policy alternatives. In areas of the world characterized by different natural environmental conditions, social structures or economic systems, and differing levels of development, there can be different interactions and responses to climatic variability. The basic studies should aim at an integration of climatic, ecological and socio-economic factors entering into complex problems of vital importance for society, such as availability of water, food, and energy. Specifically, the Programme should strive for:
>
> (a) Improvement of our knowledge of the impact of climatic variability and change in terms of the specific *primary responses* of natural and human systems (such as agriculture, water resources, energy, ocean resources and fisheries, transportation, human health, land use, ecology and environment, etc.);
> (b) Development of our knowledge and awareness of the *interactive* relations between climatic variability and change and human socio-economic activities;
> (c) Improvement of the *methodology employed* so as to deepen the understanding and improve the simulation of the interactions among climatic, environmental and socio-economic factors;
> (d) Determining the characteristics of human societies at different levels of development and in different natural environments which make them especially resilient to climatic variability and change and which also permit them to take advantage of the opportunities posed by such changes;
> (e) Application of this new knowledge of techniques to practical problems of concern to developing countries or which are related to a common need for all mankind.
>
> (World Meteorological Organization [1980], *Outline Plan and Basis for the World Climate Programme, 1980–1983*, 32–34)

At the time of the World Climate Conference in 1979, many of the major impacts of climate variation were already well known and others were under study. Participants reported on this sampling of impacts that were then known:

- Natural disasters claim an average of $40 billion in global resources and at least 250,000 deaths a year. Of this dollar amount, $30 billion accrue from three major events with a significant atmospheric component: floods (40 percent), tropical cyclones (20 percent), and drought (15 percent). The distribution of deaths and damages is widely skewed, with 95 percent of deaths occurring in poorer nations and 75 percent of economic damages in wealthy nations. (Kates [1979], in World Meteorological Organization's *Proceedings of the World Climate Conference*, 683)
- The current grain-producing systems of the world are still highly sensitive to the occurrence of large climatic anomalies. The trend toward higher grain yields has slowed down, or even leveled out, since the early 1970s. Some agriculturalists attribute this to worsening weather. Evidence also exists to suggest that grain yields have been subject to more weather-related variability during the 1970s than during the previous two decades, when dramatic increases in yields suggested that technological inputs were overcoming the variability of weather. (McQuigg [1979], in *Proceedings of the World Climate Conference*, 420–421)
- The increasing use of air conditioning and electric heating in homes has increased the sensitivity of energy demand to temperature changes. Results of studies in the United States showed that in one year out of 100 years one should expect the total demand for heating fuel to exceed the long-term average demand (for constant economy) by as much as 10 percent and at least 3.6 percent of an average of one heating system in five. The probable extreme deviations are larger when regions are considered; for example, for the South Atlantic states of the United States, in one year out of 100 years one should expect a total demand for heating fuel to exceed its long-term average demand by 20.4 percent. (Williams, Häfele, and Sassin [1979], in *Proceedings of the World Climate Conference*, 281–282)
- A substantial amount of the production of any economy is directly or indirectly used to offset or negate the economic effects of climatic variation. Considering only the purchases by consumers in the northern hemisphere above 40° latitude, the amount spent may be as high as 10

percent of per capita income. (d'Arge [1979], in *Proceedings of the World Climate Conference*, 656)

Along with impacts, the World Climate Conference was informed about practical actions that are taken to anticipate, prevent, reduce or mitigate undesired impacts or to take advantage of desirable ones. These include:

- For agriculture, crops are planted late or harvested early, and are partially stored for use during exceptionally severe periods of drought or cold. Through genetic selection, hardier or heat resistant varieties of crops are obtained and applied. Farm operators plant a mixture of crops to protect against climate extremes and thereby avoid the possible loss of a single weather-sensitive crop. Energy-intensive machinery is utilized to reduce time for seeding or harvesting. (d'Arge [1979], in *Proceedings of the World Climate Conference*, 656)
- Industries stockpile raw materials to avoid shortages due to reduced deliveries during inclement weather. Employers hire additional workers and adjust working hours to reduce production stoppages due to employee illness or inability to travel to work during periods of extreme climate. Special snow removal equipment is purchased and stored in case of severe storms. (d'Arge [1979], in *Proceedings of the World Climate Conference*, 656)

Additional actions were proposed. For example, it was reported that in the opinion of the authors the:

- Use of the best practice currently available in developing countries could reduce the world death toll from drought, flood, and tropical cyclones by 85 percent and similar use of best practice in industrial countries could reduce property damage by 50 percent. (Burton *et al.*, 1978; quoted in Kates [1979], in *Proceedings of the World Climate Conference*, 687)

Thus the World Climate Impact Program addressed practical necessity: preventing and mitigating the disasters of extreme events; tuning climate-sensitive sectors of the economy (such as energy, food, fiber, water) to accommodate climate variation better; and anticipating, preventing and adapting to natural and human-induced climate change. The work at that date was at best suggestive. Systematic efforts at climate impact assessment were recent; methods, however, are evolving rapidly.

The Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions undertook to prepare the authoritative review of the methodology of climate impact assessment called for in the World Climate Impact Program. The objectives of the review were:

1. to examine existing methodology;

2. to foster the development of new methodological approaches; and
3. to inform a broad range of disciplines as to the available concepts, tools and methods beyond their own specialty.

This volume is a major product of that review. But of equal importance is the network of scientific interest that has been created in the course of the project. Over three hundred individual researchers and administrators from thirty-six countries have participated, exchanged publications, or expressed continuing interest in the review and the general field. Contact with them has been maintained by two SCOPE newsletters devoted to climate impact assessment and will be continued through informational letters coordinated by the US National Climate Program Office.

Included in this network are the thirty-eight authors of papers (from thirteen countries), the one hundred invited reviewers of papers (from twenty-three countries), the eight members of the SCOPE-appointed Scientific Advisory Committee, and the fourteen national correspondents from SCOPE National Committees. The network itself and the production of this volume were coordinated by the Clark University Climate and Society Research Group, using funds from the US National Science Foundation, the United Nations Environment Program (UNEP), the Scientific Committee on Problems of the Environment (SCOPE), the US National Academy of Sciences, and the Oak Ridge Associated Universities. In addition, through SCOPE, the Andrew W. Mellon Foundation provided funds for William Riebsame to serve as postdoctoral research fellow.

The SCOPE effort began with a Scientific Advisory Committee, chaired by F. K. Hare, whose members were J. de Vries, J. Escudero, H. Flohn, A. Mascarenhas, W. J. Maunder, J. L. Monteith, and R. Slatyer. At the same time, the national correspondents (V. V. Alexandrov, USSR; J. Aragón, Spain; A. P. M. Baede, The Netherlands; C. Capel-Boute, Belgium; P. K. Das, India; M. Glantz, USA; W. Kuhnelt, Austria; S. C. Lu, Taiwan; K. Meyer-Abich, West Germany; J. L. Monteith, United Kingdom; J. Neumann, Israel; Y. Omoto, Japan; A. B. Pittock, Australia; and D. Rosell, The Philippines) appointed by National Committees were solicited for information and suggestions. These were reviewed at a meeting of the Scientific Advisory Committee at St Hilda's College, Oxford University, in September 1980. There the Committee adopted a framework to select topics, authors, and a common set of instructions for contributors. Another meeting, hosted by the Atmospheric Environment Service of Canada a year later, brought together review authors to discuss either preliminary drafts or their plans for papers.

Papers were submitted over the following two years and each received an international, interdisciplinary review from a group consisting of J. L. Anderson, W. Bach, C. L. Bastian, E. Bernus, A. K. Biswas, E. Boulding, R. Bryson,

M. I. Budyko, J. J. Burgos, J. C. Caldwell, L. J. Castro, C. Caviedes, R. Chen, L. S. Chia, W. C. Clark, D. Cushing, G. Dahl, K. Devonald, J. Dooge, M. El-Kassas, N. J. Ericksen, H. Flohn, H. D. Foster, W. J. Gibbs, E. S. Gondwe, G. Gunnarsson, J. C. Hock, C. S. Holling, M. A. Islam, W. W. Kellogg, A. Khosla, A. V. Kneese, V. A. Kovda, M. Lechat, T. A. Malone, A. Mani, B. Martin, G. A. McKay, D. H. Meadows, D. Mileti, J. K. Mitchell, S. H. Murdock, T. Murray, W. Nordhaus, J. S. Oguntoyinbo, P. O'Keefe, T. O'Riordan, J. P. Palutikof, C. Pfister, J. D. Post, T. Potter, T. K. Rabb, C. Sakamoto, S. H. Schneider, W. R. D. Sewell, M. M. Shah, M. S. Swaminathan, J. A. Taylor, T. Vasko, R. A. Warrick, G. F. White, G. D. V. Williams, J. S. Winston, B. Wisner and C. P. Wolf. These reviews were followed by several rounds of revision.

At Clark University, Mimi Berberian, Thomas Downing and William Riebsame organized the initial stages of the review, and Maggie Grisdale of Trinity College, Toronto directed the ensuing meeting that brought together review authors. The many drafts of papers were patiently typed by Jane Kjems, Joan McGrath, and Lu Ann Renzoni. I served as volume editor, aided by Jesse Ausubel and Mimi Berberian. Jeanne Kasperson provided invaluable bibliographic assistance.

If one adds to the group of participants the many scientists and publishers that shared material and illustrations with us, literally hundreds of people have generously tendered assistance, motivated by the common bonds of science that transcend discipline and nationality and by shared concerns for climate and society. I hope they can take much satisfaction from our collective activity, as I relieve them of responsibility for any fault or error. I am particularly grateful for the endless patience of the authors, the universal helpfulness of the reviewers, and the generous understanding of funding agency program officers. Relieved also of fault, but tendered special gratitude arising from five years of close collaboration, I thank Ken Hare for his counsel and support; Bill Riebsame for his energy and insight; Jesse Ausubel for his knowledge and versatility; and for all of us, Mimi Berberian, for her skill and sense.

A project, a network, a volume: this is also a set of papers. The individual papers transcend professional boundaries and examine climate impact assessment in a non-disciplinary fashion as a set of linked analytic components, as techniques of case study and modeling, and as reviews of past experience. Each author has sought to review the state of his or her art, not for peers, but for scientific colleagues who are interested in climate impact assessment but schooled in a different discipline or lacking experience in a particular technique. The achievements, weaknesses, and capabilities of the various methodologies are set forth with candor, tempered by empathy. It is our hope that workers new to climate impact assessment will be realistic in their expectation of the various methods, sympathetic with the common scientific problems faced, and challenged both by their practical necessity and intellectual adventure.

ROBERT W. KATES

Worcester, Massachusetts (USA)
June, 1984

Part I
Overviews

Running as a thread through the entire volume, linking together the sectoral studies, the analytic methods and the case examples, are conceptual models of the interaction of climate and society, definitions of climate variability and change, and assumptions as to the state of knowledge concerning climate processes. These concepts and definitions, presented by Kates in Chapter 1 and Hare in Chapter 2, provide to all authors a common vocabulary for describing climatic events, consequences and human responses, a common framework for linking climate and societal impacts, and a common interest in both industrialized and developing countries.

Within this framework, climate variability and change provide three types of events of interest: extreme weather events, persistent periods, and little ages. These events impact on exposed social, areal, or activity units of human or ecological organization, leading to ordered biophysical, social, or ecological consequences. In turn these impacts are modified by cultural adaptation and adjustment responses that may amplify or dampen the consequences of climate events. In the simplest of frameworks, the links between events, units and consequences of climate impact models are linear. In the more realistic and complex interaction model framework, causality is jointly determined by climate and society. As with all such frameworks, relationships are linked in ordered flows that belie the reality and simultaneity of the real world.

The degree to which the authors employ these common concepts, concerns and vocabulary differs, as considerable translation of disciplinary or sectoral practice or tradition is often required. Nonetheless, all have tried, and brief editorial introductions to the major sections guide the reader to the connections between a particular chapter and the overarching schema of climate impact assessment.

The overview on research by Riebsame in Chapter 3 serves a different function, providing a common conceptual and historical review of climate–society research organized under four key concepts: climate as setting, as determinant, as hazard, and as resource. Riebsame's view that research, both past and future, flows directly from these different, but not exclusive, concepts of climate–society interaction serves not only to organize the diverse literature of this interdisciplinary field, but to analyze its structure as well.

The final overview, Chapter 4 by Maunder and Ausubel, links directly to the rest of the volume by posing the question of how one begins to undertake specific climate impact studies. They suggest that one major way to begin is by assessing the overall climate sensitivity of activities, places, or groups of interest. Past experience and current methods for determining overall sensitivity are presented. It emerges from many studies that agriculture and water resources are activities and sectors that are clearly sensitive to climate. Methods appropriate to the study of these and other sensitive sectors follow in Part II of this volume.

Climate Impact Assessment
Edited by R. W. Kates, J. H. Ausubel and M.

CHAPTER 1
The Interaction of Cl

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Part II

Biophysical Impacts

In the simplest of impact models, climate affects places, people and their activities, leading to a set of ordered consequences. The first set of consequences is designated as biophysical impacts, because their causal mechanisms (where known) or transfer functions (where inferred) are in the realm of physical and non-human biological relationships: crops grow, rainfall runs off, cattle graze, fish feed, and buildings cool.

As indicated in the previous chapter on climate sensitivity, all five of the sectoral chapters deal with highly climate-sensitive activities. But they do not exhaust the set of such activities; indeed they only illustrate them. Particularly missing are chapters on unmanaged, natural ecosystems, sensitive industrial activities such as construction and transportation, and service activities such as insurance and recreation. However, the five chapters well illustrate the range of methods available for determining first-order impacts, the comparative precision and validity of these methods, and some common directions for future investigation.

In Chapter 5, Nix suggests five methods for analyzing the impacts of climate on agriculture: trial and error, analogy, correlation, simulation modeling, and systems analysis. This typology serves well to describe not only methods employed in the agricultural sector, but also to compare the methods available in other sectors as well. Agriculture (Chapter 5), Water Resources (Chapter 8) and Energy Resources (Chapter 9) employ the full range of methodologies. The analysis of pastoralism (Chapter 7), as distinct from modern ranching, is with a few exceptions still at the level of analogy and simple correlation. The link between climate and fisheries (Chapter 6), with the possible exception of 'El Niño' types of phenomena, is still trial and error, uncertain analogy and correlation.

Greater predictability of transfer functions is found in physical than biological functions and in small-scale, controllable human activities. Thus it is easier to predict temperature–energy or rainfall–runoff relationships than the climate yields of agriculture, pastoralism or fisheries. Similarly it is easier to predict the energy demand for a building than for a city, or the yield of a field than that of a grazing area or an ocean current. The chapter authors have not limited themselves to first-order impacts. Although concerned with biophysical impacts, all the authors work from a framework in which climate impact relationships are constrained or changed by human action. Thus as Nix (Chapter 5) shows, agricultural models must be confined to a particular crop, place and technology or specifically include changes in technology as a major variable in yield functions. Kawasaki (Chapter 6) explores the still indeterminate issue of whether fluctuations in fishery catch reflect natural (including climate) cause or simply overfishing. A similar issue is posed by LeHouérou relative to the success of human adjustment to drought. Nováky, Pachner, Szesztay and Miller (Chapter 8) argue for the need to consider water-related impacts of climate clearly within the context of socially related management activities. Similarly Jäger (Chapter 9) notes that climate–energy demand relationships are changing rapidly as conservation methods come into widespread use.

Thus a common research question for methodological development is posed by the need, in even the simplest of impact models, to allow for the interaction of climate and society. A second issue is posed most clearly in the analysis of Le Houérou, but is also evident in the chapters on water, agriculture and energy. Le Houérou traces the systematic amplification and dampening of impacts along the causal chain of the impacts model, suggesting that variability in climate is amplified in primary productivity of grazing lands, but in turn is dampened in livestock yield and in human impact. Similarly Chapter 8 shows that fluctuations in rainfall are amplified by fluctuations in streamflow but are dampened by water resource management measures. The systematic comparison of climate–yield–impact ratios for different sectors might well lead to improved understanding of the processes of interaction.

Climate Impact Assessment
Edited by R. W. Kates, J. H. Ausubel and M. Berberian

CHAPTER 5
Agriculture

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5.1 INTRODUCTION

Not a single farmer, forester or stockbreeder needs any reminder that production systems are subject to the vagaries of climatic variation and the hazard of extreme weather events. The primary role of climate and weather in conditioning biological and physical processes and in determining much of the structure and function of both natural and man-modified systems should need no further emphasis. Yet, the development, testing and practical application of methods of agroclimatic analysis have not been given a high priority in most agricultural and biological research programs. Why is this so?

While there are intrinsic problems, the major limitations have been extrinsic. Farm, forest and grazing management involve a mix of controlled and uncontrolled variables. Since climate and weather are, for most practical purposes, uncontrolled, research emphasis has been given to those compo-

Part III

Social and Economic Impacts and Adjustments

As the impact analyst moves from first-order biophysical impacts to higher-order consequences, the possibilities, outcomes and human choices attached to each link increase, and the causal chain becomes less distinct. Part III reflects that complexity. Three of the chapters, written from disciplinary perspectives, deal with second-order consequences on human health (Chapter 10), economy (Chapter 12), and society (Chapter 13). Three of the chapters deal with case study methods to assess so-called 'natural experiments', focusing on historical study (Chapter 11), climatically and economically marginal places (Chapter 14), and extreme weather and climate events (Chapter 15). Finally, two chapters deal with adjustment responses and mechanisms for their perception and choice (Chapters 16 and 17).

When studying self-provisioning societies it is convenient to think of human nutrition and related health effects as second-order consequences—climate-related yields of food leading to various health and demographic impacts. But there are few fully self-provisioning societies, therefore biological increases or decreases in the availability of foodstuffs must be traced through a network of existing social and economic relationships. Escudero's proposal for a case comparison of both shores of the Windward Passage is a case in point.

Economic and social relationships are the substance of the social sciences, particularly economics and sociology. Within the framework of market economies, but with some applicability to all economies, there are a set of well-defined quantitative approaches designed to answer two fundamental questions of how economies interact with climate. Given a change in either the mean or distribution of climate events, how will the allocation of resources change and which persons or places will lose or gain from such resource changes? As Lovell and Smith point out in Chapter 12, robust methods exist to answer these questions, but rarely have been applied. Nor have they been adapted to the special qualities of climatic variability and change: stochastic nature, large-area impact, and long time-horizon over which consequences take place.

Ironically, the more diffuse, less-defined social impacts appear to be better illustrated, with interesting and recent case examples from studies of weather modification and extreme events. With a broader view than economic analysis, social impact analysis, as Pilgrim notes in Chapter 13, is a class of policy analysis that arose from a concern with the 'hidden costs' of societal undertakings. Thus there is a strong emphasis on identifying the many different stakeholders affected by climatic variability or change and assessing the differential impact upon them.

Historical analysis, de Vries informs us in Chapter 11, employs the full array of social science methods and is limited only by the availability of data from the past. Climate adds to the rationale of historical explanation of human events, and historical events allow us to expand the stock of relevant climates and societies to examine. (See also the extensive discussion in Chapter 21.) In the latter case, historical analysis is often employed for the two types of natural experiments that are emphasized in this volume—a focus on vulnerable margins or groups and a focus on extreme climatic events, usually of interannual or decadal length.

Natural hazard research, described by Heathcote in Chapter 15, provides a rich body of relevant methodology to study the extreme events of the past as well as those of current experience. To illustrate, Heathcote reviews such methods within the ordered sequence of impacts and the interactive model of human response. The immediate dramatic impacts of violent storm or persistent drought are most easily identified and measured; the long-term impacts, however, are much in doubt. The margins of climatically sensitive activities that Parry documents in Chapter 14 seem to be more sensitive barometers of the impacts of longer-term changes in climate.

Woven throughout Part III are specific issues of adjustment and adaptation. Although some studies of biophysical impact attempt to ignore or to constrain societal interaction, studies of social and economic impacts are always interactive, analyzing the differential societal impacts of climate change and variability in the light of the differential ability to cope with or take advantage of such change. Indeed, several authors point out that the differential between societies and their resources is much greater than the differential between climatic regions or epochs in their impact on human beings.

At the level of individual and small-group decision-makers, studies of perception, alluded to in Chapters 11 and 15 and given full treatment by Whyte in Chapter 16, have served as a major link to studies of adjustment of the type described by Jodha and Mascarenhas in Chapter 17. Reports of the nature of adjustment to climate change and variability are scattered throughout the text. Lists of adjustments are given in most of the sectoral chapters. Given the bias towards industrialized nation experience, however, Jodha and Mascarenhas examine specifically developing country adjustment, drawing on their rich experience in South Asia and Africa.

When this set of disciplinary methods and case study opportunities for identifying human social and economic impacts is compared, a strong negative bias emerges. Most methods and case studies focus on climate as hazard; only scattered efforts have been made to study climate as a resource. Within the focus on climate as hazard, the balance of effort has been to identify the residual damages and losses caused by the impact of climate events on vulnerable groups or regions; less effort has been expanded on identifying and measuring the social cost of adaptation and adjustment. Assessing the social cost of climate adjustment and the opportunities of climate as a resource are important items for a research agenda.

Part IV

Integrated Assessment

Studies that combine several links in the chain of sensitivity studies, biophysical impact studies, social and economic impact studies, and adjustment responses are integrated assessments. Examples of integrated assessments and problems of linkage between types of studies are found throughout the volume. Part IV explores in depth one major technique for providing linkage in integrated assessment—the use of modeling and simulation. In addition it reviews the experience with both historical and recent integrated assessment.

Integrated assessments involve a scale of activity and a set of complex linkages that encourage the use of modeling and simulation techniques. Such techniques provide an orderly and systematic way to store and analyze large arrays of data, to link data sets together, and to translate different disciplinary approaches into common mathematical language. A special attraction lies in the parallelism with general circulation models (GCMs), the favored tool for exploring dynamics of climate at a global scale. These models, representing the apogee of causal explanation, scale of detail, and massive data handling and computation requiring the most sophisticated of computers, establish a criterion for modeling towards which many biological and social scientists working on integrated assessment seem irresistibly drawn. Thus the opening chapter of Part IV begins with an exploration of global modeling and simulations (Chapter 18).

In Chapter 18 Robinson examines some twenty global models for their potential in climate impact assessment use. She is cautious in her conclusions. Global social, economic and environmental models have not been designed for climate impact analysis, are at best pioneering efforts, and are difficult to use. Nonetheless they can provide insight, data and answers to restricted questions. The pioneering quality of global models is demonstrated by the coevolution biosphere model of the Computing Center of the USSR Academy of Sciences Moisseiev, Svirezhev, Krapivin, and Tarko describe their ambitious, but incomplete, integrative model of climate, ecosystem and society—a model attuned to a time horizon of centuries.

A more modest and limited form of modeling is presented by Lave and Epple (Chapter 20) under the rubric of scenario analysis. They assert three virtues of scenario analysis: stretching the imagination to encompass a wide range of actions and implications: formal modeling of the causes and consequences of climate change and potential adjustments; and interdisciplinary integration to transcend the parochialism of professional method and tradition. Scenarios, and indeed all modeling to date, appear to be exploratory tools, not to be used for reliable prediction but rather to explore the bounds of both the unusual and the possible.

Large-scale modeling is an appealing tool, but still not a broadly realized one. What, then, can be said of other efforts at integrated climate assessment? Wigley, Huckstep, Ogilvie, Farmer, Mortimer and Ingram offer their evaluation of historical climate impact assessment (Chapter 21), considering some 24 examples of historical case studies. To do so they review extensively the methodological underpinnings of historical study, and Chapter 21 should be read jointly with the chapter on historical analysis by de Vries (Chapter 11). Wigley *et al.* note the attractiveness of historical case studies, seemingly free from the complications and confusions of oft polarized current historical explanation. But ironically they find the field suffering from polarities of a different sort, with exaggerated claims and rebuttals for the role of climate in history. Yet within the seeming excess of rhetoric, perhaps half of the studies examined handle both data and assumptions thoughtfully and carefully.

Glantz, Robinson, and Krenz (Chapter 22) examine only five examples of major assessments of climate impacts of recent or future experience, but do so in considerable depth. They focus on comparative issues of study design and length, research staff and linkages between the individual study components, and public presentation of findings. It is clear from these experiences that major climate impact assessments are substantial undertakings, requiring extensive research and time, flexibility in design, and repetition as new data and methods become available. Assessments with strong scientific leadership can advance the state of the art; those organized on a constructive basis can at best attempt only to answer the questions addressed.

The review of integrated assessment concludes with the Chinese proverb: to know the road ahead, ask those coming back. The road ahead is unfolding. In the 4 years that this volume has been in preparation a second generation of

integrated studies has been undertaken, and more are planned. Some of these studies simply repeat the past, with little evidence of having sought the advice of those coming back. But most of these half dozen studies evidence a high degree of methodological sophistication, scientific clarity, flexibility in their design, and excellence in their scientific leadership. Another final chapter is being written.