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Overview of Impacts, Adaptation, and Vulnerability to Climate Change

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1.1. Overview of the Assessment

The world community faces many risks from climate change. Clearly, it is important to understand the nature of those risks, where natural and human systems are likely to be most vulnerable, and what may be achieved by adaptive responses. To understand better the potential impacts and associated dangers of global climate change, Working Group II of the Intergovernmental Panel on Climate Change (IPCC) offers this Third Assessment Report (TAR) on the state of knowledge concerning the sensitivity, adaptability, and vulnerability of physical, ecological, and social systems to climate change. Building on the Second Assessment Report (SAR), this new report reexamines key findings of the earlier assessment and emphasizes new information and implications on the basis of more recent studies.

Human activities—primarily burning of fossil fuels and changes in land cover—are modifying the concentration of atmospheric constituents or properties of the Earth's surface that absorb or scatter radiant energy. In particular, increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes observed during the 20th century and are expected to contribute to further changes in climate in the 21st century and beyond. These changes in atmospheric composition are likely to alter temperatures, precipitation patterns, sea level, extreme events, and other aspects of climate on which the natural environment and human systems depend.

One of several primary issues this report has been organized to address is a key question before the United Nations Framework Convention on Climate Change (UNFCCC): What are the potential impacts for societies and ecosystems of different atmospheric concentrations of GHGs and aerosols that absorb and scatter sunlight (United Nations, 1992)? Answering this question is a necessary step in assessing what constitutes "dangerous anthropogenic interference in the climate system." This report does not make any judgments about what level of concentrations is "dangerous" because that is not a question of science *per se* but a value judgment about relative risks and tradeoffs. The task is to make the evidence about relative risks as clear as possible. This report therefore describes what is known about the distribution of impacts; how, why, and to what extent they differ from region to region or place to place; and how this relates to the distribution of vulnerability and capacity to adapt. However, it critically assesses the literature to help inform policymakers about effects associated with different concentration levels, so they may judge what levels of risk are acceptable. Assessment of what constitutes dangerous interference in the climate systems will require analysis of the interactions of climate change and social and economic conditions, which are inextricably linked. Understanding the role of socioeconomic factors, particularly adaptive responses and capacity, is critical.

Part of the justification for a TAR at this time is the abundance of new evidence that has come to the attention of the expert community since publication of the SAR. The evidence is drawn predominantly from published, peer-reviewed scientific literature. Evidence also is drawn from published, non-peer-reviewed literature and unpublished sources such as industry journals; reports of government agencies, research institutions, and other organizations; proceedings of workshops; working papers; and unpublished data sets. The quality and validity of information from non-peer-reviewed and unpublished sources have been assessed by authors of this report prior to inclusion of information from these sources in the report. The procedures for the use of information from non-peer-reviewed and unpublished sources are described in IPCC (1999a) and discussed in Skodvin (2000).

Although this report builds on previous assessments, including the SAR and the IPCC's *Special Report on Regional Impacts of Climate Change* (IPCC, 1998), the TAR departs from them in important respects. In comparison to previous assessments, greater attention is given to climate change adaptation; multiple pressures on systems; links between climate change, sustainable development, and equity; and characterization of the state-of-the-science and confidence levels associated with key conclusions of the assessment (see Box 1-1). This overview chapter does not attempt to provide a comprehensive summary of the principal findings of the TAR, but it helps to illustrate basic concepts by selectively reporting on a few key conclusions, as well as providing a more comprehensive road map to the materials presented later in the report:

- Part I sets the stage for assessment of impacts, adaptation, and vulnerability by discussing the context of climate change, methods for research on impacts, and development of scenarios. These are important additions to what was emphasized in the SAR. Consideration of the context of change (in this chapter) draws attention to the relationship of climate change and sustainable development, including interactions of climate variability and change with other environmental changes and evolving demographic, social, and economic conditions that affect driving forces of change and resources available for adaptation. Assessment of methods (Chapter 2) and approaches for developing and applying scenarios (Chapter 3) cover scientific and technical aspects of research on impacts, providing a review of the science underlying the topics covered in other chapters of the report.
- Part II assesses recent advances in experimental work, observations, and modeling that contribute to the current state of knowledge of baseline trends, vulnerabilities, and adaptation options in six sectors or resource areas. This section of the report integrates material that had been covered in 18 chapters in the SAR, focusing to a greater extent on cross-sectoral issues. For example, Chapter 5, Ecosystems and their Goods and Services, integrates what had been separate chapters on forests, rangelands, deserts, mountain regions, wetlands, agriculture, food security, and other systems; it also adds assessment of climate change impacts on

wildlife—an issue not covered in the SAR. Integrating these issues into a single chapter provides an opportunity for improved assessment of interactions across these systems, the effects of change on landscapes, and the distribution of land use and cover. Information on the impacts of natural variability and the potential for nonlinear interactions also is included in the chapters in Part II.

- Chapters in Part III build on key findings of the IPCC's *Special Report on Regional Impacts of Climate Change*. Each chapter and subchapter in this part of the report explores what has been learned regarding the context of change, sensitivity, adaptation, and vulnerability of key sectors. A chapter is devoted to each of eight regions of the world: Africa, Asia, Australia and New Zealand, Europe, Latin America, North America, polar regions, and small island states (see Figure 1-1). These regions are chosen to correspond to continents or—in the case of polar regions and small island states—to bring together in one chapter areas that share important attributes related to climate change vulnerability. This regionalization of the world is convenient for organizing the report, but it must be recognized that there is a high degree of heterogeneity within each of these regions in terms of climate, ecosystems, culture, and social, economic, and political systems. Consequently, climate change impacts, adaptive capacity, and vulnerability vary markedly within each of these regions. These chapters provide an opportunity to place vulnerability and adaptation in the context of multiple stresses and regional resources for adaptation. This is an extremely important development because it calls attention to the issues that regional and local decisionmakers in the private and public sectors will be facing in each of the regions.

Areas of important new findings include detection of impacts of observed climatic changes on environmental systems, transient scenarios, vulnerability to changes in climate variability, and vulnerability to strongly nonlinear, complex, and discontinuous responses to climate change. Another distinction from previous assessments is the recognition in the TAR that the many complexities of analysis logically lead to a focus on ranges of outcomes and characterizations, using subjective probabilities of events, rather than primary emphasis on "best guesses," point estimates, single "optimum," or aggregate conclusions.

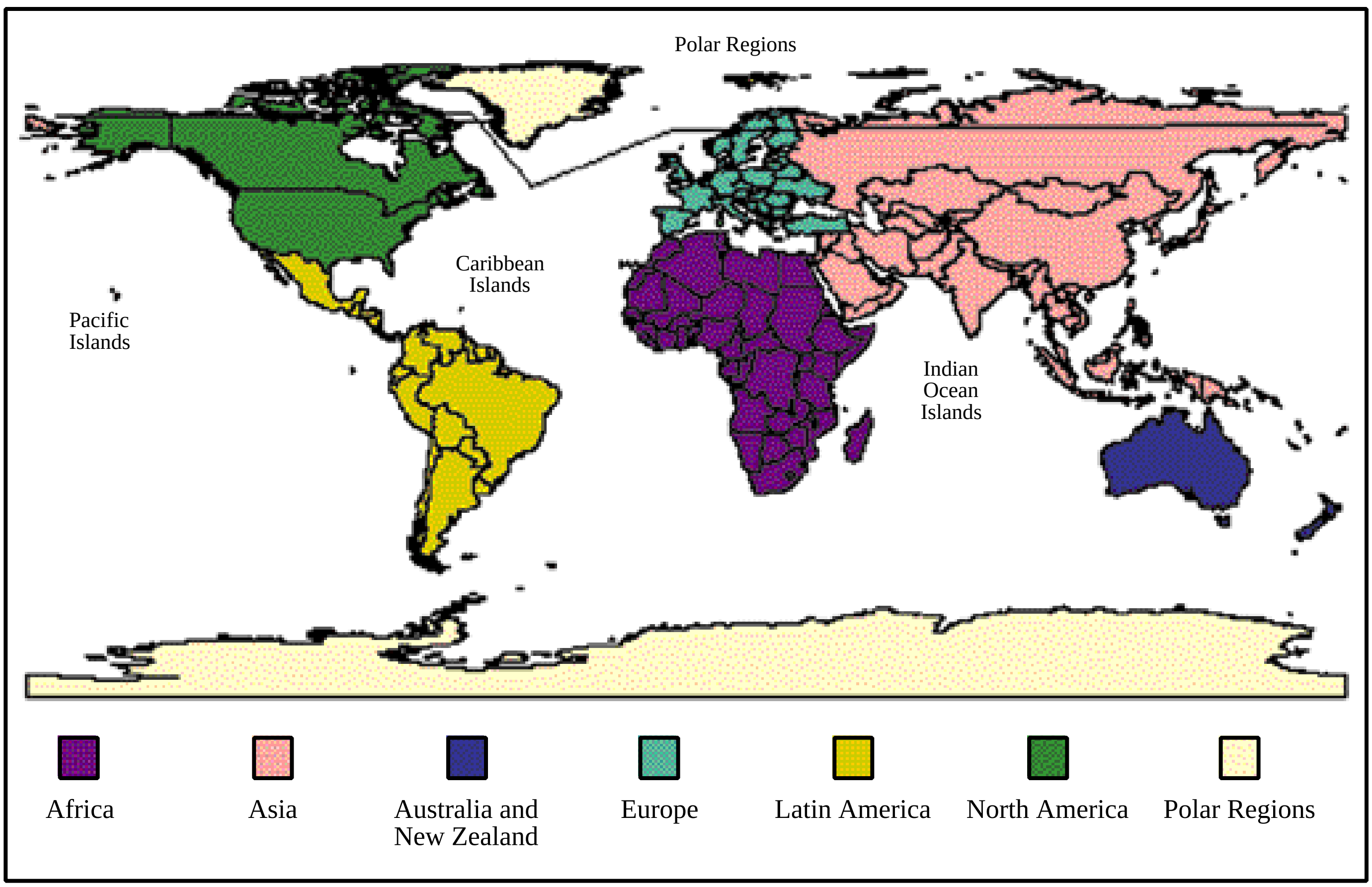


Figure 1-1: Regions for the IPCC Working Group II Third Assessment Report. Note that regions in which small island states are located include the Pacific, Indian, and Atlantic Oceans, and the Caribbean and Mediterranean Seas. The boundary between Europe and Asia runs along the eastern Ural Mountains, River Ural, and Caspian Sea. For the polar regions, the Arctic consists of the area north of the Arctic Circle, including Greenland; the Antarctic consists of the Antarctic continent, together with the Southern Ocean south of ~58°S.

Box 1-1 Uncertainties and Confidence Scale

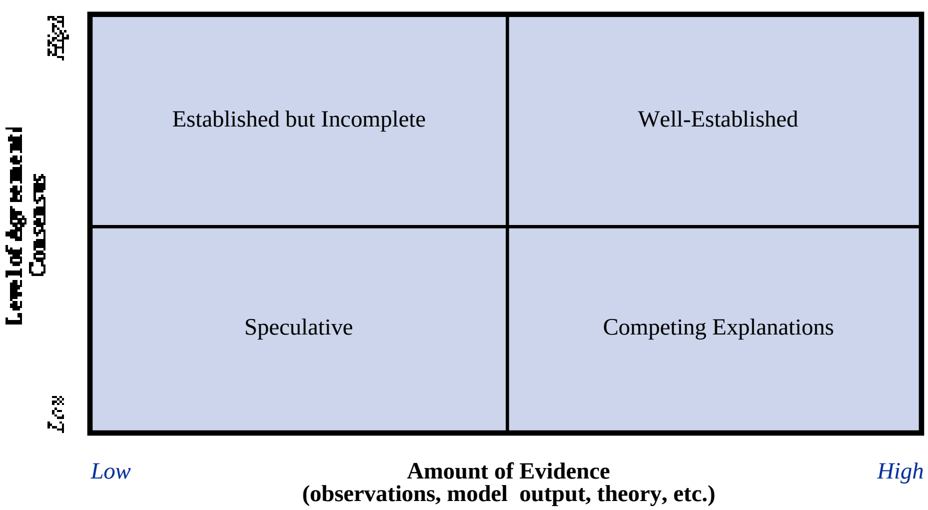
The many conclusions presented in this report are subject to varying degrees of uncertainty. The degree of uncertainty attached to conclusions in this report are assessed and reported in two different ways. One is to assess and report a confidence level for a conclusion, using a Bayesian probability framework. (Bayesian assessments of probability distributions would lead to the following interpretation of probability statements: The probability of an event is the degree of belief that exists among lead authors and reviewers that the event will occur, given observations, modeling results, and theory currently available.) The second is to assess and report the quality or level of scientific understanding that supports a conclusion.

The 5-point confidence scale below is used to assign confidence levels to selected conclusions. The confidence levels are stated as Bayesian probabilities, meaning that they represent the degree of belief among the authors of the report in the validity of a conclusion, based on their collective expert judgment of all observational evidence, modeling results, and theory currently available to them.

5-Point Quantitative Scale for Confidence Levels

95% or greater	Very High Confidence
67–95%	High Confidence
33–67%	Medium Confidence
5–33%	Low Confidence
5% or less	Very Low Confidence

For some conclusions, the 5-point quantitative scale is not appropriate as a characterization of associated uncertainty. In these instances, authors qualitatively evaluate the level of scientific understanding in support of a conclusion, based on the amount of supporting evidence and the level of agreement among experts about the interpretation of the evidence. The matrix below has been used to characterize the level of scientific understanding.



Key to Qualitative "State of Knowledge" Descriptors

- *Well-Established*: Models incorporate known processes; observations are consistent with models; or multiple lines of evidence support the finding.
- *Established but Incomplete:* Models incorporate most known processes, although some parameterizations may not be well tested; observations are somewhat consistent but incomplete; current empirical estimates are well founded, but the possibility of changes in governing processes over time is considerable; or only one or a few lines of evidence support the finding.
- *Competing Explanations*: Different model representations account for different aspects of observations or evidence or incorporate different aspects of key processes, leading to competing explanations.
- *Speculative*: Conceptually plausible ideas that haven't received much attention in the literature or that are laced with difficult to reduce uncertainties.

Box 1-2. Cross-Cutting Issues Guidance Papers

Four cross-cutting guidance papers (Pachauri *et al.*, 2000) were available to all Lead Authors of all three IPCC working groups. Many of the concepts in these papers were previously unfamiliar to a large number of the Lead Authors. Significant efforts were made to incorporate the uncertainties guidance and at least consider the guidance in other papers by each working group. Future assessments will be increasingly able to benefit from the suggestions and frameworks in these four cross-cutting guidance papers.

Development, Sustainability, and Equity (DSE) (Munasinghe, 2000)

DSE is relevant to Working Group II with respect to three questions: How do development paths and equity conditions influence vulnerability to climate change and the capacity to adapt to or cope with climate change? How might climate change impacts and adaptation responses affect prospects for attaining sustainable development and equity goals? What types of policies are capable of reducing climate change vulnerability and promoting sustainable development and equity objectives?

DSE is a response to principles contained in UNFCCC Article 3.4 (to promote sustainable development). Article 3.2 takes into account the special needs and circumstances of developing countries. Article 4 deals, for example, with the responsibility of developed nations, competing priorities for developing nations, and "common, but differentiated responsibilities," and Article 2 says to avoid "dangerous" interference with the climate system (United Nations, 1992). DSE is closely tied to sustainable development with respect to three underlying dimensions: economic, social, and environmental.

Development has been characterized as "qualitative improvement" (Ishida, 1998), including economic growth and social dimensions. Sustainability of a system refers to its durability or its capacity to withstand and recover from disturbances (WCED, 1987)—in other words, its resilience. Equity refers to procedural as well as distributional issues. Procedural issues relate to how decisions are made (e.g., internal equity and governance structures within nations could have significant effects on adaptive capacity). Distributional equity, on the other hand, relates to how the costs of impacts, mitigation, and adaptation are shared. Equity considerations are important in addressing global climate change for several reasons, including moral and ethical concerns; facilitating cooperation because equitable decisions carry greater legitimacy; the social dimension of sustainable development; and the UNFCCC itself, which considers equity as one of its basis principles (in Article 3.1).

Climate change could undermine social welfare, equity, and the sustainability of future development. In particular, it is generally believed that developing countries and disadvantaged groups within all countries are more vulnerable to the impacts of climate change (e.g., Chapter 18) as a result of limited resources and low adaptive capacity.

Uncertainty (Moss and Schneider, 2000)

Anticipating the imperfect nature of available information, UNFCCC Article 3.3 provides guidance to the effect that "where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to anticipate, prevent, or minimize the causes of climate change and mitigate its adverse effects" (United Nations, 1992). The uncertainties guidance paper develops a unified approach for assessing, characterizing, and reporting uncertainties in the TAR. The most important contribution of the uncertainties guidance paper is the construction of confidence schemes and qualitative terms to describe the state of science, which are reproduced in Box 1-1. The goal is to promote consistency in evaluating the judgments of scientific experts, to facilitate communication of these judgments to nonspecialists, and to provide peer-reviewed guidance for policymakers. Thus, a great deal of importance is attached to assessing the scientific merit of information in the literature and "explicitly distinguishing and communicating which findings are well understood, which are somewhat understood, and which are speculative" (Moss and Schneider, 1997). Section 2.6 discusses in more detail the differences between the well-calibrated ranges in the literature and the much larger, full range of uncertainty as well as the cascade of uncertainty that occurs when ranges in climate scenarios are cascaded with uncertainties in each successive step of assessment. In Chapters 4–19, selected findings are assigned levels of confidence, using either the scale for assessing confidence level quantitatively or the matrix for assessing the state of knowledge qualitatively.

Especially in the regional chapters, uncertainty about future climate is the dominant cause of uncertainty about the character and magnitude of impacts. In such cases, confidence estimates are evaluated conditionally on a specific climate change scenarios to avoid "cascades" (see Figure 2-2) in which confidence in the occurrence of an event does not include compounded uncertainties in each factor that contributes to the final outcome. Instead, the assessment evaluates each step in the cascade separately—what is called a "traceable account"—and is particularly appropriate for any aggregate conclusions.

Finally, the TAR has circulated cross-cutting "guidance papers" to all three working groups to try to achieve more consistency in dealing with four areas: development, sustainability, and equity; uncertainties; costing methodologies; and decision analytic frameworks (see Box 1-2).

The IPCC's charge to Working Group II for the TAR implies that consideration of the impacts of climate change in the SAR is insufficient *per se* as a basis for decisionmaking. In general, the SAR was able to address the implications of climate change only for single economic sectors or environmental components. With this in mind, Chapters 4–19 consider the various decision analysis framework tools to improve upon the responses to the impacts of climate change provided in the SAR. In the current exercise, not only are possible implications of climate change for the various economic sectors or environmental components assessed, options to alleviate identified impacts are investigated. In addition, direct and indirect costs of adaptation options are explored, and an extensive assessment of direct and indirect benefits is provided. Where monetary values can be assigned, CBAis employed to determine the optimal value of adaptation measures, including sensitivity analysis to critical parameters, and CEAis adopted to identify the least-cost solution to targeted mitigation objectives.

The concluding section of this report (Chapters 18 and 19) examines global issues and offers a synthesis. A significant addition to previous assessments is Chapter 18, which is devoted

Box 1-2. Cross-Cutting Issues Guidance Papers (continued)

Costing Methodologies (Markandya and Halsnaes, 2000)

This guidance paper discusses many issues related to assessing the impacts of climate change, including identifying the costs of mitigation and adaptation and benefits from avoiding climate damages (market versus nonmarket values; bottom-up versus top-down; willingness-to-pay versus willingness-to-accept-payment); recognizing value-laden assumptions associated with the dollar metric; addressing problems with aggregating costs and benefits that confound differentiated costs and benefits across groups; and determining how to account for ancillary (or co-)benefits and costs. Many of these issues are discussed more fully in the text of this chapter; see also Chapter 2. As noted in the uncertainties guidance paper, a "traceable account" of all aggregations is essential to maintain transparency of any conclusions.

"Cost" refers to any adverse consequence that humans would be willing to expend resources to avoid. "Benefit," on the other hand, is defined as any advantageous consequence that humans would be willing to expend resources to secure. With respect to adaptation, costs are attached primarily to measures employed to alleviate the impacts of climate change. Real costs, however, are computed as the difference between total expenses on adaptation measures and the value of benefits generated in the process of alleviating impacts. Costs also are attached to damages that would be sustained in the event of no response or inadequate response.

Section 2.5 provides details about methods of costing and valuation used in the TAR. Elements of costing and valuation described include opportunity costs and discounting. Costing of market impacts, nonmarket impacts, and uncertainty are discussed and their applications in decision analyses, scenario analyses, and integrated assessments outlined. In Chapters 4–19, cost-benefit analysis is used to present and evaluate information about impacts and their consequences on ecosystems, socioeconomic sectors, and human health, convenience, and comfort. Where information is available, costs and benefits are quantified and given in monetary units. Often the magnitude of costs and benefits is linked explicitly to specific climate scenarios. As much as possible, the sensitivity of costs and benefits to different magnitudes and rates of climate change and the potential for nonlinear costs or benefits are assessed. For example, the sensitivity of costs and benefits to socioeconomic conditions and differences between developed and developing countries are assessed—with obvious implications for DSE. The contributions of costing and valuation to uncertainty levels in the major conclusions also are described.

Decision Analysis Frameworks (Toth, 2000)

Details on methods and tools of decision analysis frameworks that are applicable in the context of adaptation are provided in Section 2.7, which describes major decision analysis frameworks—including decision analysis (DA), cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), and the policy exercise approach (PE). DA integrates utility theory, probability, and mathematical optimization in a procedure designed to select the best pathway. CBAinvolves valuing all costs and benefits of a proposed project over time on the basis of WTP and specifying a decision criterion to accept or turn down the project. CEA takes a predetermined objective and seeks ways to accomplish it as inexpensively as possible. PE synthesizes and assesses knowledge in several relevant fields of science for policy purposes in light of complex practical management problems. Application of these decision analysis frameworks cuts across the assignments of Working Groups II and III.

to assessment of opportunities for and barriers to adaptation. This chapter considers determinants of adaptive capacity; lessons from adaptation to present-day climate variability and extremes; the potential effectiveness of adaptation measures; and global-, national-, and local-scale options for strengthening adaptive capacity, especially for vulnerable populations, countries, or zones. Chapter 19, a synthesis, also is new to the TAR. It draws on the analyses of other chapters, synthesizing information that is important for interpretation of Article 2 of the UNFCCC and key provisions of international agreements to address climate change. Potential global impacts of different stabilization levels of atmospheric concentrations of GHGs are assessed. Chapter 19 assesses vulnerability within the framework of sustainable development and equity, acknowledging common but differentiated responsibilities.

The issue of what constitutes sustainable development was advanced in 1987 by the World Commission on Environment and Development (the so-called Brundtland Commission; WCED, 1987). The commission defined *sustainable development* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and notes that "even the narrow notion of physical sustainability implies a concern for social equity between generations, a concern that must logically be extended to equity within each generation." The goal of sustainable development is a stable human environmental system in which available resources are sufficient to meet the needs of society in perpetuity. Questions have been asked about whether "needs," as conceived in the Brundtland Commission report, should be limited to environment-dependent basic necessities of food, clothing, shelter, and health or should include more qualitative aspects such as comfort, convenience, or other "quality of life" measures. There is no consensus in the literature regarding what constitutes the limits of "needs" in this context.

Because available studies have not employed a common set of climate scenarios and methods and because of uncertainties regarding the sensitivities and adaptability of natural and human-dominated systems, assessment of regional vulnerabilities is necessarily qualitative. Whenever possible, quantitative estimates of the impacts of climate change are cited in this report. Field or experimental data often provide quantitative underpinnings for specific circumstances, but rarely are complex systems sufficiently described by the limited number of cases in which a large quantity of "hard data" is available. Thus, most quantitative estimates are still dependent on the specific assumptions employed regarding future changes in climate, as well as the particular methods and models applied in the analyses. On the other hand, issues in which there is a great deal of relevant field or lab data are likely to carry higher confidence in any such quantitative estimate. To interpret these estimates, it is important to bear in mind uncertainties regarding the character, magnitude, and rates of future climate change that will affect society's degree of exposure. Of comparable importance are uncertainties associated with future states of the human condition—for example, the extent and quality of economic development throughout the world and the evolution of traditions and institutions in societies—that will affect profoundly the capacity for coping and adaptation, hence level of vulnerability. These uncertainties impose limitations on the ability of the research community to project the impacts of climate change, particularly at regional and smaller scales.

This introductory chapter is organized to address a series of questions: What is potentially at stake as a result of changes in climate (Section 1.2)? How has society responded to the risks and potential opportunities (Section 1.3)? How are impacts, adaptation, and vulnerability assessed in the report (Section 1.4)? How do the complexities of analysis affect the assessment (Section 1.5)? How can this assessment be used to address policy-relevant questions (Section 1.6)?

1.2. What is Potentially at Stake?

The stakes surrounding anthropogenic climate change can be very high in terms of the vulnerabilities of some sectors and regions and in terms of the distributional consequences of actions taken to deal with these possibilities. The context is that humankind already is challenged today to provide the opportunity for this and future generations to achieve a more sustainable and equitable standard of living. Billions of people today live without adequate nourishment, access to clean water, modern energy services, and other basic human needs (see, e.g., UNDP, 1999). Providing for the increasing well-being of humans, especially the poor, in the context of sustainable and equitable development is one of the great challenges of the 21st century. Unabated climate change is likely to make meeting this challenge significantly more difficult. On the other hand, it also is argued (e.g., Grossman and Krueger, 1995) that increasing economic growth may lead to reductions in population growth and environmental degradation. Throughout the past century, however, per capita carbon dioxide (CO_2) emissions from combustion of fossil fuels have been driven primarily by growth in gross domestic product (GDP) per capita (although the growth rate in CO_2 emissions generally has not been as fast as the growth in GDP, owing to improvements in energy and carbon intensities of industrial economies (e.g., Hoffert *et al.*, 1998).

The impact (I) of a given population on the environment can be decomposed into the product of three factors: population size (P), affluence per capita (A), and unit impact per unit of affluence, which is related to technologies used (T) (Ehrlich and Holdren, 1971; Ehrlich and Ehrlich, 1990). Rising per capita consumption and a growing world population have resulted in unprecedented human resource use, which is altering global systems, including climate (Bartiaux and van Ypersele, 1993; Yang and Schneider, 1998). According to all of the scenarios considered in the IPCC's *Special Report on Emissions Scenarios* (SRES) (IPCC, 2000), the human population will continue to grow until at least 2050, reaching a population that is 60–100% larger than it was in 1990. The SRES scenarios describe futures that generally are more affluent than today; many of the SRES scenarios assume a narrowing of income differences (in relative but not absolute terms) among world regions. This implies that the third factor in the "I=PAT" identity, the unit impact per unit of affluence, will have a very important role in assessment of the global impact of human activities. Increasing population and affluence, if not accompanied by significant decreases in unit impact per unit of affluence, will make the challenge of promoting sustainable development even more difficult—particularly in developing countries, where most of the increase in population is projected to take place.

We have reached the point that the cumulative interaction of several factors related to human activities (e.g., land-use changes and emissions of GHGs, ozone-depleting substances, and local air pollutants) increases the risk of causing or aggravating potentially irreversible events, such as loss of species, forests, human settlements, glaciers, or heritage sites near coastlines and, in the long term, altered oceanic circulation regimes.

Although some regions may experience beneficial effects of climate change (e.g., increasing agricultural productivity at high latitudes), previous IPCC assessments have concluded that net negative climate impacts are more likely in most parts of the world (assessment of potential positive and negative impacts is one of the main purposes of this report; see Sections 2.5.6 and 2.6.4 and subsequent sections in this chapter for a discussion of uses of and problems with net monetary aggregation of impacts, and see Chapter 19 for a synthesis). These impacts will affect human welfare directly and indirectly, in many cases undercutting efforts to promote sustainable development that, in turn, serve as driving forces of environmental change.

Moreover, the time scales of change vary tremendously. For environmental systems, these time scales range from decades (for restoration of slightly disturbed ecosystems) to many centuries (for equilibration of the climate system and sea level), even with a stable level of atmospheric GHG concentrations. These environmental time scales imply that human activities in the short term will set in motion a chain of events with long-term consequences for the climate that cannot be reversed quickly, if at all.

For most human institutions, the time scales range from years for very short electoral cycles that determine the tenure of a government to a half-century or more for the useful lifetimes of buildings and major infrastructure such as irrigation projects, transportation networks, or energy supply systems. It may take a generation or more to effect significant changes to institutions. Because of these time scales, some decisions taken during the next few decades may limit the range of possible options in the future with respect to emissions reduction and adaptation, whereas other decisions may expand this range of options. During this period, many more insights into the effects and impacts of climatic changes will emerge. However, it is well established that uncertainties will remain, and efforts to manage risks in the face of considerable uncertainty will be a characteristic of climatic change assessments for decades more.

Working Group II's contribution to the TAR focuses principally on the time horizon reaching from the present to the year 2100—which reflects the preponderance of studies on this time period in the literature and the high degree of uncertainty about the state of socioenvironmental systems beyond the 21st century. By 2100, most projections of human-induced climate change fall into ranges of about 1.4 to almost 5.8°C increase in annual global mean surface temperature (see Figure 5d in the TAR WGI Summary for Policymakers) compared to 1990 (although estimates that are outliers to both ends of even this large range can be found in the literature; Morgan and Keith, 1995) and about 10- to 90-cm rise in mean sea level (Figure 5e, TAR WGI Summary for Policymakers). By the time of doubling of CO_2-equivalent concentration, the global mean precipitation is projected to be about 1–5% higher than in 1990. These global numbers hide complex spatial patterns of changes (especially for temperature and precipitation), which are summarized in Chapter 3. In some regions, temperature increases are projected to be three times the global mean. In addition, high confidence is attached to "projected changes in extreme weather and climatic events" (e.g., see Table 1 in the TAR WGI Summary for Policymakers). Such changes, particularly at the higher ends of the ranges given, represent significant deviations from the climatic conditions of recent centuries. As noted above, warming of the climate and sea-level rise would continue for centuries beyond 2100, even if atmospheric concentrations of GHGs stabilize during the 21st century. For perspective, it should be noted that since the early Miocene (about 24 million years ago), atmospheric CO_2 concentrations appear to have remained below 500 ppmv (Pearson and Palmer, 2000). If human emissions of GHG until 2100 remain at or—as in many scenarios in the literature—increase well beyond current levels, CO_2 concentrations will be significantly above this value. It can therefore be remarked that climate changes in the 22nd century could exceed any experienced in more than 1 million years (see, e.g., Crowley, 1990; Crowley and North, 1991). Indeed, these authors estimate that global temperature was never significantly warmer than the present during the past 2 million years and that one would need to return to the early Pliocene (3–5 million years ago) or even the Miocene (5–25 million years ago) to find a climate that is warmer than today by more than 2°C. The potential impacts of these very large projected changes cannot be disregarded, even though it is difficult to imagine what human societies would look like in the 22nd century (see, e.g., Cline, 1992). However—reflecting the scarcity of studies of climatic impacts beyond 2100, despite their potential relevance to Article 2 of the UNFCCC—these impacts are not a major focus in the TAR (although Chapter 19 does focus on the possibilities of abrupt, nonlinear, and/or irreversible climatic changes in the centuries ahead).

1.2.1. Climatic Change Represents Opportunities and Risks for Human Development

Climate change is likely to present opportunities for some sectors and regions. For example, agriculture could expand into regions where it currently is limited by low temperatures, if adequate soils are present (see Chapter 5). Thinning of Arctic sea ice might allow surface navigation in areas that previously were accessible only to submarines and icebreakers (see Chapter 16). The increase in winter temperature could decrease heating demand or mortality from cold spells (see Chapter 9). However, climate change also is likely to have numerous negative effects on human development and well-being. This is documented in Chapers 4–17 and reflected in the first sentence of the UNFCCC, which states that "changes in the Earth's climate and its adverse effects are a common concern of humankind" (United Nations, 1992). The very existence of the UNFCCC demonstrates that the international community exhibits great concern for the risks that climatic change represents for human development and well-being, despite the potential opportunities it offers. Those risks are classified in Article 2 of the UNFCCC, which describes the Convention's ultimate objective (preventing "dangerous anthropogenic interference with the climate system"). That article mentions the need "to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." Because a key function of the IPCC's assessment reports is to help decisionmakers determine what constitutes "dangerous anthropogenic interference with the climate system" (as evidenced by approval at a 1999 IPCC Panel meeting of a series of Policy-Related Questions directed to the Synthesis Report authors; IPCC, 1999b), the discussion that follows is framed according to the aforementioned three categories of impacts.

1.2.1.1. Allow Ecosystems to Adapt Naturally to Climate Change

The speed and magnitude of climate change affect the success of species, population, and community adaptation. The rate of climatic warming may exceed the rate of shifts in certain species ranges; these species could be seriously affected or even disappear because they are unable to adapt (Chapter 5). Some plant and animal species (such as endangered species generally and species adapted to narrow niches for which habitat is discontinuous and barriers impede or block migration) and natural systems (such as coral reefs, mangroves, and other coastal wetlands; prairie wetlands; remnant native grasslands; montane ecosystems near ridges and mountaintops; and ecosystems overlying permafrost) could be adversely affected by regional climatic variations that correspond to a less than 1°C mean global warming by 2100. With mean warming of 1–2°C by 2100, some regional changes would be significant enough so that adverse impacts to some of these highly sensitive species and systems would become more severe and increase the risk of irreversible damage or loss, and additional species and systems would begin to be adversely impacted. Warming beyond 2°C would further compound the risks (note discussions and citations in Chapters 5 and 19).

1.2.1.2. Ensure that Food Production is not Threatened

Human production factors notwithstanding, food production is influenced mostly by the availability of water and nutrients, as well as by temperature. Increases in temperature could open new areas to cultivation, but they also could increase the risk of heat or drought stress in other areas. Livestock (e.g., cattle, swine, and poultry) are all susceptible to heat stress and drought (Gates, 1993). The effects of climatic changes—even smooth trends—will not be uniform in space or time. For smoothly evolving climatic scenarios, recent literature (see Chapter 5) tends to project that high latitudes may experience increases in productivity for global warming up to a 1°C increase, depending on crop type, growing season, changes in temperature regimes, and seasonality of precipitation. In the tropics and subtropics—where some crops already are near their maximum temperature tolerance and where dryland, non-irrigated agriculture predominates—the literature suggests that yields will tend to decrease with even nominal amounts of climate change (IPCC, 1998; Chapter 5). Moreover, the adaptive capacity of less-developed countries in the tropics is limited by financial and technological constraints that are not equally applicable to more temperate, developed countries. This would increase the disparity in food production between developed and developing countries. For global warming greater than 2.5°C, Chapter 5 reports that most studies agree that world food prices—a key indicator of overall agricultural vulnerability—would increase. Much of the literature suggests that productivity increases in middle to high latitudes will diminish, and yield decreases in the tropics and subtropics are expected to be more severe (Chapters 5 and 19). These projections are likely to be underestimates, and our confidence in them cannot be high because they are based on scenarios in which significant changes in extreme events such as droughts and floods are not fully considered or for which rapid nonlinear climatic changes have not been assumed (Section 2.3.4 notes that vulnerability to extreme events generally is higher than vulnerability to changing mean conditions).

Water availability can be regarded as another component of food security. Water quantity and distribution depends to a large extent on rainfall and evaporation, which are both affected in a changing climate. Typically, estimated patterns of changes for 2100 under SRES scenarios include rainfall increases in high latitudes and some equatorial regions and decreases in many mid-latitude, subtropical, and semi-arid regions—which would increase water stress (the ratio between water usage and renewable flow) in the latter regions and decrease it in the former. As noted in Chapter 4, negative trends in water availability have the potential to induce conflict between different users (e.g., Kennedy *et al.*, 1998). For perspective, it should be remembered that the capability of current water supply systems and their ability to respond to changes in water demand determine to a large extent the severity of possible climate change impacts on water supply. Currently, 1.3 billion people do not have access to adequate supplies of safe water, and 2 billion people do not have access to adequate sanitation (Gleick, 1998; UNDP, 1999). In addition to changes in average water supply, climate extremes such as droughts and floods often are projected to become a larger problem in many temperate and humid regions (IPCC, 1998; Table SPM-1, WGII TAR Summary for Policymakers).

1.2.1.3. Enable Economic Development to Proceed in a Sustainable Manner

Sustainable development, as noted earlier, implies "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Besides food and water, essential needs include a space to live, good health, respite from extreme events, peace and basic freedom, energy and natural resources that allow development, and so forth. Each of these factors could be affected by climatic change. For example, if there were no significant adaptive responses, a 1-m sea-level rise would decrease the area of Bangladesh by 17.5% or that of the Majuro Atoll in the Marshall Islands by 80%. Human health impacts of global climatic change include changes in the geographic range and seasonality of various infectious diseases (with positive and negative impacts), increases in mortality and morbidity associated with heat waves, and effects on malnutrition and starvation in some regions as a result of redistribution of food and water resources (Chapter 9). The possibility of improved conditions in other regions remains, but, as noted in Chapter 5, the literature tends to project that positive effects in agriculture would be concentrated in high latitudes and negative effects in lower latitudes—precisely where problems of hunger already exist. The frequency and severity of extreme events such as heat waves, high rainfall intensity events, summer droughts, tropical cyclones, windstorms, storm surges, and possibly El Niño-like conditions are likely to increase in a warmer world (Table SPM-1, WGII TAR Summary for Policymakers), which would have a range of adverse impacts and would affect the conditions of development. Migration of populations affected by extreme events or average changes in the distribution of resources might increase the risks of political instabilities and conflicts (e.g., Myers, 1993; Kennedy *et al.*, 1998; Rahman, 1999). For each of these potential impacts, the relative vulnerability of different regions to adverse impacts of climatic change is largely determined by their access to resources, information, and technology and by the stability and effectiveness of their institutions. This means that possibilities to promote sustainable development will be affected more negatively by climatic change in developing countries and among less-privileged populations. Thus, climatic change could make satisfying the essential needs of these populations more difficult, in the short term and in the long term. In that sense, climatic change is likely to increase world and country-scale inequity, within the present generation and between present and future generations, particularly in developing countries. Given this potential vulnerability, steps to strengthen adaptive and mitigative (see TAR WGIII Chapter 1) capacity and to lessen nonclimatic stressors could well enhance sustainable development.

1.2.2. Human-Environment Systems: Implications for Development, Equity, and Sustainability

The TAR attempts to place the issue of climate change more centrally within the evolving socioeconomic context. This context is critical to evaluation of the vulnerability of sectors or regions to climatic changes and thus must be borne in mind by anyone who attempts such assessments, as well as policymakers who will need to consider the wide range of implications of technological or organizational choices on the resilience of natural and social systems to climatic changes.

Development of social institutions and technological innovations over the past 10,000 years (the era of civilization after the glacial age when ice largely disappeared) has led to rapid advancement in material well-being but also, very importantly, population growth and resource pressures (e.g., Cohen, 1995; Meyer, 1996). This development process has accelerated and become much larger in scale in recent decades. Globally, growth in annual per capita income has been estimated to have risen from about 0.6% in the 19th-century period of industrial expansion to more than 2% yr^{-1} in the post-World War II era of high technological innovation and global economic cooperation (Cooper, 2000). Some analysts attribute this boom to the combination of stabilization of national economies by governmental management and liberalization of trade allowed by international organizations. Indeed, in this vision—which has been labeled the "cornucopian world view" (Ehrlich and Ehrlich, 1996)—a competitive system that fosters and rewards innovation has led to a prolonged period of development and growth that will increasingly embrace currently less-developed nations as well. Furthermore, according to Kates (1996), it is possible to achieve a world without famine, with little seasonal or chronic undernutrition and virtually no nutrient deficiencies or nutrition-related illnesses. In the area of energy and natural resources, according to von Weizsäcker *et al.* (1998), it is possible to increase resource productivity by a factor of four: The world would then enjoy twice the wealth that is currently available, simultaneously halving the stress placed on our natural environment.

However, this level of development continues to be an elusive goal for a large fraction of the world's population. There is a noticeable disparity between the levels of development that have been achieved in various societies. These differences are obscured by globally averaged income growth data such as those reported by Cooper (2000). For example, gaps between the rich and the poor are widening between developed and developing countries and within tropical African, Asian, and Latin American countries (UNDP, 1999). Although there have been notable successes, many countries in these regions have experienced increases in economic instability, social insecurity, environmental degradation, and endemic poverty. Despite spectacular gains in the means of development—such as advances in science, technology, and medicine during the past century—development planning at national and global levels has not always alleviated poverty and inequity (see Box 1-2; Munasinghe, 2000).

Global food security clearly has improved in recent years as the focus of famine has shifted from large, heavily populated countries to sparsely populated and small nations, but the number of people at risk of hunger still is very high, even in parts of heavily populated nations. Chen and Kates (1996) estimate that the population at risk of outright starvation could be as high as 35 million; FAO (1999) estimates that about 800 million people in developing countries and 34 million people in developed countries suffer from undernourishment. Achieving global food security is complicated by growth in human population and political instability that disrupts food delivery systems. Projections vary widely, ranging from stabilization of population at near-present levels sometime in the 21st century to a greater than three-fold increase by the end of the century (e.g., Fischer *et al.*, 1996; Lutz, 1996; IPCC, 2000). At current population growth rates, world food production must double within the next 40 years to feed this population; such a doubling of food production may require expansion of agricultural land into forests and areas that presently are considered marginal for agriculture (but not necessarily marginal in other respects). On the other hand, some authors (e.g., Waggoner *et al*., 1996) have argued it is possible to increase the dietary standard of all humans up to a doubling of current populations and at the same time to "spare land for nature" (Ausubel, 1996). This expansive vision follows from the belief that resources can be made available for the extension of current intensive agricultural practices to currently low-technology regions. The extent to which such practices can be extended is debated, on social and environmental grounds, by those who hold an opposing worldview, which has been called "limits to growth" (e.g., Ehrlich *et al*., 1995). Moreover, even if such agricultural intensification were to occur, there is no guarantee that extensive land use for economic development activities other than growing food would not simultaneously occur. Thus, the hope of "sparing land for nature" via intensification likewise is a controversial vision.

The need to improve productivity per unit area has led to more intensive methods in developing countries—which, together with low or negative economic support for agricultural products, often has driven smallholders off their land and led to emigration to urban centers (WCED, 1987). The influx of poor, unskilled, and often unemployable people has led to explosive and difficult-to-manage growth in these centers (O'Meara, 1999). This sets the stage for the gestation of a new set of environmental problems, including substandard housing, squatter settlements, solid waste buildups, unsatisfactory sewage disposal, urban floods, and urban water pollution, as well as the characteristic problems of large cities such as crime and social insecurity.

In opposition to the aforementioned expansive visions, others (e.g., Daily, 1997) express concern that services provided by ecosystems to society may be undermined by a combination of unsustainable population growth, destruction of natural habitats, and pollution of air, soils, and waters. Three decades ago, debate raged about whether indefinite economic expansion would be limited by environmental and other resource constraints. Meadows *et al.* (1972) postulated in a controversial work that environmental protection and economic growth are not compatible; there are "limits to growth." For those holding this worldview, current development patterns will not allow continued improvement of the human condition for much longer; instead, such development will ensure continuing degradation of natural assets such as biodiversity (e.g., Pimm, 1991). Thus, it is feared that the environment may be losing part of its capacity to support life and therefore may be imposing another set of constraints on the development process—disturbances to air, waters, soils, and species distributions brought about by human activities—that will require responses to reduce additional risks. Several sharp critiques appeared (e.g., Cole *et al.*, 1973), noting that the "limits" paradigm ignored enhanced productivity brought about by innovation and that although limits eventually might become a problem, increased knowledge generated by economic expansion could create substitutes for resources that were being used nonrenewably, and much less energy and materials would be needed to produce economic growth as technology blossomed (e.g., Grossman and Krueger, 1995; but see Myers and Simon, 1994). Moreover, it has been argued that enhanced wealth and knowledge also can reduce vulnerability to environmental stresses such as climatic change.

Subsequently, a modified view that considered both the "cornucopian" and "limits" paradigms emerged: the strategy of sustainable development. It is designed to promote conservation of resources and protection of the environment while sustaining a healthy society whose needs are securely provided. In response to requests from governments participating in the IPCC process, the TAR is attentive to the concept of sustainable development.

Technology and organization clearly have reduced the vulnerability of humans in some countries to a variety of hazards. In the context of the IPCC process, this would include, for example, flood control engineering projects that have reduced lives lost in catastrophic flooding. However, pioneering analyses in the natural hazards literature (e.g., Burton *et al.*, 1993) note that large-scale dependence of massive populations on the functioning of giant engineering projects or social institutions often has simply transformed our risks from the predevelopment state of high-frequency, low-amplitude risk (many localized threats to small numbers of people in each instance) to the present state of low-frequency, high-amplitude vulnerability (where a rare levee failure or the simultaneous occurrence of drought in several major exporting granaries poses the risk of infrequent but very catastrophic losses). Moreover, the consequences of these risks are unlikely to be equitably distributed within and across income groups and nations, which requires assessment of the distributional implications of developmental risks and benefits (e.g., Box 1-2). In many developing regions, population pressures and poverty have led to occupation of hazardous lands (e.g., steep slopes, valley bottoms) and has greatly increased vulnerability to climate extremes. Of course, many factors other than those mentioned above can contribute to vulnerability (e.g., Etkin, 1999).

In addition to this huge list of challenges, potential threats to the global environment are connected to the development process. The TAR identifies scientific and policy linkages among key global environmental issues, one of which is climate change. Other global environmental issues include loss of biological diversity, stratospheric ozone depletion, marine environment and resource degradation, and persistent organic pollutants (Watson *et al*., 1998). Other contemporary issues are evident in many places across the globe—though each instance is not global in scale (e.g., Turner *et al.*, 1990)—such as freshwater degradation, desertification, land degradation, deforestation, and unsustainable use of forest resources. None of these threats implies that the *net* effects of human developments are necessarily negative, only that embedded in many development activities are a host of negative aspects that many analysts and policymakers believe must be considered in development planning. Strategies to modify the amount and/or kinds of development activities to account for these threats are considered more comprehensively in the report of Working Group III. The TAR also focuses on linkages between climate change on one hand and local and regional environmental issues—for example, urban air pollution and regional acid deposition—on the other. (Strategies to deal with these issues that also help with adaptive or mitigative capacity for climate change often are called co-benefits.) Among the new areas of emphasis in the TAR are linkages between global environmental issues and the challenges of meeting key human needs such as adequate food, clean water, clean air, and adequate and affordable energy services.

1.3. How has Society Responded?

1.3.1. International Responses

A primary response to concerns about climate change has been *international* action to address the issue, particularly through the UNFCCC. International action to date has focused mainly on mitigation, although adaptation is mentioned in UNFCCC Article 4.1 (e) and in funding by the Global Environment Facility (GEF) of adaptation studies (e.g., the Caribbean Planning for Adaptation to Climate Change program). Multinational action is required because no single country or small group of countries can reduce emissions sufficiently to stop GHG concentrations from continuing to grow and because wherever emissions originate, they affect climate globally. Because the extent and urgency of action required to mitigate emissions depends on our vulnerability, a key question is the degree to which human society and the natural environment are vulnerable to the potential effects of climate change.

At the first meeting of the Conference of Parties to the UNFCCC in 1995, governments reviewed the adequacy of existing international commitments to achieve this goal and decided that additional commitments were required. They established the Ad Hoc Group on the Berlin Mandate (AGBM, 1995) to identify appropriate actions for the period beyond 2000, including strengthening of commitments through adoption of a protocol or another legal instrument. The AGBM process culminated in adoption of the Kyoto Protocol in December 1997 (United Nations, 1997). In the Kyoto Protocol, industrialized countries (Annex I Parties to the UNFCCC) agreed to reduce their overall emissions of six GHGs by an average of 5% below 1990 levels between 2008 and 2012. The Protocol also allowed the Parties to account for the removal of GHGs by sinks resulting from direct, human-induced land-use change and forestry activities, emissions trading, "joint implementation" (JI) between developed countries, and a "clean development mechanism" (CDM) to encourage joint emissions reduction projects between developed and developing countries and a commitment to provide assistance in meeting the costs of adaptation for countries deemed most vulnerable to the adverse effects of climate change using the proceeds of the CDM (Article 12). To date, the Kyoto Protocol has not entered into force. The UNFCCC also established national reporting requirements for all Parties regarding their emissions and their potential vulnerabilities/adaptation options. These reporting obligations are being fulfilled through preparation of National Communications to the UNFCCC.

The foundation for any policy to address the climate change problem is information on GHG emissions, the climate system and how it may change, likely impacts on human activities and the environment, and the costs and co-benefits (e.g., protecting primary forests not only retains stored carbon in the trees but also confers the "co-benefit" of biodiversity protection; Kremen *et al*., 2000) of taking steps to reduce GHG emissions or to change land use. To provide the best available scientific information for policymakers and the public, governments established the IPCC to periodically assess and summarize the state of knowledge in the literature related to climate change. The IPCC completed comprehensive assessments in 1990 and 1995 of the effects of human activities on the climate system, potential consequences of climate for natural and human systems, and the effectiveness and costs of response options (IPCC, 1990, 1996a,b,c). In addition, the IPCC has prepared numerous special reports, technical papers, and methodologies on topics ranging from radiative forcing of climate to technologies, policies, and measures for emissions mitigation. As knowledge has progressed, IPCC assessments have added a regional focus by assessing regional climate modeling and regional sensitivities and adaptive capacity.

Other international bodies also are taking up the challenge of climate change. These organizations include the World Bank, the United Nations Environment Programme (UNEP), the UN Development Programme (UNDP), and the GEF, as well as a variety of regional institutions. Although a primary audience for this report is those who are involved in negotiating and implementing the UNFCCC and, to some extent, other international agreements on global environmental problems, the report also contains information that is useful to other international institutions. The report has been designed to be useful in assessing potential projects and opportunities for investment that will be robust to potential negative effects and to emerging opportunities from climate change.

1.3.2. National and Local Governmental Responses

Governments have initiated a spectrum of responses, ranging from international assessments of climate science, impacts, and abatement strategies (the United States, for example) to implementation of a legally binding mitigation policy (Sweden, for example, has implemented a domestic carbon tax on direct fuel use and on fuel use in the transportation sector; see also OECD, 1999). Governments also have produced country studies, vulnerability assessments of sea-level rise, and national communications; carried out GHG reductions in other countries; and created research opportunities and fora for exchanges of ideas and data. Such management of climate-related research and educational activities has accelerated in the wake of climatic assessment that suggested a discernible human influence on climate (IPCC, 1996a). Similarly, many countries have implemented policies for reasons unrelated to climate change that nevertheless have led to reductions of GHG emissions (e.g., the ethanol program in Brazil, support to renewable energy and energy efficiency in a large number of countries). With regard to adaptation, the first National Communications to UNFCCC from most countries contained analyses of vulnerability and adaptation options.

At the local level, dozens of cities—mainly in industrialized countries—have adopted GHG emission reduction targets and have taken measures to implement them, mostly in the energy and transport sector. In many cases, these policies have been defined by coupling climate protection objectives with other, more local objectives: co-benefits such as reducing air pollution, traffic congestion, or waste production. Some measures, such as water conservation, are adaptive (more resilient to drought) and reduce emissions (less energy for pumping). The use of "social" policy instruments such as public awareness campaigns, information, and technical assistance is commonplace (OECD, 1999). With regard to adaptation, for example, the Federation of Canadian Municipalities is promoting adaptation as well as mitigation measures.

Many countries have developed national climate strategies that are based on a diverse range of policy instruments such as economic instruments, regulation, research and development, and public awareness and information. Energy efficiency, fuel switching, public transportation, and renewable energies typically are promoted. The government sector itself is an increasingly common target for GHG mitigation, and "greening" of government purchasing policies has started to take place in some countries (OECD, 1999).

Overall, these policies and measures to date have had limited effect on emissions, probably because of their lack of integration in a truly global, long-term framework, as well as continued economic growth around the world (AGBM, 1995).

1.3.3. Organizational Responses

Numerous private businesses have developed plans to facilitate trading of permits for carbon emissions or have set up schemes to help manage CDM transactions if the Kyoto Protocol is ratified or some other instrument of carbon policy is put in place by some nations. Moreover, large multinational corporations such as Shell International and BP Amoco have declared that they will voluntarily observe elements of the Kyoto Protocol (van der Veer, 1999; Browne, 2000).

International scientific organizations have responded to the prospect of climate changes for more than 2 decades, from the second objective of the Global Atmospheric Research Program (GARP) to a series of World Climate Conferences sponsored by the World Meteorological Organization and UNEP. The International Council of Scientific Unions and dozens of national scientific societies have responded by creating journals to publish the results of climatic assessments, organizing many meetings and symposia to further our understanding of climate-related scientific issues, and creating committees to help steer research in promising directions.

Similarly, environmental nongovernmental organizations (NGOs) around the world have initiated climate campaigns with the aim of convincing citizens and governments to strengthen the Kyoto Protocol. Meanwhile, direct advertisements have appeared in the media—primarily sponsored by organizations that are attempting to influence public opinion to oppose the Kyoto Protocol.

1.3.4. Adaptive Responses

Natural and human systems have adapted to spatial differences in climate. There also are examples of adaptation (with varying degrees of success) to temporal variations—notably, deviations from annual average conditions. Many social and economic systems—including agriculture, forestry, settlements, industry, transportation, human health, and water resource management—have evolved to accommodate some deviations from "normal" conditions, but rarely the extremes.

Adaptations come in a huge variety of forms. Autonomous adaptations invariably take place in reactive response (after initial impacts are manifest) to climatic stimuli as a matter of course, without directed intervention by a public agency. The extent to which society can rely on autonomous, private, or market adaptation to reduce the costs of climate change impacts to an acceptable or nondangerous level is an issue of great interest. There is little evidence to date that efficient and effective adaptations to climate change risks will be undertaken autonomously (see Chapter 18).

Planned adaptations can be reactive or anticipatory (undertaken before impacts are apparent). Potential adaptations include sharing losses, modifying threats, preventing or decreasing effects, changing use, and changing location. There are many lists of adaptation measures, initiatives, or strategies that have potential to moderate impacts, if they were implemented. Such lists indicate the range of strategies and measures that represent possible adaptations to climate change risks in particular sectors and regions. Only in a few cases have such lists of potential adaptations considered who might undertake them, under what conditions might they be implemented, and how effective might they be.

Knowledge of processes by which individuals or communities actually adapt to changes in conditions over time comes largely from analog and other empirical analyses. These studies indicate that autonomous adaptations tend to be incremental and ad hoc, take multiple forms, occur in response to multiple stimuli (usually involving a particular catalyst, rarely climate alone), and are constrained by economic, social, technological, institutional, and political conditions

Although an impressive variety of adaptation initiatives have been undertaken across sectors and regions, responses are not universally or equally available. Adaptation options generally occur in socioeconomic sectors and systems in which turnover of capital investment and operating costs is shorter, and less often where long-term investment is required. Examples include purchase of more efficient irrigation equipment by individual farmers in anticipation of increased evapotranspiration in a warmer climate, design of bridges or dams to account for an expected increase in sea level or extremes of drought and flood, purchase of insurance, abandonment of insurance coverage to people living in high-risk areas such as coastlines, and creation of migration corridors for species expected to be forced to migrate with climate change.

Often more than one adaptation option is available. People rarely seem to choose the best responses—those among available options that would most effectively reduce losses—often because of an established preference for, or aversion to, certain options. In some cases, there is limited knowledge of risks or alternative adaptation strategies. In other cases, adoption of adaptive measures is constrained by other priorities, limited resources, or economic or institutional barriers. Recurrent vulnerabilities, in many cases with increasing damages, illustrate less than perfect adaptation of systems to climatic variations and risks. Chapter 18 describes some evidence that the costs of adaptations to climate conditions are growing.

Current adaptation strategies with clear applications to climate change in agriculture include moisture-conserving practices, hybrid selection, and crop substitution. In the water resources sector, current management practices often represent useful adaptive strategies for climate change. Some analysts go further to point out that certain adaptations to climate change not only address current hazards but may be additionally beneficial for other reasons. Such evaluations are further complicated by the existence of secondary impacts, related to the adaptation itself. For example, water development projects (adaptations to water supply risks) can have significant effects on local transmission of parasitic diseases. Improved water supply in some rural areas of Asia has resulted in a dramatic increase in Aedes mosquito breeding sites and, consequently, outbreaks of dengue (Section 18.4.4).

1.4. How are Impacts, Adaptation, and Vulnerability Assessed in this Report?

An important new category of issues on climatic impacts pertains to methodological advances; Chapter 2 provides more details. These advances include methods for assessing impacts and vulnerability, methods for detecting biotic response to climate change in natural ecological systems by using indicator species, and detection and attribution of observed changes in environmental systems to climatic changes, as distinct from other possible causal factors (Chapter 5). Other new methods relate to costing and valuation, decision analytic techniques and frameworks, uncertainties assessment, and consistent characterization of levels of confidence that could be attached to observations or conclusions (see Box 1-2 and Chapter 2). All of these developments extend methodological considerations beyond those typically employed in the SAR. Development and application of regional-scale scenarios to climate change impacts, adaptations, and vulnerability (as described in Chapter 3) represent a new emphasis of a technique that was limited in the SAR to the science of climate change. The directive in the IPCC's charge to Working Group II to emphasize regional issues is reflected in the eight regional chapters (Chapters 10–17). This directive calls for utilization of new advances in knowledge, including integrated methods, to assess the most cost-effective approaches to adapt to changes in climate at the regional level. This section elaborates briefly on several issues that are related to assessment of impacts, vulnerability, and adaptation and illustrates several of the foregoing methodological considerations.

1.4.1. Sensitivity, Adaptability, and Vulnerability

This report assesses recent advances in our understanding of the vulnerability of major sectors, systems, and regions to climate change. Consistent with common usage and definitions in the SAR, *vulnerability* is defined as the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the *sensitivity* of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects), *adaptive capacity* (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and the degree of *exposure* of the system to climatic hazards (Figure 1-2). Under this framework, a highly vulnerable system would be a system that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained. *Resilience* is the flip side of vulnerability—a resilient system or population is not sensitive to climate variability and change and has the capacity to adapt.

Adaptation is recognized as a crucial response because even if current agreements to limit emissions are implemented, they will not stabilize atmospheric concentrations of GHG emissions and climate (Wigley, 1998). Hence, adaptation is considered here, along with mitigation—the more widely considered response to climate change—as a key component of an integrated and balanced response to climate variability and change (MacIver, 1998). Adaptations, which can be autonomous or policy-driven, are adjustments in practices, processes, or structures to take

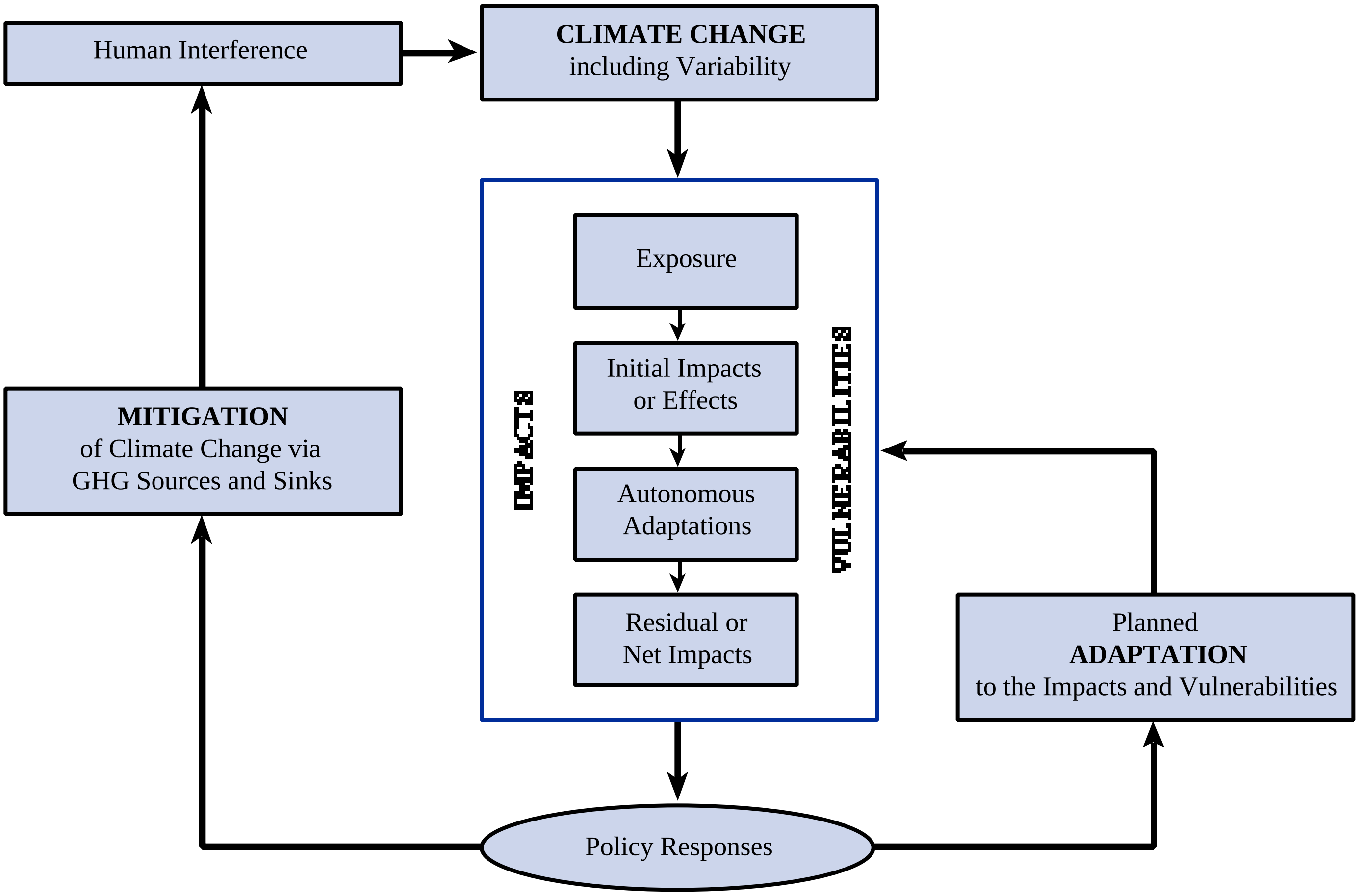


Figure 1-2: Places of adapatation in the climate change issue (Smit *et al*., 1999).

account of changing climate conditions. Impacts, however, sometimes are difficult to identify, let alone quantify, in part because of the nonlinear nature of climate change itself. Impacts can be subtle but nonetheless significant, and their consequences can differ for different members of the same community—as when some individuals or groups perceive an opportunity with change and others experience a loss, thereby changing community dynamics and complicating decisions about how to adapt and the apportionment of costs of adaptation. Negative impacts often are observed as chance occurrences (surprises) beyond critical values (thresholds) of accustomed weather parameters. They can be conceived as risks or the "probability of occurrence of a damaging event," such as flood, drought, strong winds, heat wave, subfreezing temperatures, or forest or bush fire. "The extent to which natural ecosystems, global food supplies and sustainable development are in danger depends partly on the nature of climate change and partly on the ability of the impacted systems to adapt" to these events (Smit *et al.*, 1999).

The capacity of a sector or region to adapt to climatic changes depends on several factors (see Figure 1-2 and Chapter 18). The literature emphasizes that studies that neglect adaptive potential are likely to overestimate the costs of climatic impacts (e.g., Reilly *et al.*, 1996). However, more recent literature also notes that maladaptations are possible—particularly when information about future climatic and other conditions is much less than perfect—as a response to an incorrect perception of such changes, often driven by a masking of slowly evolving trends by large natural variability or extreme events (West and Dowlatabadi, 1999; Schneider *et al.*, 2000a; West *et al.*, 2001). Maladaptations can increase the costs of impacts relative to those when adaptive agents have perfect foresight or when adaptive responses are absent. On the other hand, appropriate adaptations can reduce negative impacts or take advantage of new opportunities presented by changing climate conditions. The SAR assessed technical options for adaptation but did not evaluate the feasibility of these options for different regions and circumstances because little information was available in the literature. The *Special Report on Regional Impacts of Climate Change* focuses to a greater extent on the regional dimensions of adaptation; because the report is based largely on the SAR, as well as early and preliminary results from country studies and national communications to the UNFCCC, however, many questions about the capacities required to implement theoretically promising adaptation options remain. Hence, in this report, greater attention has been focused on societal determinants of adaptive capacity and vulnerability. To the extent possible, the report seeks to examine information in the literature on the interaction of these factors to develop options for bolstering adaptive capacity.

Previous IPCC assessments conclude that most systems are sensitive to the magnitude and the rate of climate change. Sensitive systems include, for example, aspects of food and fiber production, water resources, ecosystems of all types, coastal systems, human settlements, and human health. This sensitivity includes adverse effects in many regions, as well as potentially beneficial effects in some regions and sectors (high confidence). Social systems generally are more resilient than natural systems because of the potential for deliberate adaptation (high confidence). However, confidence in most specific aggregate estimates of impacts remains low because of uncertainties and complexities of analysis (as detailed further in succeeding sections).

For systems that already are exposed to increasing resource demands, unsustainable management, and pollution, exposure to climate change is an important additional pressure. Systems that are exposed to multiple pressures (synergistic effects) usually are more vulnerable to climate change than systems that are not (high confidence).

1.4.2. Detection and Attribution of Impacts to Climate Change

Many observed changes in ecosystems, animal (e.g., butterfly and bird patterns) and plant (e.g., timing of flowering) species, and physical systems (e.g., glaciers or river runoff) have been associated with observed changes in climate (not necessarily anthropogenic changes) in recent decades (high confidence). Moreover, as described in Chapters 5 and 19, such observed changes often are in the directions expected as a response to climate stimuli, based on understandings expressed in the literature about biophysical processes that govern responses to climate (e.g., Root and Schneider, 2001; Root *et al.*, 2001). This consistency has led the authors of such studies to conclude that surface temperature trends of recent decades are likely to be discernible at regional scales through observed changes in biological and physical entities for several systems (varying confidence, depending on which specific system is considered; see, e.g., Chapters 5 and 19). From these observed responses to the relatively small climate changes observed to date (as compared to changes projected for the next century), it is concluded that many environmental systems can be highly sensitive to climate change. However, determination of a potential causal relationship between the response of a physical or biological system to observed recent climatic changes does not imply that regional climate changes were a direct result of anthropogenic global climatic trends, although the latter are likely to have had significant influence on many regional trends. Working Group II does not focus on evaluating the likelihood that regional observed climatic variations are caused by anthropogenic climate changes; detection and attribution assessment of climatic changes is primarily a Working Group I activity. As noted, however, Working Group II does address attribution of observed changes to environmental systems to observed climate changes, even if the connection to possible anthropogenic climate changes is not specifically addressed here.

1.4.3. Key Determinants of Impacts

1.4.3.1. Magnitude of Change

Early studies concentrated on impacts caused by changes in global mean temperature. Often these studies were carried out at a few elevated temperatures—typically, 2°C and 4°C (corresponding to the bulk of the range of IPCC Working Group I SAR equilibrium temperature rise expected for a doubling of CO_2 concentration above pre-industrial levels). Global mean temperature still is a significant variable, serving as a modulus of change against which to compare climate sensitivities and impacts. In addition to mean quantities, however, other characteristics of climate measures, such as climate variability or runs of unusually warm weather, have become important variables for analysis (e.g., Mearns *et al.*, 1984; Colombo *et al.*, 1999), as has specification of changes in regional temperatures, sea level, and precipitation. These expanded measures of climatic change are routinely included in recent impact studies (e.g., IPCC, 1998). Less often considered are changes in extreme events (but see Table SPM-1, WGII TAR Summary for Policymakers), despite their potential importance.

1.4.3.2. Rate of Change

It is essentially undisputed that a sustained 2°C temperature change occurring in a decade would have a more profound impact than one occurring over a century. The effect of rates of change on impacts is still under active investigation (see Chapter 19). Early results have suggested that rates of change exceeding the ability of ecosystems to migrate would be particularly damaging (see Chapter 5). Adaptation of coastal dwellers to rapid climatic changes or a high background "noise level" of natural variability would be more difficult relative to slowly occurring changes or smoothly varying climates (e.g., West *et al.*, 2001). Finally, as noted by IPCC Working Group I (1996a, p. 7), "nonlinear systems, when rapidly forced, are particularly subject to unexpected behavior." In other words, the adaptability of various decision agents would be reduced if any change is unexpected; thus, a rapid rate of change is more likely to generate "surprises" that inhibit effective adaptation by natural and managed systems. Table 1-1 describes several extreme events that can substantially influence the vulnerability of sectors or regions to climatic changes (see also Table SPM-1, WGII TAR Summary for Policymakers).

Economists also have suggested that the transient stage of moving from one equilibrium climate to another could cause the greatest economic impacts, even if the static impacts of the new equilibrium climate were small (Nordhaus and Boyer, 2000).

1.4.3.3. Transient Scenarios

Climate sensitivity—the globally averaged response of the surface temperature to a fixed doubling of CO_2—is based on static or equilibrium calculations in which the climatic model

***Table 1-1**: Typology of climate extremes.*

Type	Description	Examples of Events	Typical Method of Characterization[a]
Simple extremes	Individual local weather variables exceeding critical level on a continuous scale	Heavy rainfall, high/low temperature, high wind speed	Frequency/return period, sequence and/or duration of variable exceeding a critical level
Complex extremes	Severe weather associated with particular climatic phenomena, often requiring a critical combination of variables	Tropical cyclones, droughts, ice storms, ENSO-related events	Frequency/return period, magnitude, duration of variable(s) exceeding a critical level, severity of impacts
Unique or singular phenomena	A plausible future climatic state with potentially extreme large-scale or global outcomes	Collapse of major ice sheets, cessation of thermohaline circulation, major circulation changes	Probability of occurrence and magnitude of impact

[a] Stakeholders also can be engaged to define extreme circumstances via thresholds that mark a critical level of impact for the purposes of risk assessment. Such critical levels often are locally specific, so they may differ between regions.

is allowed to reach a steady state after the CO_2 increase is applied. The real Earth, on the other hand, is being forced by a time-evolving forcing of GHGs and other global change forcings; this, combined with the time-evolving response of the climate system to any forcing, means that the amount of global climatic warming, as well as the time-evolving patterns of climatic changes, are likely to be different during the transient phase of climatic change than in equilibrium. Recent studies of climate change impacts have made use of transient or time-dependent scenarios of climate change that are derived from fully coupled, ocean-atmosphere general circulation models (AOGCMs). These studies indicate that many systems would be notably affected (see Chapter 19)—some adversely and some beneficially—by changes in climate within the next 2 to 3 decades (high confidence). Farther into the 21st century, as radiative forcing on the climate builds, the magnitude of adverse impacts would increase, the number and scale of many beneficial effects would decrease (Chapter 19), and the probability that adverse impacts would predominate would increase (high confidence). Transient scenarios are just entering the climate impacts literature, which unfortunately tends to lag the climate effects literature by several years; thus, much of the impacts literature still is based on equilibrium climate change scenarios. To the extent possible, Working Group II has assessed literature that uses transient scenarios. It is important to use transient scenarios as much as possible because the climate effects literature suggests that static calculations (typically, CO_2 held fixed at double pre-industrial concentrations) do not produce the same time-evolving regional patterns of climatic changes as do transients—and because, of course, the actual Earth is undergoing a transient response to anthropogenic forcings.

1.4.3.4. Climate Variability and Extreme Events

Most studies of climate change impacts have focused on changes in mean climate conditions. However, global climate change is likely to bring changes in climate variability and extreme events as well. This is relevant here because decisionmakers often consider hedging strategies to be prepared for the possibility of low-probability but high-consequence events—a risk management framework. Features of projected changes in extreme weather and climate events in the 21st century include more frequent heat waves, less frequent cold spells (barring so-called singular events), greater intensity of heavy rainfall events, more frequent midcontinental summer drought, greater intensity of tropical cyclones, and more intense El Niño-Southern Oscillation (ENSO) events (Table SPM-1, WGII TAR Summary for Policymakers).

Asmall number of studies have investigated the potential impacts of hypothesized changes in climate variability and/or extreme events. Results of these studies, coupled with observations of impacts from historical events (e.g., Chapter 8), suggest that changes in climate variability and extremes are likely to be at least as important as changes in mean climate conditions in determining climate change impacts and vulnerability (high confidence). The literature suggests that omission of changes in extreme events and/or climate variability will yield underestimates of climate change impacts and vulnerability. In its assessment of potential vulnerabilities and adaptation options, Working Group II has focused on the interactions of natural climate variability and anthropogenic change and the potential for "win-win" adaptation options that would increase resilience to both phenomena.

1.4.3.5. Thresholds

In many environmental fields, there are thought to be thresholds below which only minor effects occur. Critical levels in acid rain are one example (Brodin and Kuylenstierna, 1992). These kinds of thresholds also are possible in climate change and are incorporated into some models as "tolerable" levels that must be exceeded before significant impacts occur (Hope *et al.*, 1993).

However, in climate change, thresholds have been proposed that are much more complicated. Below the threshold, there may be some impacts, but they will be smoothly varying with the change in climate. Some positive effects might even be observed in some regions or sectors for a small global warming, giving the impression that there is little impact. Above the threshold, however, potentially damaging events may occur. For example, most models show (by 2100) a weakening of thermohaline circulation that transports warmer water to the North Atlantic (see TAR WGI Summary for Policymakers) but only very low confidence that there will be full collapse of the thermohaline circulation by 2100—although some rapid greenhouse buildup scenarios suggest that emissions during the 21st century could trigger a collapse in the following century (e.g., Rahmstorf, 1999; Schneider and Thompson, 2000). Likewise, only very low confidence is given to the prospect of substantial collapse by 2100 of the West Antarctic Ice Sheet (TAR WGI Summary for Policymakers). Other examples of potential threshold phenomena can be found in the literature for regional situations. For example, Wang and Eltahir (2000) demonstrate that rainfall in the Sahel region of Africa can have several equilibrium values, depending on the level of disturbance to vegetation cover. For vegetation removal of less than a threshold value, the system recovers within a few years. For vegetation removal above a threshold, however, there is a new steady-state rainfall regime that is much reduced from "normal" conditions. These thresholds may be, as characterized previously, a result of rapid transient forcing of the climate system, in terms of altered radiative properties of the atmosphere or characteristics of the land surface. Although such threshold events remain somewhat speculative, their impacts clearly would be more severe than smoothly varying (and thus more adaptable) events. Some thresholds in impacts, however, are much less speculative, such as hospital admissions for heat conditions above a threshold temperature—and these threshold temperatures vary regionally as there is some acclimatization to heat stress (Chapter 9)—or species living near mountaintops that would be forced out of existence, even by smooth climatic warming, because they reached the threshold of having no place to move up into (e.g., Still *et al.*, 1999).

Sometimes the expression "threshold" is used as an approximation when the response actually is more likely to be smooth but strongly nonlinear. The release of methane from gas hydrates trapped in deep sediments and the health impacts of thermal stress would be examples of this category. Working Group II assesses potential thresholds for ecological and human systems.

1.4.3.6. Surprises

By definition, it is difficult to give examples of the surprises that might be created under a changed climate. Such surprises, however, can make even the most careful calculation of impacts extremely inaccurate, as noted previously. Surprises have been classified by many authors in many contexts (see Schneider *et al.*, 1998, for a review of the literature and many citations). In particular, low-probability events—or those whose probability is difficult to assess—often are labeled rhetorically as "surprises," even though the event has been classified or identified as known. Strictly speaking, such events are more accurately called "imaginable surprises;" true surprises are wholly unexpected events. Another useful category is "imaginable conditions for surprise" (Schneider *et al.*, 1998), where the specific event in question is unexpected but a set of conditions that increases the likelihood of surprises can be assessed; increasing the rate of forcing of the climatic system is one example, as noted in Section 1.4.3.2.

1.4.3.7. Nonlinear, Complex, and Discontinuous Responses

Investigations into climate change and its potential consequences have begun to highlight the importance of strongly nonlinear, complex, and discontinuous responses. These types of responses, called singularities, can occur at all temporal and spatial scales of systems influenced by climate change (high confidence can be given to the likelihood that some such singularities will occur, but low confidence usually is assigned to any specific example of a possible abrupt event; see Chapter 19). Strongly nonlinear responses are characterized by thresholds—which, if exceeded by a stimulus, result in substantially greater sensitivity to further stimulus or dramatic change, explosive growth, or collapse. Complex responses involve interactions of many intricate elements that yield outcomes that are not easily predicted. Examples of these types of responses include coral bleaching, collapse of fish stocks, disease outbreaks, changes in fire and other disturbance regimes in vegetation systems, crop failure, malnutrition and hunger, and collapse of pastoral communities. Advances in our understanding of these types of responses are largely qualitative, but they are important in understanding the character of dangers posed by climate change. Omission of potential nonlinear and complex responses from climate change impact assessments is expected (well-established, but incomplete) to yield underestimates of impacts (see Chapters 5 and 19). Because of the magnitude of their potential consequences, large-scale discontinuous responses warrant careful consideration in evaluations of climate change dangers. Working Group II points to the potential for such occurrences and their potential consequences for human and natural systems, but it is unable to provide detailed assessments of potential effects, given the paucity of information in the literature.

1.4.4. Synergies and Tradeoffs

1.4.4.1. Synergies and Tradeoffs between Climate Change and Other Environmental Issues

Climate change is only one issue among many. The early stages of economic development typically lead to an increase in many pollutants, and actions taken to reduce one can have ancillary benefits caused by simultaneous reduction of others. Assessments that neglect these synergies can seriously underestimate the justification for cutbacks. On the other hand, impacts from climate change can depend on the levels of other pollutants. For example, forests weakened by acid rain are likely to be more vulnerable to changes in rainfall brought on by climate change or warming, and lake acidification can have a synergy with ultraviolet radiation penetration into the water (e.g., Schindler *et al.*, 1996). While maintaining its primary focus on decadal to centennial-scale climate change, Working Group II has examined linkages among climate change and other environmental issues, including climate variability, loss of biodiversity, deforestation, and desertification.

1.4.4.2. Synergies and Tradeoffs between Adaptation and Mitigation

It is often argued in the literature that there is a tradeoff between adaptation and mitigation in that resources committed to one are not available for the other. This is debatable in practice because the people who bear emission reduction costs or benefits often are different from those who pay for and benefit from adaptation measures. Arguments are given on both sides of this issue. On one hand, in a straight comparison, several factors point to the wisdom of initially committing resources to adaptation. Insofar as no level of mitigation will completely prevent some climate change, some adaptation will be necessary. The benefits from adaptation are received in the country that incurs the costs, so there is no "free-rider" problem; climate change from GHG emissions that already have occurred means that adaptation will be required even if quite stringent mitigation also is agreed on; many adaptation options, such as switching agricultural crops and strengthening seawalls, are relatively cheap options for some (but not all—e.g., for small island states), and there may be ancillary benefits of the adaptation action even if climatic change effects turn out to be small (e.g., "no regrets" policies such as improving the efficiency of irrigation equipment).

On the other hand, it has been argued that climatic changes today still are relatively small, thus there is little need for adaptation, although there is considerable need for mitigation to avoid more severe future damages. By this logic, it is more prudent to invest the bulk of the resources for climate policy in mitigation, rather than adaptation.

It is reasonable to assume that many adaptation options will be pursued. This means that the baseline against which mitigation options should be assessed is one with adaptation also occurring. If the adaptations were effective in reducing the costs of climatic impacts, this can significantly reduce the benefits that otherwise would have been attributable to mitigation. On the other hand, as Section 1.4.1 notes, lack of perfect foresight about future climatic or other relevant social trends can lead to maladaptations. This situation would then argue for more emphasis on mitigation because maladaptations in the future would increase the costs of climatic impacts thus justify stronger abatement efforts. Furthermore, it has been argued that early steps toward mitigation can lower long-term costs of carbon abatement by reducing the rate at which the energy-intensive capital stock has to be turned over, by inducing research and development, and/or by enhancing learning by doing (Grubb *et al.*, 1994; Azar, 1998; Goulder and Schneider, 1999). Others have argued that delayed abatement is more cost-effective because the bulk of the climate damages are likely to occur in the future, whereas the costs of immediate abatement occur in the nearer term; thus, discounting reduces the present value of the benefits of avoided climate damage versus less discounted abatement costs (e.g., Wigley *et al.*, 1996). Working Group III explores these issues in more depth, but in the context of the Working Group II mandate it must be recognized that many factors that still contain considerable uncertainty enter the debate about tradeoffs between timing and magnitudes of adaptation and mitigation efforts.

1.4.5. Integrated Assessment

Given the multi-sectoral, multi-regional, multidisciplinary, and multi-institutional nature of the integration of climatic change assessments of effects, impacts, and policy options, methods to perform "end-to-end" analyses have been developed and often are labeled "integrated assessments" (see, e.g., Weyant *et al.*, 1996; Morgan and Dowlatabadi, 1996, and references therein). Integrated assessment models (IAMs) have been developed to provide the logical consequences of a variety of explicit assumptions that undergird any formal assessment technique. IAMs seek to combine knowledge from several disciplines that is relevant to climate change in mathematical representations of the determinants of GHG emissions, responses of the climate system and feedbacks to emissions, effects on socioeconomic activities and ecosystems, and potential policies and responses (Parson and Fisher-Vanden, 1997). To date, IAMs have relied primarily on highly aggregated representations that directly link monetized measures of projected impacts to mean climate variables—principally, annual global mean temperature. Over time, these sorts of estimates have been extended by introducing variation between regions, by separating market and nonmarket damages, or by introducing other climate variables such as precipitation (Parson and Fisher-Vanden, 1997). A few IAMs adopt a process-based, geographically explicit approach to modeling, thus have more detailed representation of impacts, often including changes in physical units (e.g., crop yields) as measures of impact. These models do not translate impacts into a common metric, such as money. This makes comparing the level of impacts depicted in the two different modeling approaches very difficult (Tol and Fankhauser, 1998).

IAMs have evolved from a variety of disciplinary tools that often were developed for purposes other than assessments of climatic changes. IAMs have been classified into a hierarchy of five levels (Schneider, 1997). This classification scheme does not imply that each successive level of modeling along the hierarchy (see Section 2.3.8) incorporates all of the elements at lower levels or that incorporation of additional levels of comprehensiveness or complexity provides more fidelity in the model's simulation skills; that depends on the validity of the underlying assumptions and the accuracy of methods used to formally solve the equations that represent those assumptions. Finally, difficulties are encountered in aggregating costs or benefits across the many categories of impacts or opportunities, and a traceable account of any aggregations must be paramount to maintain transparency of any analytic methods such as IAMs (see Sections 1.5.6 and 2.6.4).

Despite these complexities, IAMs are a principal tool for studying systematic sets of interactions that are believed to be important in explaining systems behavior or simulating the consequences of various policies on the magnitude and distribution of risks and benefits of climatic changes or policies to enhance adaptation or encourage mitigation. The goal of IAMs has been to provide insights about the possible interactions of many factors in a complex socionatural system, rather than "answers" to specific scientific or policy questions.

1.5. How do the Complexities of Analysis Affect the Assessment?

The threat posed by climate change must be considered in the context of efforts by countries around the world to achieve sustainable development (see Section 1.1). Improved analysis of impacts of and adaptation to climate change is important for the development of appropriate policy measures. However, the chain of events from human behaviors that give rise to disturbances to the climatic system; to atmospheric changes; to impacts on humans, societies, other species, ecosystems, and their adaptive responses is very complex (as noted in Chapters 2 and 19). Uncertainty is a common feature in the discussion of complexity, and it is compounded by the complex interactions of many subsystems that constitute the socionatural system, each of which has its own inherent uncertainties (see Box 1-2). This section summarizes some of the complexities that make it difficult to provide very many highly confident projections about climatic impacts—assessments that are directly relevant to the oft-asked policy question: "What should we do about climate change?" (see Chapter 2 and references therein for more complete treatment).

1.5.1. Regional Climate Uncertainties

At the regional level, there is a wide range of projected changes in temperature and precipitation simulated from a doubling of CO_2 concentrations because of large model-to-model differences. Annex B of the *Special Report on Regional Impacts of Climate Change* (IPCC, 1998) provides the following conclusion regarding the confidence that can be placed in regional climate projections:

> "Analysis of surface air temperature and precipitation results from regional climate change experiments carried out with AOGCMs indicates that the biases in present-day simulations of regional climate change and the inter-model variability in the simulated regional changes are still too large to yield a high level of confidence in simulated change scenarios. The limited number of experiments available with statistical downscaling techniques and nested regional models has shown that complex topographical features, large lake systems, and narrow land masses not resolved at the resolution of current GCMs significantly affect the simulated regional and local change scenarios, both for precipitation and (to a lesser extent) temperature (IPCC, 1996a). This adds a further degree of uncertainty in the use of GCM-produced scenarios for impact assessments. In addition, most climate change experiments have not accounted for human-induced landscape changes and only recently has the effect of aerosols been vigorously investigated. Both these factors can further affect projections of regional climate change."

The wide range of projected changes in temperature and precipitation would affect the degree of exposure of systems and populations to climatic stimuli and hence their vulnerability to climate change. This range suggests that high confidence will not often be assigned to any regional impact assessments that are based on GCM results. Difficulty in obtaining many highly confident outcomes is why the term "climate scenarios" has been adopted in most impact assessments. Such scenarios should be regarded as internally consistent patterns of plausible future climates, not predictions carrying assessed probabilities (see Section 2.6 and Chapter 3). Decisionmakers need to be aware of the large range of plausible climate projections when they formulate strategies to cope with the risks of climate change. However, in the absence of some explicit estimation of the likelihood of various scenarios by those who produce them, users of the many decision frameworks in the literature (see Box 1-2 and Section 2.7) often have to impute likelihood to various scenarios to apply many of these methods.

The review chapters in this report summarize impact studies that are based on a range of climate scenarios, when available. As noted earlier, transient scenarios are particularly valuable because the Earth currently is undergoing a transient response to global change disturbances. Great care is required in interpreting and comparing results from research or assessments that use different climate scenarios, particularly when some conclusions follow from static scenarios and others from transient scenarios. Unfortunately, such mixed use of scenarios is still a problem in the literature and in assessments of it.

1.5.2. Socioeconomic Uncertainties

An often overlooked source of uncertainty in assessments of impacts and vulnerability is the wide difference in assumptions (often not even stated) in the initial conditions and trends of environmental systems and socioeconomic conditions. These assumptions include information on population and related variables (e.g., population density), economic trends (e.g., income levels, sectoral composition of GDP, or levels of trade), other social indicators (e.g., education levels, private- and public-sector institutions), culture, land cover and use, and availability and use of other resources such as water. They are important not only for determining the forces driving global changes but also for understanding the general capabilities available to societies for adaptation. Projections of these factors for time periods such as the middle of the 21st century are at least as uncertain as projections of future climate; hence, it is probably most advisable to use such information as scenarios of change, or conditioning assumptions (IPCC, 1998). Moreover, culture exerts important influences on socioeconomic processes, problemsolving methods, and the like. The formation of coalitions, social movements, and educational programs directed toward changing institutional norms that might influence people's behavior concerning climatic change is culturally determined, like other complex social and psychological processes. Cultural processes and economic behavior, for example, can be modeled to capture some of the complexity of the social processes, structures, and cognitive behavior involving culture (e.g., Rotmans and van Asselt, 1996; Koizumi and Lundstedt, 1998). Thus, it is simply impossible to predict with high confidence how societies and economies will develop in the future—hence the extent to which they will have the capacity needed for adaptation. The use of scenarios to assess driving forces and adaptive capacity is one way to explicitly acknowledge these kinds of structural uncertainties (e.g., IPCC, 2000). Socioeconomic scenarios, as already noted, are not predictions of future states of the world but consistent and plausible sets of assumptions about issues such as population growth, economic development, values, and institutions.

Although the emphasis on adaptation to reduce vulnerability and take advantage of emerging opportunities is increasing in impact assessment, many uncertainties remain regarding the effectiveness of different options, the relationship between adaptation to short-term climate fluctuations and long-term climate change, and constraints and opportunities that will be imposed by factors such as existing institutional structures, economic and financial limitations, and cultural resistance (IPCC, 1998).

1.5.3. Risk and Uncertainty

Uncertainties are pervasive throughout climate change impact assessment. For some sectors, such as agriculture, uncertainty is large enough to prevent a highly confident assessment of even the sign of the impacts. Until a few years ago, uncertainties in assessments were so great that few researchers were willing to carry their analysis through to numerical estimates of monetary impacts. Even today, as the applicability of subjective probabilities is becoming more accepted, impact estimates with explicit confidence intervals are the exception rather than the rule (a few exceptions are Peck and Teisberg, 1992; Hope *et al.,* 1993; Nordhaus, 1994a; Manne and Richels, 1995; Morgan and Dowlatabadi, 1996; Titus and Narayanan, 1996; Roughgarden and Schneider, 1999). Figure 2-2 (Moss and Schneider, 2000) graphically depicts how uncertainties in emissions scenarios feed into uncertainties in carbon cycle response, climate sensitivity, regional climate responses, and ranges of impacts in an "explosion" or "cascade" of widening uncertainty bounds. However, despite this daunting expansion of uncertainty, methods to classify and formally treat such uncertainties via subjective probability distributions are available in the literature (see Box 1-2 and Section 2.6) and can help to clarify which subcomponents of the overall human-environment system are most critical to integrated assessments of the costs and benefits of climatic changes or climate policies.

1.5.4. Low-Probability Catastrophic Events

Efforts to deal with low-probability, potentially catastrophic events in integrated assessments of climate change are not well-represented in the literature. One possibility would be to treat these risks like any hazard and use methods from risk analysis: The value of the risk is the probability of occurrence multiplied by the consequences of the event. For rare and catastrophic possibilities, there is very little frequency data; thus, probabilities assessed are based largely on subjective methods (e.g., Nordhaus, 1994b; Roughgarden and Schneider, 1999). Equally important, under these conditions the expected cost estimate would be very sensitive to the analyst's (subjective) assumptions about the costs of catastrophic events. Subjective probabilities can vary widely from analyst to analyst under such conditions. This partly explains why most analysts have been reluctant to include low-probability but potentially catastrophic events in integrated assessments (for a recent exception, see Mastrandrea and Schneider, 2001). However, absence of analysis does not necessarily imply absence of risk, and many risk management decisions in the private and public sectors are based on strategic hedging against low-probability but highly costly possibilities, such as insurance and deterrence (see Chapter 8). However, the expected cost approach would imply a risk neutrality—an uncomfortable position for those holding risk averse values in the face of possibilities such as collapse of the "conveyor belt" circulation in the North Atlantic Ocean (e.g., Broecker, 1997; Rahmstorf, 1999; Chapter 19) or melting of the West Antarctic Ice Sheet (e.g., Oppenheimer, 1998). Risk-averse individuals often worry about the possibility that a forecast for a high-consequence event is either accurate or an underestimate—the "type 2 error." Such individuals have argued that a better way to treat the possibility of catastrophe is to ensure that all possible efforts are taken to avoid it—the "precautionary principle" (see, e.g., Wiener, 1995). However, spending valuable, limited resources to hedge against possible catastrophic outcomes with a low probability of occurring is infeasible in practice; scarce resources could have been used more productively elsewhere, including dealing with more probable climatic threats. People who are concerned about "squandering" resources on what they perceive to be unlikely threats or even an erroneous forecast—the "type 1 error"—often are engaged in contentious debates with those more concerned with type 2 errors—a situation that is well-known in risk management disciplines. Thus, it is difficult to apply the precautionary principle unambiguously to justify a hedging strategy against a potential catastrophic climatic event without also applying it to the possibility of negative outcomes from the hedging strategy itself, then weighing the relative risks of type 1 versus type 2 errors (Wiener, 1995).

1.5.5. Valuation Methods—Monetary Measures or Multiple Numeraires

Although much progress on valuation techniques is being made, as noted in Box 1-2, uncertainties are still large, and many impact estimates are "highly speculative" (Nordhaus and Boyer, 2000). Impacts can be divided into market and nonmarket impacts.

Market impacts occur in sectors or activities such as agriculture, forestry, provision of water, insurance against extreme events, transportation, tourism, and activities that use low-lying coastal land. Where these activities produce marketed goods, a monetary estimate of impacts (in units of dollars per °C, for example) sometimes can be made with fairly straightforward techniques, at least under present-day conditions; this has been the most common approach in impact studies to date (e.g., Mendelsohn *et al.*, 2000). Market prices, adjusted to correct for market distortions (e.g., externalities), are the appropriate measure for unit impacts. Although the techniques are well established, the numbers obtained still are approximate as a result of all the uncertainties that surround impact assessments. Working out how the impacts will unfold in the distant future is much less straightforward. Impacts could increase as the intensity and scale of the activity increases (e.g., loss of coastal property) or decrease as more modern and robust systems replace existing ones (e.g., new crop strains are introduced with more climatic adaptability). Also, as noted in Box 1-2, impacts expressed in economic terms embed the values people attribute to the impacts across several numeraires, as well as the values of future generations (see Section 2.5.6 for further elaborations).

For example, the use of highly aggregated decision analysis frameworks (see Box 1-2 and Chapter 2) can be controversial because aggregation of positive and negative costs of even a limited number of market category sectors involves the arithmetic sum of many subelements that contain large uncertainties and are related to different regions. Furthermore, important market costs could be incurred by political instability (e.g., Kennedy *et al.*, 1998), migration of displaced persons (e.g., Myers, 1993), diminished capacity of damaged ecosystems to provide accustomed services (e.g., Daily, 1997), or loss of heritage sites from sea-level rise (e.g., Schneider *et al.*, 2000b). Moreover, losses in nonmonetary categories (i.e., other numeraires such as biodiversity lost, lives lost, quality of life degraded, or inequity generated—all per °C) are very controversial (e.g., Goulder and Kennedy, 1997, discuss attempts to estimate the intrinsic value of species). Any aggregation over such numeraires into a common metric—usually the dollar—cannot be accomplished transparently unless a variety of assumptions are explicitly given for the valuation of each of these numeraires before aggregation hides the underlying assumptions of how valuation was accomplished.

1.5.6. Damage Aggregation and Distributional Effects

Aggregation of various damages into a single estimate sometimes is appropriate to provide policymakers with information about the magnitude of damages that can be expected on a global scale. However, as noted in Box 1-2, Section 1.5.5, and Section 2.6.4, there also is the risk that such aggregation conceals rather than highlights some of the critical issues and value-laden assumptions that are at stake.

As a hypothetical but concrete example, assume that climatic change would cause destruction of lives, ecosystems, and property in Bangladesh, corresponding to a loss of 80% of its GDP. This loss to Bangladesh would amount to roughly 0.1% of global GDP. If the global economy grows at 2% yr^{-1}, this assumed impact on Bangladesh would correspond to a delay in global income growth of less than 3 weeks. It is debatable whether adding, say, the possible benefits for temperate agriculture to the losses of lives resulting from sea-level rise in Bangladesh helps to assess the severity of climate change impacts because the "winner" does not compensate the "loser" (i.e., benefits for temperate agriculture offer little relief to those who have been affected by sea-level rise in other regions). Authors in the literature have expressed concern about trading the costs of emission reduction in some countries (e.g., more efficient end-use energy technologies) with large-scale losses of lives and human health in others (e.g., Munasinghe, 2000). Still, this is implicitly done in most conventional cost-benefit analyses of climate change available in the literature. As noted above and in Section 2.6.4, this points to the necessity of using appropriately disaggregated cost and benefit data to make the analysis more transparent. Possible ways of incorporating equity concerns include use of distributional weights in cost-benefit analysis (e.g., Azar and Sterner, 1996; Fankhauser *et al.*, 1997; Azar, 1999).

Owing to the complexities of valuation and aggregation analyses described above and in the preceding subsection, the TAR authors are cautious about the applicability of single "optimal" answers. Instead, they attempt to examine ranges of outcomes calculated under a variety of assumptions available in the literature, for which alternative valuation methods can be applied to different categories across various numeraires.

1.5.7. Discounting

Comparing impact, mitigation, and adaptation costs that occur at different points in time requires them to be discounted. There is longstanding debate about the appropriate rate of discount to use (e.g., Arrow *et al.*, 1996; Portney and Weyant, 1999). Uncertainty regarding the discount rate relates not to calculation of its effects, which is mathematically precise, but to a value judgment about the appropriateness of the present generation valuing various services for future generations (see Section 2.3.1 for elaboration).

Two different approaches to discounting are presented in the SAR (Arrow *et al.*, 1996). The *descriptive* approach focuses on intertemporal cost-efficiency, and the discount rate is based on observed market interest rates. The *prescriptive* approach emphasizes that normative issues are involved in valuing the future. One important problem for both approaches is the fact that we cannot observe future market interest rates or know the level of income that will prevail in the future (at least for time horizons involved in the climate change debate). Most analysts have resolved this dilemma by using constant discount rates over the entire horizon, despite the fact that they are likely to change. Others have suggested or used non-fixed discount rates that apply strong short-term discounting but entail little further discounting for the very long-term future (e.g., Azar and Sterner, 1996; Heal, 1997). That would cause events a decade or two hence to be significantly discounted but would not cause events a century hence to be reduced in value by powers of 10, as is the occurrence with conventional exponential (compound interest) discounting. Because the largest costs from climate change usually are believed to occur many decades in the future, conventional discounting renders the present value of such future damages very small, whereas non-fixed discount rates (e.g., "hyperbolic discounting") would cause present generations to take serious notice of very large potential damages, even a century hence. Because both the value of the discount rate and the choice of discounting approach involve value judgments about the ethics of intergenerational transfers, it is important for all assessments to be clear about what discounting formulations have been used and the sensitivity of the conclusions to alternative formulations.

1.5.8. "Safe Emission Levels," Cost-Effectiveness Analysis, and the Timing of Emission Abatement

Several issues raised in this section are discussed primarily in the report of Working Group III. However, because this chapter is intended to provide a context for impact, adaptation, and vulnerability issues, this section briefly reviews several emissions abatement complexities that have a bearing on the adaptation/mitigation tradeoff issues (see Section 1.4.4.2 and Chapter 2). Because estimates of the monetary costs of impacts span a wide range of values given the many uncertainties and often are value laden, some analysts have argued that climate change targets should be based on physical or social, rather than economic, indicators—for example, past fluctuations in temperature or expected climate-related deaths or some general reference to sustainability or the precautionary principle (see Section 1.5.4). This precautionary approach is used in European negotiations on emissions of acidifying substances and is acknowledged in Article 3, paragraph 3, of the UNFCCC, which states as a principle that "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures...." Such threshold levels (see Section 1.4.3.5) also have been used as upper ceilings on the amount of warming considered "tolerable" in the academic sphere (see Alcamo and Kreileman, 1996; Azar and Rodhe, 1997) and the political sphere (for instance, the European Union has adopted a maximum of 2°C temperature change above pre-industrial levels or a maximum of 550 ppm CO_2 concentration target). Implicit in this approach is the assumption of the possibility of very nonlinear damage functions. One drawback with this approach is that necessary tradeoffs between climate damage avoidance and the opportunity costs of resources used to mitigate that climate change often are not made explicit.

Even if the precautionary approach were taken, cost-efficiency analysis would be used to identify the lowest cost of meeting the predefined target. Several studies have made an argument that "where" and "when" flexibility in emissions reductions can greatly reduce its costs (Wigley *et al.*, 1996). Ha-Duong *et al.* (1997) and Goulder and Schneider (1999) show that preexisting market failures in the energy sector could reduce the costs of immediate climate policies substantially or that neglect of inducing technological changes by delaying incentives associated with immediate climate policies could reverse the conclusions that delayed abatement is more cost-effective. Unfortunately, there is very little literature on how climate policies might induce technological change (see WGIII TAR). Another reason for the controversy in the literature about abatement timing is a misreading of Wigley *et al.* (1996) that they do not endorse efforts over the next 30 years to make abatement cheaper in the future. Azar (1998) argues, however, that if stabilization targets would be at or below 450 ppm CO_2, early abatement (not just efforts to make future abatement cheaper) would be cost-efficient, even in the Wigley *et al.* (1996) model.

Furthermore, the problem of valuing impacts in monetary terms cannot be avoided entirely even under the cost-efficiency approach. Different trajectories toward the stabilization target have different impacts and costs associated with them. How does delaying mitigation affect the impacts, including distributive consequences? The answer to this question is unclear, partly because of large remaining uncertainties about the extent to which rapid forcing of the climate system could trigger threshold events (e.g., Tol, 1995). Moreover, the difference in impacts between early and delayed mitigation responses appears to be sensitive to assumptions about sulfate aerosol cooling and whether small transient temperature differences can have significant effects.

1.5.9. Validation

Validation of models and assessments that deal with projections over many decades is a serious issue. Often it is not helpful in the context of sustainable development to suggest postponing policy responses until model predictions can be directly compared against reality because that would require experiencing the consequences without amelioration. Instead, models and assessments are subjected to varying levels of quality control, intercomparison with standard assumptions, comparisons with experiments, and extensive peer review. Some authors have argued (e.g., Oreskes *et al*., 1994) that it is impossible in principle to "validate" models for future events when the processes that determine the model projections contain structural uncertainties (see Boxes 1-1-and 2-1). Although the impossibility of direct before-the-fact validation is strictly true, this does not mean that models cannot be rigorously tested. Several stages are involved. First, how well known are the data used to construct model parameters? Second, have the individual processes been tested against lab experiments, field data, or other more comprehensive models? Third, has the overall simulation skill of the model been tested against known events? Fourth, has the model been tested for sensitivity to known shocks (e.g., an oil price hike in an economic model or a paleoclimatic abrupt change in a climate model)? For example, crop yield models are tested against actual yield variation data (Chapter 5), and sea-level increase models are tested for their ability to reproduce observed changes in the 20th century. The ability of a model to reproduce past conditions is a necessary, but not necessarily sufficient, condition for a highly confident forecast of future conditions, unless the underlying processes that gave rise to the phenomena observed in the past will be fully operative in the future and the model captures the influence of such phenomena. Finally, has the comparison between model and data been done at commensurate scales, so that small-scale data are first aggregated to the scale of the lowest resolved element of the model before attempting evaluation (e.g., Root and Schneider, 1995)? When such validation protocols are performed and a model performs "well," subjective confidence that assessment teams can assign to various projections based on such models increases considerably (see Section 2.6), even if "definitive proof" of a specific forecast before the fact is impossible in principle.

All of these considerations demonstrate how the complexities of analysis have led Working Group II TAR authors to emphasize risk management approaches to climate change and policy assessment, rather than just an optimizing framework (e.g., see Section 2.7). These complexities of analysis are not problematic only for the assessment of impacts, vulnerabilities, and adaptability; they also carry forward to questions of tradeoffs between investments in adaptation and mitigation strategies and make a connection between the purviews of Working Groups II and III.

1.6. How can this Assessment be Used to Address Policy-Relevant Questions? A Users' Guide

1.6.1. United Nations Framework Convention on Climate Change

An important audience for this report is the UNFCCC Conference of Parties and Subsidiary Bodies, through which implementation of the provisions of the Convention (United Nations, 1992) and associated protocols will be negotiated. The major issue is contained in Article 2 of the UNFCCC and relates to identifying the level for stabilization of GHG concentrations. As stated in that Article, the level for stabilization is set in terms of impacts of climate change. Hence, the focus of this report is on identifying impacts potentially associated with different rates and levels of climate change. It is important to reiterate that readers will not find any magnitude or rate of climate change defined as "dangerous" by this report. As noted earlier, this is because such a designation is necessarily political for two important reasons. First, the impacts associated with any given concentration target or emissions trajectory will be unevenly distributed across countries, ecosystems, and socioeconomic sectors. Thus, some sectors or regions may receive some benefit from a particular pattern of climate change, whereas others will be harmed. It is not the role of the scientific community to determine whether a particular pattern of impacts constitutes "dangerous" interference; that is a political judgment to be negotiated among participating governments and institutions. Second, there are scientific uncertainties associated with climate change scenarios and our knowledge of impacts that may result. Thus, it is not possible to state in absolute terms that particular impacts will be associated with a given concentration target or stabilization pathway. Instead, information about impacts will be conditional and is best considered in a risk management framework—that is, different stabilization targets or pathways pose different risks to food production, ecosystems, and economic development, and such risks are likely to vary by region and over time. There is no way to determine scientifically what level of risk is acceptable under the UNFCCC. This, too, will be a matter for negotiation by governments. However, information on the state of the science presented in IPCC assessments is widely believed to help put such decisionmaking exercises on a firmer factual basis (see discussion of guidelines for practitioners from an international social science assessment of human choice and climate change in Rayner and Malone, 1998).

The TAR focuses on the vulnerability of different systems and regions to various rates and magnitudes of climate change. Assessment of vulnerability and adaptation is relevant not only to identifying impacts associated with different targets but also to identifying "developing country Parties that are particularly vulnerable to the adverse effects of climate change" (Article 12; United Nations, 1997); these countries are to be compensated from the proceeds of the CDM to help meet the costs of adaptation.

1.6.2. Links to Biodiversity Loss, Desertification, Deforestation and Unsustainable Use of Forests, Stratospheric Ozone Depletion, and Other Global Environmental Issues

Climate change is not an isolated issue; it is intimately connected to other recognized natural hazards and global environmental problems. Separate international conventions and processes exist to address these issues; in several cases, these include successful scientific assessment mechanisms. This report contains information of relevance to these bodies and processes, although it is not the intention of the report to supercede or contradict information developed in those assessments. The purpose of incorporating information of relevance to these issues is to highlight scientific and policy links among them, so that unnecessary tradeoffs can be avoided and potential multiple benefits can be realized (e.g., Orlando and Smeardon, 1999; Kremen *et al.*, 2000). For example, several international conventions and agreements call for sustainable management and use of land and water resources, with varying goals (such as enhancing GHG sinks and reservoirs, protecting biological diversity, safeguarding aquatic ecosystems, managing forests to meet human needs, and halting desertification). To the extent that these objectives are potentially affected by climate change, and to the extent that options to adapt to changing climate conditions can be structured to help attain additional environmental or socioeconomic objectives associated with these other agreements (i.e., co-benefits), this is highlighted in the relevant sections of the TAR.

1.6.3. Resource Planners, Managers in National and Regional Institutions, and Actors in Specialized International Agencies

Although the primary audiences of this report are involved in negotiating and implementing the UNFCCC (United Nations, 1992) and, to some extent, other international agreements on global environmental problems, the report also contains information that is useful to resource managers in national governments; regional institutions such as regional development or lending agencies; and specialized international agencies such as the World Bank, UNEP, UNDP, or the GEF. In the chapters that focus on sectors or systems of climate change (e.g., Chapters 4–9, which cover advances in our understanding of impacts and adaptation options in water resources, agriculture, health, ecosystems, and so forth), planners and managers in national ministries or regional planning authorities will find information on how their mandates—such as encouraging agriculture, providing freshwater, protecting endangered species, or increasing energy production—could be affected by climate change. To the extent provided in the literature, these chapters also include detailed technical and cost information on adaptation options and factors that will influence their implementation. In chapters that focus on regional analyses, managers and planners at regional and international agencies will find information on baselines and trends (climate, socioeconomic, and other environmental); each chapter also highlights particular vulnerabilities and opportunities for adaptation that may occur in each region. It is hoped that this information will be useful in assessing potential projects and opportunities for investment, so that these can be structured to be more robust to potential negative effects of climate change or to take advantage of emerging opportunities. In addition, this report will be useful in the education of the media and the general public about climate, the environment, and development issues.

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