SOCIETAL RESPONSE TO CO_2-INDUCED CLIMATE CHANGE: OPPORTUNITIES FOR RESEARCH

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Abstract. How might a climate change, induced by increased CO_2 in the atmosphere, affect societies? What is the range of existing and potential mechanisms for societal response? And how might research contribute to a reduction of the adverse impact (or enhancement of the unique opportunities) of a climate change by providing greater understanding of the processes involved in climate and society interaction? This paper reflects an initial effort to shed light on these questions. It offers first a framework for identifying key issues in climate-society interaction; eight major questions are suggested by the framework. A discussion of each major question is then presented with the purpose of reviewing the current state of knowledge, identifying the gaps in understanding, and offering opportunities for research to fill those gaps. In all, twenty-two research needs are outlined and are summarized at the conclusion of the paper. The perspective is interdisciplinary, but the review draws heavily from the geographic literature, reflecting the disciplinary bias of the authors.

0. Climate and Society Relationships

Initially, we would like to comment on recent approaches to climate and society research. As the need for, and interest in, climate impact assessment has become evident during the last several years, a flurry of research activity has taken place. These efforts, however, oftentimes rely upon a rather simple conception of climate and society, a conception we would like to term 'neo-environmental determinism' in its most extreme form. It is a conceptual model which depicts a one-way, causal relationship between climate (or environment, if you will) and human activity. Although the roots of such explanation of society can be traced to the classical Greeks, a resurgence of intellectual environmental determinism was strongly evident in the first decades of the 20th century. Ellsworth Huntington, a geographer, was noteworthy as the spokeperson for this view, as reflected in his *Civilization and Climate* (1915). This view assumes that climate is the independent variable whose explanatory power is pervasive in understanding social structure, settlement patterns, and human behavior. The arguments led easily into racial or cultural stereotyping (the tropical climate fosters lazy, unmotivated peoples, and the midlatitude regimes promote vigorous, industrious humans), and finally to explanations of the differences in the global patterns of economic development we see today. These views fell out of intellectual favor as being too simplistic and mechanistic, and largely disappeared (at least in their overt form) for many decades. With the recent concern over CO_2 and other

Climatic Change **3** (1981) 387–428. 0165–0009/81/0034–0387$04.20.

climate-related issues, however, such notions seem to be reappearing – some strongly, others subtly. Such 'neo-environmental determinism' is hinted at in the works of Carpenter (1968) and Bryson, Lamb and Donley (1974), for example, who suggest that drought was the chief cause of decline of Mycenaean Greece during the late Bronze Age, or in the work of Biswas (1980a) or Biswas and Biswas (1979) who argue for renewed attention to climate as a determining factor in agricultural underdevelopment or human health. Lambert (1975) attempts to demonstrate the linkages between climate change and the growth of civilizations. In its most extreme form, climatic determinism is exhibited in the more popular literature. One of the latest is an article in *New Scientist* by Harrison (1979) in which everything from labor efficiency to agricultural productivity is attributed to climate differences (not unlike the Greek theories). In many cases, such explanations are too simplistic, ignoring factors of human choise and societal adaptability. Kates (1980a) suggests that most of the work in climate impact assessment to date adheres implicitliy to this conceptual model.

This is not to say that climate does not exert a strong influence on society. Indeed, perhaps environment as an explanatory variable was shunned unnecessarily for many years because of its association with the earlier, discredited environmental determinism school. In fact, a simple model of this sort is not necessarily undesirable, since it is easier to operationalize and leads to more tractable research problems. However, caution should be exercised in relying too heavily upon such a formulation, for it tends to guide the research questions which are asked and the methodologies employed. More importantly, it neglects the many interacting variables involved in climate change and human adaptation. Critical questions concerning societal vulnerability, response mechanisms, adjustment choice processes, and feedbacks of societal responses to natural and human systems are not integral to the model. For these kinds of questions, we must formulate our conception of climate and society differently.

0.1. A Framework for Identifying Research Needs

In this regard, the conceptualization displayed in Figure 1 increases the complexity and portrays climate effects – beneficial as well as detrimental – as products of variation in both the natural and social systems. Thus, the consequences of climate change are just as much a result of societal characteristics as of environmental fluctuation, as indicated in the lefthand side of the diagram. Following the arrows, the initial effects on selected sectors (e.g. agriculture, energy, water supply, etc.) diffuse through social systems via pathways and linkages ingrained in social organization at any given time and place. Eventually, these are translated into culturally defined effects – both positive and negative – on human well-being. As depicted by the 'major information components' in Figure 1, response strategies are formulated on the basis of information on climate change, on the level and distribution of societal effects, and on the range of mechanisms which could be adopted. How this information is utilized depends partly upon the ways in which it is channeled and upon its perception and interpretation by decision-makers (as, for example, by farmers, energy planners, water supply managers, or politicians). Final choice of strategies is subject to a complex set of incentives and constraints imbedded in economic,

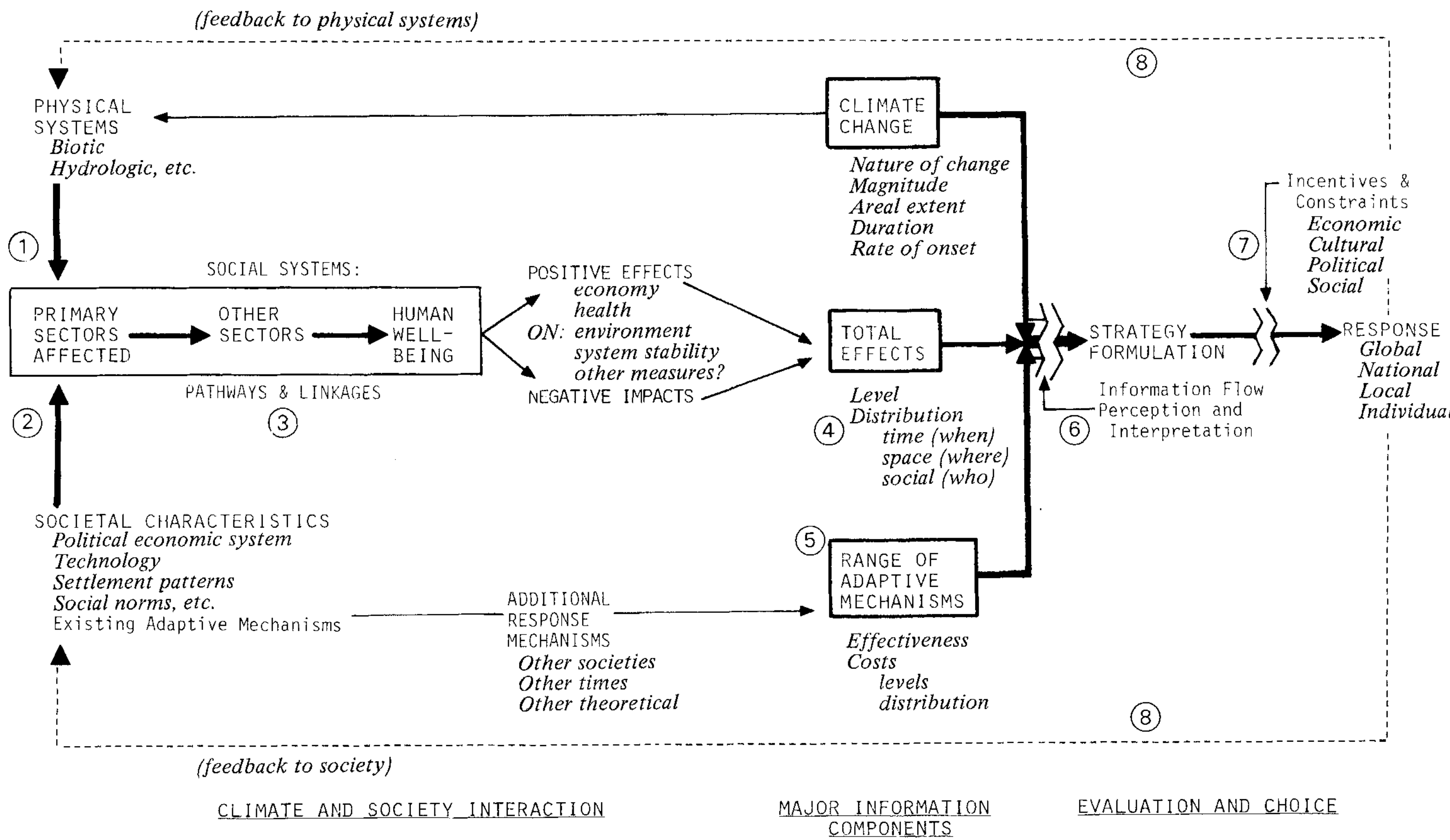

Fig. 1. A framework for identification of research on the societal effects of CO_2-induced climate change, with an emphasis on decision information and response.

social and political institutions. Those strategies alter either the natural systems, the social systems, or both, as the dashed lines in Figure 1 suggest. According to this view, the entire system is interactive and dynamic, changing as societies change and adjust. Generically, Kates (1980a) would call this formulation an 'interactive' model with feedback'; it is similar to the model proposed by the SCOPE Workshop on the Climate/ Society interface (SCOPE, 1978).

However, the primary purpose of presenting this conceptualization is not to define and defend one particular descriptive model of climate and society. Other models exist and can be argued convincingly. Rather, our intention is to provide a framework for systematically organizing our thoughts about CO_2 research needs. In this respect, the framework emphasizes strongly the role of information, decision-making, and response. This is purposeful. A major assumption is that the research results are intended for key decision-makers; therefore, it is critical not only to understand the processes of society and climate interaction, but also to known about the role of information and the process by which it leads to effective response.

0.2. The Nature of Climate Change and Social Adaptation

Implicit to this framework are also assumptions about the nature of climate variations and change and about the ways in which societies adapt. As Hare (1979; personal communication) points out, climate is an intellectual construct composed of an ensemble of central tendencies, variabilities about these tendencies, and rare extreme events, all derived from a span of time long enough to give the averages, spectra, and extremes some statistical meaning. Although there is the possibility of a sudden 'flip' to a new climatic ensemble from CO_2 buildup, in all likelihood the shifts will be slow and continuous. The best understanding of the atmospheric effects of CO_2 buildup is in terms of their influence on central tendencies, as in gradually increasing average global temperatures. However, climate variabilities and frequencies of extreme events may also be affected, though we are currently not sure how; there is not always a clearcut relationship between trends in central tendencies and variance, as recently demonstrated by van Loon and Williams (1978). Nevertheless, it is sobering to note, as did Bryson and Padoch (1980), that '. . . an often overlooked fact about climatic data is that small differences in the mean temperature may mean significant differences in the frequency of occurrence of extreme values' (p. 589); this is particularly true for certain regions of the world, which might be termed climatically marginal environments. Finally, actual regional climatic changes could prove to be quite disparate, and may actually differ in sign from one region to the next. In short, the global effects of a CO_2 buildup will be anything but uniform (Kellogg and Schware, 1981).

The critical issue for us is the process by which society adapts to climatic change. One possibility is that society gradually adapts to a slow cumulative change in central tendencies. If that is simply the case, society can be optimistic since human adaptability appears rapid in comparison to the slow rates of climatic change due to CO_2 (Margolis, 1979). However, it is also possible that individuals and society do not fix on slow changes in averages, but rather react to discreet events which represent departures from average conditions; and that the accumulation of a series of step-like social changes in the short term leads to adaptation to climate change in the long term. If this is the case, the rate of societal adaptation would then change with the change in *frequency* of such initiating climate events.

For example, to a farmer the knowledge that average temperature may increase by 4 °C over the next 50 yrs means little. Farmers react to good and poor crop years. When droughts or freezes are too extreme and/or frequent in relation to farm operations, changes will be made in land use, technology, or even location. Similarly, alterations in water supply systems tend to be made on the heels of precipitation failures severe enough to jar communities into action; perceived changes in the frequency of such events may prompt system redesign.

The notion that the changing frequencies of disruptive (or beneficial) climatic occurrences may be the key factor in societal adaptation to climate change finds support in several recent case studies. For instance, Whyte (1981), in a study of climate influences on agriculture in early Scotland, argues that "... climatic deterioration in marginal areas is more likely to have manifested itself to farmers and their landlords in terms of increasing frequencies of short-term difficulties rather than in declining average productivity over extended periods" (p. 25). Similarly, Parry (1978) concludes that the increased incidence of harvest failure in upland fields of Little Ice Age Scotland was of greater significance in changing land use and settlement patterns than the gradual changes in mean yields. Moreover, there exist instances in which societies may have failed to perceive even rapid climate changes, thus making them extremely vulnerable to disruptive climatic occurrences; this may have been the case in the disappearance of the Norse Greenlanders (McGovern, 1981).

If, indeed, society does adapt (or fails to adapt) to climate change in a step-like manner, then the occurrences which stimulate societal adaptation are ones for which society has plenty of experience – droughts, frosts, cold spells, etc. Included are opportunities as well as adversities, like increases in growing seasons with favorable weather. So, although we may not know exactly how the frequency distributions of socially-relevant climatic phenomena will change with CO_2 enrichment of the atmosphere, at least we can learn about the adaptation process by examining societal response within our present climate and sociotechnical system.

Regardless of whether society adapts slowly to changes in central tendencies or in a step-like fashion to changes in variability – or some combination of both – the research community has its challenge. In the absence of better theory, we assume that both modes of adaptation may be at work. In fact, the most pressing research need overall is the development of theory regarding societal adaptation to climate change. We remain hopeful that many of the research opportunities described herein will lead to improved theoretical understanding.

0.3. Key Questions for Research

Our framework suggests eight key questions which pertain directly to the issue of CO_2-

induced climatic change. The questions, as noted below, provide the structure for the remainder of this paper.

(1) What are the relationships between *climate variations and sectors of society*?

(2) What are the characteristics of society that determine differential *vulnerability* to climatic change?

(3) What are the *pathways* and *linkages* within social systems through which the effects of climatic variations are transmitted?

(4) What is the *level and distribution of total effects* arising from climatic change?

(5) What is the range of *mechanisms* by which societies adjust to climatic variations? And what are their costs and effects?

(6) How is information (scientific or otherwise) on climate change and its effects *perceived, interpreted, valued, and channeled* into strategy formulation?

(7) What are the *conditions of choice* which guide societal response to climatic change?

(8) What are the *dynamic feedback effects* to nature, society, and subsequent response?

The circled numbers in Figure 1 indicate how each of the eight key questions relates to the framework. In the body of the text, we will ask what is known about each question, what are the important gaps in knowledge, and what research should be conducted to fill those gaps. Our thinking partly reflects a geographic perspective; at this point, the reader who is unfamiliar with the discipline of geography may wish to divert his or her attention to the Appendix before reading further.

1. What Are the Relationships Between *Climate Variations and Sectors* of Society?

Although climate change or fluctuation may have direct implications for human well-being through physiological effects, the more important adverse effects stem from disruption of the socio-economic sectors upon which society relies for normal functioning. Aside from the possibility of a dramatic sea level rise and inundation of coastal settlements (Schneider and Chen, 1980), it is probably safe to assume that the major impacts (either positive or negative) from CO_2-induced climate change will depend largely on the ways in which sectors such as agriculture, energy, transportation, water supply, or fisheries are affected.

1.1. The Climate-Sector Connection

Much of the work carried out in climate-sector research is concerned with establishing *climate transfer functions*: for example, to translate winter weather conditions into heating fuel demand for energy; precipitation and temperature into crop yield for agriculture; or precipitation into streamflow for water supply. Although establishing the direct functional *relationship* is central to such efforts, another important element for planning and design is related to *timing* – that is, to frequency, probability, persistence, and/or duration. The two go hand in hand. For instance, while the direct effects of growing season precipitation and temperature on wheat yields is of prime interest, the frequency with which particular climatic conditions lead to agricultural impacts can be equally important. Climate transfer functions provide basic building blocks upon which more complex models of climate-sectoral systems can be constructed.

For purposes of identifying those sectors for which further research would prove most useful, it is instructive to separate sectors roughly into three groups: socio-technical, physico-ecologic, and intermediate sectors. *Socio-technical* sectors are those which are imbedded primarily in human systems and are largely human-created. Examples include energy, transportation and the construction industry. If one adheres to the arguments presented in Bennett and Chorley (1978), socio-technical systems can be characterized as flexible, adaptable, and resilient in the face of perturbation. With respect to time-scales comparable to CO_2-induced climate change, rates of adjustment within these systems appear rapid. For example, the socio-technical changes necessary to meet soaring electricity demands in the U.S., or to meet new standards of air pollution in the U.K. (Burton *et al.*, 1974), transpired relatively quickly over a few decades. Rough estimates of the time required for *major* structural alterations in technological systems vary from 20 to 50 yrs – about that required for a doubling of atmospheric CO_2. But incremental adjustments similar to what we are seeing with respect to world oil supplies can take place concurrently with those major alterations, especially if currently available climate information is used in planning supply and demand (Quirk, 1980).

The conclusion is that with respect to a slow onset CO_2 problem, climate-related research on the socio-technical sectors is less urgent than research on other sectors.* Two additional reasons support this argument. First, we already possess a fairly good understanding of the relationship of weather and climate to these sectors. For example, NOAA has been developing climate transfer functions to relate seasonal weather forecasts to heating fuel demands in the U.S. (Mitchell *et al.*, 1973; NOAA, 1974), while similar work has been conducted in the U.K. on heating fuel and electricity (Craddock, 1965; Barnett, 1972). Furthermore, knowledge about short-term weather effects on the outdoor construction industry is fairly extensive (see major works by Russo, 1965, and ESSA, 1966; also Robert, 1960 or Maunder *et al.*, 1971). The same holds true for the transportation sector (see McQuigg, 1975 for an overview of economic impact of weather and climate). Second, the understanding for these specific relationships is only useful as it applies to the particular socio-technical context within which it is developed, and these contexts evolve quickly over time. In hindsight, would it have proven worthwhile to have initiated major research 40 yrs ago on the consequences of a long-term climate change on steam locomotive transportation?

On the other hand, we face a rather different situation with respect to *physico-ecologic* sectors. These sectors are imbedded firmly in the natural systems, and include fisheries and forestry. Inherently, these sectors may not contain the flexibility and resiliency characteristic of social systems. In contrast to social systems, climatic pertubations encounter a restricted number of routes through natural ecosystems. Instead of leading to

* Which is not to say that research on alternative energy systems or energy conservation as substitutes for fossil fuel burning should not be pursued vigorously.

new equilibria, these perturbations may cause qualitative change, as in the extinction of a population (Holling, 1973). Many such systems may be fragile and sensitive to local environmental alteration brought about by climate change. The case of 'El Niño' is illustrative: The sudden depletion of anchovies induced by the recurrence of the stronger (and longer) than normal outbreak of warm surface waters and a temporary failure of cold upwelling (perhaps related to regional wind patterns) brought the Peruvian anchovy industry to a standstill. Similarly, the California coast sardine industry totally collapsed with a combination of environmental fluctuation and a human perturbation, overfishing (Radovich, 1981).

While fishery resources may indeed be sensitive to climatic changes, there exists limited knowledge upon which to construct climate transfer functions (cf. Cushing, 1979; Murray *et al.*, 1980). We perhaps possess better understanding of the related ecological, economic and policy aspects (Rettig, 1978; Caviedas, 1975). The same holds true of forestry in which little work has been done on climate/yield relationship.* In short, with the prospect of shifts in climate from increased CO_2 on the far horizon, we have little idea of the major consequences to key physico-ecologic sectors, like fisheries and forestry.

Perhaps the sectors of greatest social concern are those *intermediate*, 'hybrid' sectors, like agriculture and water supply (plus certain energy systems, like hydro-electric power). It is probably within these sectors that the most research on climate-sector relationships has been conducted and where further work is still most needed. In the agricultural sector, for example, a great deal of effort has been expended in developing climate-yield models (e.g., see reviews by McQuigg, 1975; Baier, 1977; Biswas, 1980b; or U.S. Dept. of Transportation, 1975). Empirically derived statistical models represent one approach. These models are based largely on historical records of precipitation, temperature, and crop yields; the multiple regression models of U.S. grain yields by Thompson (1962, 1969a, b) are among the most widely recognized.

One problem encountered in these models is that of separating out the influence of technological trends in order to ascertain the sensitivity of crop yields to weather, or vice versa. McQuigg *et al.* (1973) and Haigh (1977) built upon the work of Thompson and others in attempting to separate technological and climatic influences on U.S. crop yields. Their main conclusion is that yields are still subject to climate variability as in the past, despite technology. Others, like Newman (1978) and USDA (1974), using similar data, reach opposite conclusions. Together these studies reflect the uncertainty and controversy surrounding the issue (Warrick, 1980).

Experimental research, in which attempts are made to control systematically for selected weather and technology variables, is another approach to the same problem (McQuigg, 1975). Physiological studies (e.g., Gupta, 1975) and simulation models address the problem by modeling the processes by which environmental stresses actually affect plant growth (Baier, 1977); thus, they deal directly with the 'black box' problems inherent to regression modeling (Katz, 1977).

* However, Baumgartner (1979) tends to downplay the potential impacts of climate shifts on forest ecosystems, despite the fact that forest shifts are traditional indicators of past climate fluctuations.

While climate-yield research has been extensive in the U.S., Canada (Baier and Williams, 1974), and other industrialized countries, there are many places and crops for which little effort has been expended. Some state-of-the-art assessments have been conducted and others planned. Preliminary crop-climate models have been developed for parts of India, Korea, Bangladesh, Burma, Sri Lanka, Thailand, and Japan (cf., Takahashi and Yoshino, 1978). Similar efforts are under way for Latin America (Food and Climate Forum, 1981, p. 68). But on the whole, from a global perspective, the knowledge about climate-yield relationships remains meager. For example, the most ambitious global yield prediction scheme, NASA's Large Area Crop Inventory Experiment (LACIE) project, which is based on Thompson's early climate-yield regression models (EDIS, 1979), only managed to make reasonable crop estimates for three countries: Canada, the U.S. and the U.S.S.R. Efforts to assess the likely effects of a CO_2-induced change in variability if global food systems are constrained by the lack of knowledge of climate-yield relationships.*

In the water supply sector, climate transfer functions describe climate-hydrologic relationships (say, between weather variables and streamflow), needed for water resource planning and design. Models abound. However, there is some evidence to suggest that it would be sanguine to place, unconditionally, high credibility in them. For instance, one study tested ten models in up to six watersheds and found that forecasted streamflows were often greatly in error (WMO, 1974, as reported in NAS, 1977, p. 28). As far as information on 'timing' (e.g., probability of high or low streamflows), the same caution should be advanced. Typically, values of central tendency or variability are determined from climatic or hydrologic data derived from a historic period of record (often a short one). They serve as the basis for evaluating water project design performance, on the assumption that the future will be a replication of the past (Schaake and Kazmarek, 1979). If the period of record is too short or unrepresentative of long-term conditions, the results may lead to difficulties in water resource management. This is exemplified in the familiar case of the Colorado River in which hydrological studies of streamflow were based on a rather short span of wet years, which led to overestimation of water availability and overextension of demands in later years (Dracup, 1977).

In short, there is often inadequate information about agricultural and water supply sectors which relates both to describing how they are affected by climatic variables, and to specifying the likely distributions of disruptive events in time. For the CO_2 problem, there are several implications. First, careful assessment of effects of climate change on key sectors is obstructed by insufficient development of (or uncertainties about) climate transfer functions themselves. Second, since prevailing evaluation and planning methods assume a constant trend based on historic data and a future which will be like the past, existing water supply designs or food production policies have the potential for becoming outmoded in the event of climate change due to CO_2. Four opportunities for research can help rectify this situation.

* This was cited as a major reason why better results were not forthcoming from LACIE (EDIS, 1979).

1.2. Research Opportunities

In order to anticipate the possible effects of a CO_2-induced climate change, the following research activities are suggested: a systematic review of basic research on climate-resource linkages; further research on climate-yield modeling; sector sensitivity analyses; and sector resiliency analyses.

Particularly for sectors like fisheries and forestry, existing studies of climate-resources linkages have not been compiled in a way that allows the development of climate transfer functions for making meaningful estimations of the sectoral impacts of CO_2-induced climate changes. For instance, a considerable number of studies address the physical mechanisms linking climate, upwelling, biological productivity, and commercial fisheries for particular coastal regions and fish populations (e.g., the Peruvian anchoveta industry and the occurrence of 'El Niño'; the climatic mechanisms involved in the upwelling region and its fishery off the Oregon coast; or the relationships between air and sea temperatures, extent of ice cover, and the migration routes of Icelandic herring (see, for example, Thompson [1981; 1977] or J. Johnson [1976] for reviews). But most often these linkages are forged by those whose interests lie firmly in marine biology or in oceanography, not in atmospheric sciences or in the impacts of climate change. As a result, the research has not been organized in a manner conducive to tracing, from the top down, the likely shifts in fishery resources or utilization which migth accompany climatic changes resulting from CO_2 buildup (e.g., would global warming result in a permanent shift in the average position of subtropical high pressure systems and cause a spatial displacement of coastal upwelling fisheries?).

Therefore, *systematic reviews are needed of basic research on climate-fishery relationships*. Such reviews should be conducted from the perspective of climate and climate change in order to pull together in an integrated fashion the array of wide-ranging studies which specifically address the linkages between climate variation and living marine resources. This kind of activity would help to assemble and organize existing knowledge and to identify potentially interesting and important areas for further research.

For forestry resources, Reifsnyder (1976) in a National Academy of Sciences review, emphasized the need for expanded research to develop greater understanding of climate-forestry linkages.

Second, refinement of existing transfer functions appears warranted in water supply and agriculture. In particular, research on *climate-yield modelling* should be expanded, not only to sharpen existing models but to develop climate transfer functions for other areas of the globe. Rather than climate-yield modelling based solely on empirical analysis (i.e. multiple regression models), however, work should be encouraged on analytic models that simulate the actual processes which link climate to crop production. Eventually, empirical-statistical models must be superseded by understanding of the determinant linkages, particularly if CO_2-induced climate changes transcend the bounds of recent experience. The prospect that CO_2-induced climate changes will involve notable alterations (whether desirable or undesirable) in global patterns of agricultural production is very likely. The importance of building an understanding of climate-yield relationships in an international context become increasingly urgent in light of the trend toward global interconnectiveness in food production and consumption. Currently, work in this field is being carried forth by NOAA (EDIS, 1979) and others, and is deserving of solid support.

Third, there is need for exploratory research to assess the *sensitivity of various sectors to climate change*. Research could proceed in several ways. The technical adequacy of water or energy system designs could be re-evaluated, replacing assumptions of constant trends with assumptions of CO_2-induced trend changes. For example, how might an altered hydrologic regime in the Colorado River Basin, resulting from a potentially drier U.S. Midwest with a CO_2 buildup, affect the supplies and demands for water and energy in the semi-arid West where problems already loom on the horizon? Existing studies (by the Corps of Engineers, Bureau of Reclamation, or others) that have evaluated the design adequacy of the Colorado water management system under projections of future agricultural, industrial, and municipal demands could be re-worked in order to ascertain if (or to what degree) shortages might arise with differing assumptions about streamflow distributions in a CO_2-enriched future. Another approach would be to run simulation – or other – models under particular sets of climate conditions. For example, in a recent study the National Defense University (NDU, 1978, 1980) estimated the impacts on world grain production from hypothetical changes in climate, and then traced the societal consequences through the use of a global agriculture and food trade model. For both approaches, the objectives would be to identify the tolerances of existing sectors to change in physical parameters. It is quite possible that under certain circumstances, some sectors may prove to be rather insentitive to climate changes of the order of magnitude likely under CO_2 global warming (a conclusion reached by the NDU study). Obviously, this sort of research is tied to, and would profit from, the refinement of climate transfer functions noted above.

In a related fashion, there is need for study of the *resiliency of sectors to potentially disruptive perturbations*. The term 'resiliency', as used here, is the ability of systems to absorb perturbation through multiple pathways, whereby new equilibria may be achieved but basic structural relationships remain unaltered (Holling, 1973). We know relatively little about the degree of resiliency of many societal sectors or the mechanisms by which it is attained. However, we do know that some sectors of society are surprisingly resilient under conditions of stress which exceed planned design. For example, Russell, Arey, and Kates (1970) suggest that many New England water supply systems can easily accommodate 10–20% shortage through emergency conservation mechanisms. It has been shown that some western localities in the U.S., like Marin County, California, were able to cope with up to 40% reductions in water supply during the mid-seventies drought (Jackson, 1979). Case studies of sectoral resiliencies under perturbations like droughts, floods, cold spells or heat waves would increase greatly our understanding of their capacity to handle a CO_2-induced change. Such case studies should be selected globally from a range of socio-economic systems and levels of development.

2. What are the Characteristics of Society That Determine Vulnerability to Climatic Variation?

Why is it that some nations, regions, or communities exhibit a remarkable degree of resistance to climatic perturbations, while others are subject to chronic disruption? One finds a large number of historical case studies which touch upon this question. (For example, see the recent climate and history volumes edited by Rotberg and Rabb [1980]; Ingram, Farmer, and Wigley [1981]; Smith and Parry [1981]). Hardly a discipline is unrepresented. Historians, geographers, social psychologists, climatologists, anthropologists, sociologists, political scientists, ecologists, and so on, have drawn upon the diversity of experience in time and space in order to develop understanding of the bases of societal vulnerability. In the practical sense, an underlying premise of these studies is that understanding of the reasons for vulnerability is fundamental to fashioning effective strategies for dealing with the societal impacts of climate variation in the future.

However, the wide-ranging excursions into the past to develop the lessons for the future have not led to common theoretical understanding. Instead, the field has been characterized by application of several different theoretical perspectives to the problem, with the result that a number of explanations – some conflicting, some overlapping – of vulnerability have emerged. We label these the perceptual, environmental/ecological, economic, and social structural. Because of the critical implications these explanations hold for strategy choice, we will discuss them briefly below.

2.1. Explanations of Vulnerability

From a *perceptual* perspective, the explanation for vulnerability is conceived in terms of the way in which individuals perceive their environment and how they make decisions. The major underlying assumption is that societal patterns of vulnerability represent the aggregate of individual decisions, and therefore in order to understand vulnerability we must learn about the process of individual choice.

One major thrust of geographic research on natural hazards and resource management has followed this line of reasoning (Sewell and Burton, 1971; White, 1973). Much of this research was aimed at constructing and testing descriptive models of choice from empirical case studies; Simon's (1956) notion of 'Bounded Rationality' served as one theoretical basis for perception models of resource decision-making (White, 1961). For example, early research on flood hazards sought to explore the perceptions held by flood plain residents of the nature and likelihood of flood events and of the range of possible adjustments to them (Burton *et al.*, 1968; Kates, 1962). A number of case studies of other natural hazards – like droughts, earthquakes, or hurricanes – ensued. Perhaps one of the best known is Saarinen's (1966) study of the perceptions of Great Plains agriculturalists of recurring droughts. In 1973, White summarized the research of that early work, indicating that such variables as managerial role, experience, personality, and decision situation appear to be significant factors in determining the ways in which choices about hazards or resources are made. Later geographic studies expanded into cross-cultural comparisons of hazard perception and, despite some methodological difficulties, provided useful insights into hazard vulnerability in an international context (Saarinen, 1974; White (ed., 1974).

Similar approaches can be found scattered throughout the literature of other disciplines. A few deal with long-term climate change. For example, an interesting study of archaeological evidence from Greenland led McGovern (1981) to conclude that poor short-term decisions by elite elders on the eve of the Little Ice Age resulted in the disappearance of the Norse colonies. What other explanations for vulnerability could be offered?

From an *environmental* viewpoint, one might argue that it is simply the nature of the marginal environment which leads directly to the societal vulnerability to climate fluctuation. A recent study by Parry (1978), which focused on the waxing and waning of agriculture within the high altitude fringe zones of Scotland, implied that it is the environmental marginality of certain areas – e.g., the semi-arid or cool, higher altitude zones – which is responsible for the apparent vulnerability of human settlements contained within them. Similar environmental explanations of vulnerability are inherent to arguments of the causes of drought disaster in the Sahel, as, for example, by Grove (1973).

In a related manner, *ecological* explanations for societal vulnerability borrow theoretical frameworks of the biological sciences and apply them to human societies, as in 'cultural ecology' (e.g., see Grossman, 1977, for a comparison of approaches in anthropology and geography). The emphasis is on the inter-relatedness of components within ecosystems of which man is a part. The major assumption is that the concepts which describe the processes of natural ecosystems are applicable to human systems: Vulnerability is a function of the degree to which humans violate ecological principles which maintain stability within the system. Such ecological reasoning was applied widely in explaining resource degradation during the environmental movement of the 1960s and early 1970s. The ecological lessons were recited in a multitude of social contexts: Human population growth leads to exceedance of carrying capacity, which degrades man's resource base; ecosystems simplified by human intervention lack diversity and are susceptible to disruption; etc. (e.g., see Ehrlich and Ehrlich, 1970).

The ecological perspective has been applied to a number of case studies which relate societal vulnerability to environmental variation. For example, Deevey *et al.* (1979) have attributed the decline of the Mayans to accumulated vulnerability resulting from a long-term trend in soil fertility depletion. Similarly, collapse of Mesopotamian culture has been portrayed as a consequence of salinization and siltation in irrigated agricultural systems along the Tigris-Euphrates river Valley (Jacobsen, 1958). In today's agricultural systems, many researchers have warned about the dangers of eliminating ecological diversity through monoculture and perticides (e.g., Harris, 1969; Ehrenfeld, 1972; Manners, 1974) or through narrowing of the genetic crop base (National Academy of Sciences, 1972). The consequences of violating such ecological principles have been reported in a number of case study accounts; a well-known study is the FAO (1974) report of the pest population explosion following the use of pesticides on cotton in Peru, and the return of stable populations upon the cessation of its use. In an extreme case, Norwine (1978) goes so far as to claim that 'our species is more vulnerable to slight climate variations than ever before in the history of mankind'. He cites the following reasons for this state of affairs: dependence upon a small number of hybrids, costly technological innovations, and large total population.

The ecological explanation for vulnerability eventually blends into a technological explanation. Specific technologies, or technological systems, are seen to affect vulnerability, usually through ecological disruption or violation of ecological principles. Technological homegeneity, specialization, and centralization replace diversity, multiplicity, and redundancy – elements of ecosystem stability. Some studies are specifically concerned with technology assessment, as for example, Biswas (1979), who assesses the potential for Green Revolution technology to increase societal vulnerability to climatic variation. There are numerous studies of this nature. The point is that environment and technology are often put forth as the determinants of societal vulnerability to climatic fluctuations.

Probably the most theoretically well-developed paradigm within the social sciences is economics. *Economic explanations* for climatic impacts rest on a bed of neo-classical and welfare economic approaches to resources and to environmental quality. In a resource context, climate could be viewed as another factor of production. One could argue theoretically (as per Barnett and Morse, 1963) that long-term CO_2-induced climate change is analogous to a resource 'scarcity' and presents no problem that could not be remedied in the market place: as a resource becomes scarce (e.g., precipitation and thence irrigation water), prices rise, consumption drops, substitutes are found, and new technologies developed.

In the environmental quality context, anthropogenic climate problems are viewed as 'market failures'. CO_2 is seen as an 'externality' problem – an effect (detrimental or beneficial) of production which is not borne by the producers nor reflected in market price – deriving from the exploitation of a 'common property resource', the atmosphere. Because the atmosphere is not privately owned and no one can be excluded from its use, its service as a waste receptacle for CO_2 or other by-products conflicts with its service as an environmental quality control mechanism (Kneese *et al.*, 1970). Preferred strategies to correct the problems, then, often involve internalizing the externalities – pollution charges, subsidies, taxation, etc. We are slowing moving toward an understanding of the atmosphere as a resource, to be managed by economic tools (Ausubel, 1980).

For both resources and environment, the economic approach is to allocate goods and services to their most efficient use, as valued by individuals within society. Thus, there is an underlying belief in optimality, equilibrium, and order in society. Theoretically, economists would argue that there is an optimal mix of climate change and production pursuits: that is, where the marginal costs of correcting CO_2 emissions equal the marginal benefits of damages prevented. In short, vulnerability is a form of cost deriving from market failure and is theoretically correctable to an optimal level which maximizes social welfare.

Finally, the *social-structural* explanation turns to the organization of society for understanding the bases of vulnerability. For example, a summary of one collaborative set of global case studies of natural hazards (which, incidentally, also contains strong perceptual and ecological components) discusses differential vulnerabilities of traditional, developed, and developing societies (Burton *et al.*, 1978). The authors observed that folk or pre-industrial societies are characterized by high absorptive capacity and resiliency, based on a large number of adaptive adjustments to environmental perturbations. On the other hand, the industrialized societies possess a large array of technological mechanisms to manage the environment (e.g., dams, irrigation schemes, warning systems) and loss sharing mechanisms (e.g., relief programs). It is argued that the most vulnerable societies are those in which social structures are undergoing transition from traditional to industrialized; it is the transitional, developing society which has dismantled traditional mechanisms for coping with perturbations like climatic fluctuations, but has not yet incorporated the technological prowess of the developed world.

In contrast, another set of case studies views vulnerability more as a problem of underdevelopment: the most vulnerable countries are often the poorest, least developed. Explanation lies in the process of imposing of one political economic system upon another, particularly the forcing of capitalist market systems (which emphasize profit maximization) upon traditional systems (which tend to emphasize risk minimization) (see O'Keefe and Wisner, 1975). One result of this process is to reduce drastically the range of adjustive mechanisms. This effect was described by Wisner (1978), for example, who claims that in Eastern Kenya the imposition of modern agricultural systems on traditional systems leaves only migration to urban areas for wage labor as a strategy against drought. K. Johnson (1976) argues convincingly in a case study of the Otomi of Mexico that ethno-scientific methods are forgotten in the process of adopting new technologies, which leads to 'de-skilling' of the populace and greater vulnerability to drought. Various studies purport to show that the same process promotes a greater reliance upon marginal lands for subsistence while better lands are utilized for cash crops, thus intensifying land deterioration and the ability to withstand climatic fluctuations – a 'marginalization' process (Waddell, 1975; Regan, 1980; Hewitt, 1980, Spitz, 1980).

In contrast to the developing world, Worster (1979) provides a socio-structural explanation for vulnerability in a highly developed nation in his examination of the 1930s Dust Bowl in the Great Plains of the United States. He argues that the reason for one of the nation's greatest environmental crises was not the environment itself or even the agriculturalists' misperception of it. Rather the explanation lay within the cultural-economic system with its emphasis on economic efficiency. In the 1930s, agriculturalists responded exactly as the system demanded. Problems of drought vulnerability were, and are, chronic, and reflect the structure of our socio-economic system. Thus, the future may see a repeat of the tragedy.

2.2. The Explanations in Perspective

To a large extent the initial theoretical perspective – whether perceptual, environmental/ ecological, economic, socio-structural, or some variant thereof – that the researcher brings to bear on the problem predetermines conclusions as to the reasons for societal vulnerability to climate variation. This is entirely understandable (if not somewhat counter to the beliefs we often express about the objectivity of science). Furthermore, a corollary to this observation raises some very important issues: namely, that the particular explanation one holds for societal vulnerability largely predetermines the *strategies* that are offered for coping with problems like climatic fluctuation.

For example, if one believes that drought hazard in the U.S. Great Plains is largely a problem of misperception of environment and poor decisions by agriculturalists, then the appropriate stategy is to provide better information – as through county extension agents – in order to elicit more appropriate behavior (a 'cognitive fix' in the words of Heberlein, [1973]). On the other hand, if one holds an environmental/ecological view (either explicitly or implicitly) that drought is a problem of moisture stress, one is more prone to invest in cloud seeding, drought resistant crops, or irrigation schemes (a 'technological fix'). The economic explanation might lead to price supports or land set-aside programs. Finally, if Great Plains droughts are seen as symptomatic of broader inadequacies in the socio-economic structure of societal systems, then perhaps strategies such as legislating land use regulation are put forth (a 'structural' fix).

The point to be emphasized here is the critical importance of gaining a sound theoretical understanding of the reasons for societal vulnerability. For it is this understanding which strongly influences the pattern of strategies perceived as efficacious. The thread of theoretical development vis-à-vis climate-society interaction initiated at the SCOPE Workshop on the Climate/Society Interface (SCOPE, 1978), and carried on by Kates (1980a) and Timmerman (1981), must be pursued further. If society is to respond effectively to CO_2-induced climate change in the future, knowledge of the processes which promote vulnerability is vital.

The above overview of the major themes in explanations for societal vulnerability to environmental variation is intended to convey the general thrusts of research and the levels of understanding developing therefrom. We reach four conclusions. First, there is *no common conceptual framework* for the study of human effects of climate change, but rather a number of loosely connected (sometimes overlapping, oftentimes conflicting) perspectives brought to bear on the questions of societal vulnerability. Certainly, all of the perspectives have some merit; the problem is to combine them sensibly. Second, as a consequence, the *methological approaches vary greatly* from one study to the next, often within one perspective. This presents serious difficulties in comparability of results and in theory development. Third, *researchers often demonstrate limited awareness of other case study work* which bears directly on their own work. Fourth, the above problems are exacerbated by the *lack of common research questions.* If case studies such as the ones described above are to build upon one another to contribute to theoretical understanding, then at a minimum there must be a sense of a shared research focus. Otherwise, case studies tend to remain idiosyncratic and unreplicable. The research community can help in four ways.

2.3. Research Opportunities

First, there is immediate need for a *critical review of conceptual and methodological* *approaches to climate impact assessment.* This is an urgent task, since we appear to be on the brink of a whole new round of case studies, stimulated in part by the formulation of the climate impact phase of the World Climate Programme. The Scientific Committee on Problems of the Environment (SCOPE), for one has recently sponsored a research project of this nature. The critical review promises to generate new ideas about concepts and methods, and to enlarge and strengthen the international research community interested in such work (SCOPE, 1980; Kates, 1980a). This sort of research deserves solid support and encouragement as a high priority topic.

The SCOPE project also takes an initial step toward meeting a second need, that is, a *networking of research and researchers* concerned with the societal effects of climate change. As used here, the term 'networking' connotes a blend of coordination and feedback among researchers, and might encompass the following kinds of activities:

(1) The establishment of a coordinating body, or clearinghouse, whose function it is to keep researchers informed of other research endeavors and research findings (as, for example, through a climate and society newsletter).

(2) A series of workshops in which researchers with common research interests could exchange ideas, share findings, and sharpen methods. Perhaps the greatest benefit could be the formulation of, and agreement upon, a set of priority research questions which could then be pursued systematically by those involved.

We are presently hampered in drawing sound conclusions about the societal effects of climate change because if the disparate nature of climate-society research, especially case study work. A networking of researchers and research activity would enhance greatly the usefulness of past and prospective work in this field, at relatively low cost.

Third, the research community could profit considerably from the assemblage of a systematic *inventory of potential case studies.* More often than not, the selection of particular case studies has been rather haphazard, frequently depending upon individuals' related fields of expertise or other ongoing research. A deliberate selection of case studies, made possible by a thorough inventory of possibilities, could go far in fashioning a set of studies which are comparable and would return the most integrative understanding for the effort expended.

There are at least two ways to go about constructing a useful inventory. One way is to select cases on the basis of objective identification of periods of climate change in a region, in terms of both long-term climate change or short-term fluctuations.* These periods could then be differentiated according to effect: those with apparent negative societal impact and those with little, or positive, effects. Much of the research to date dwells only on the adversities of climate change; yet, examining both positive and negative effects is necessary in order to gain full understanding of societal vulnerability to environmental change.

A second way of constructing an inventory of potential case studies involves the identification of historical situations *analogous* to changes in climate. One such situation

* A difficulty which might be encountered here is in being 'objective'. Oftentimes climate 'changes' are inferred from apparent social or ecological impacts, a procedure which can lead to tautological reasoning if caution is not exercised.

is the case in which people, for one reason or another, misperceive the climate. For example, the agricultural settlers who moved into the semi-arid Mallee area of South Australia around 1900 faced both climatic adversities and opportunities for which they were largely unaware and unprepared; over time, experience with their new environment led to the development of adaptive capabilities necessary to fashion a viable livelihood system (Heathcote, 1974). For all intents and purposes, the problems and opportunities encountered often parallel those presented by actual climate change. History is full of many such examples.

Moreover, the number of possible analogues increases substantially if the CO_2-induced climate change is considered synonymous to many problems in resource management. In this light, shifts in resource supply or demand may be equivalent to alterations in climate. For instance, unexpected increases in demands for hydroelectric power over time could be considered analogous to climate-related changes in streamflow. An upsurge in crop yields resulting from technological change (such as occurred in the U.S. since the 1940s) and its side effects (national overproduction, adequate global food supplies, depressed grain prices, land retirement, etc.) may be analogous to a regional improvement in climate for crop production. In many ways, tightening of oil imports is analogous to exceptionally cold winters, and so on.

The last research opportunity builds directly on the previous two: we need *actual case study investigations of the effects of climatic change (or analogous events) on society.* But unlike our present stock of case studies, it is critical that similar research questions are asked of each (realizing, of course, that new questions will emerge in the process); that the methods employed allow for comparability of results; and that the case studies themselves be parsimoniously and systematically selected. For example, one useful way of selecting case studies is suggested by Table I, below:

TABLE I: Schema for selection of case studies of climatic changes or fluctuation of similar magnitude

	Historical period	
Cultural context	T_1	T_2
Case study area #1	Major societal effects	Minor societal effects
Case study area #2	Minor societal effects	Major societal effects

Following this schema, one is led to ask two questions: (1) Over time, why do we find differences in climate impacts within a society, given similar climatic changes? If, say, negative impacts increased, can the processes of change within a society be identified which explain the shifts in vulnerability? (2) At any given time, why do we observe differences in societal effects of climate variation from one cultural context to another? Can the particular characteristics of societies be identified which explain the differential vulnerabilities?

For carefully selected study areas, a combination of temporal cross-sectional and spatial cross-cultural approaches – cast within common conceptual and methodological frameworks – promises to lead to more generalizable results than heretofore available. One could remain hopeful that the case study investigations could build upon one another in such a way as to contribute to the development of sound theories of climate and society interaction.

3. What Are the Pathways and Linkages Within Social Systems Through Which the Effects of Climatic Variations Are Transmitted?

The human consequences of climatic variation depend largely on the ways in which direct sectoral effects filter through the socio-economic-political fabric of society. As described under questions # 1 and # 2 above, societal sectors like energy, transportation, fisheries, forestry, agriculture, and water supply are subject to disruption, as determined jointly by the characteristics of society and the nature of climatic change. However, reduced or increased crop yields, altered water supply, or modified hydroelectric output are not the ultimate concerns; rather, it is the degree to which people are actually affected, as expressed in changes in income, effects on human health, community stability, settlement patterns, or the like. It is the pathways taken by climatic variations through space and societal organization which largely determine the patterns of human effect.

For example, Figure 2 was constructed for the purpose of providing a framework for tracing the impacts of drought occurrence in the United States Great Plains (Warrick and

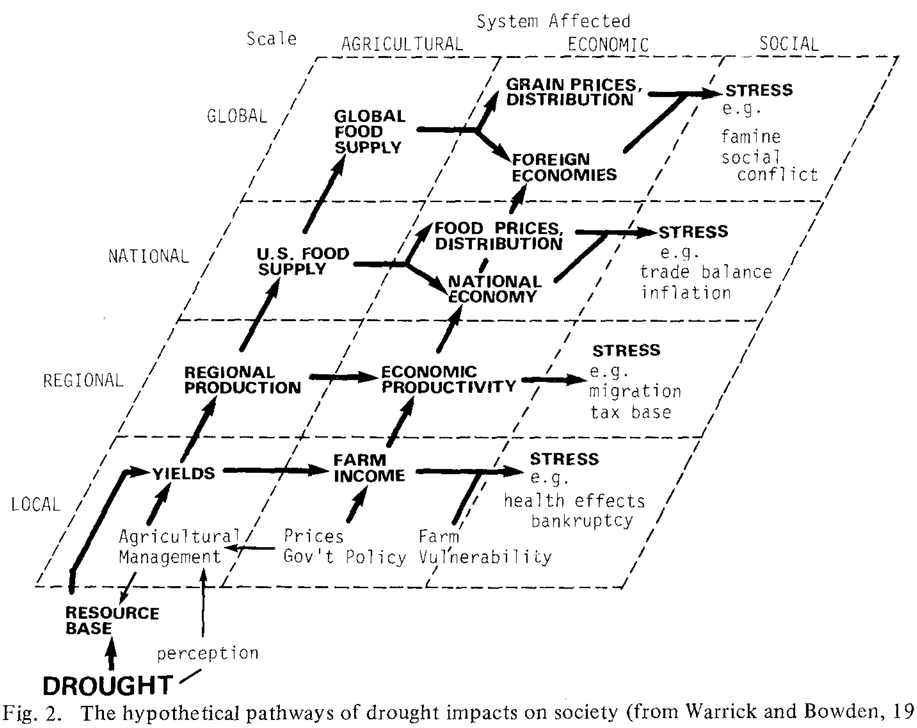

Fig. 2. The hypothetical pathways of drought impacts on society (from Warrick and Bowden, 1981).

Bowden, 1981). The diagram depicts a variety of hypothetical pathways that drought impacts potentially could take, spanning spatial scales (from local to global) and systems affected (from agricultural to social). From the lower left to the upper right quadrants in Figure 2, the drift of impact is from the more physical, direct, and immediate to the more social, indirect, and remote. The initial perturbation originates as meteorological (or hydrological) drought, that is, a decline in available moisture. This phenomenon becomes agricultural drought when yields fall below some perceived threshold, and it translates into drought impact if and when the stress is detected in the economic and social sectors. The degree to which the initial climatic event is transformed into stress is influenced by several factors, including individual and social perceptions of drought, market prices, government policy, and farm stability.

Let us make two additional comments about the drought example. First, while Figure 2 displays a hypothetical set of pathways and linkages, the actual routes of drought impact can vary over time. For instance, in the Great Plains during the 1930s, drought impacts took an essentially horizontal pathway to local stress (Warrick *et al.*, 1975). However, there is concern today that future droughts may follow a more vertical pathway. This pathway leads from yield declines to lowered national and global food reserves, with resultant increases in food prices and severe health effects among the poorest nations. Whether such a pathway would actually evolve following the onset of a rare, major drought in the Great Plains (or elsewhere) is a matter of debate.

The second point is that as pathways of drought shift, so does the range of strategies for drought management. Theoretically, opportunities for preventing drought impacts exist at any box or arrow in Figure 2. For instance, if future drought assumed a global pathway, then strategies for preventing stress from Great Plains droughts could include maintenance of grain reserves (Schneider and Mesirow, 1976) or assistance to developing countries for development of food self-sufficiency. However, the usual response is to pursue conventional drought strategies (such as irrigation expansion or conservation practices) which may be more appropriate to drought impacts of the past than to those of the present or future.

The above example serves to illustrate the following point: in order to anticipate the full range of consequences from, and possible reponses to, climatic variation, it is vital to understand the pathways and linkages by which such occurrences are transmitted through society. Furthermore, given the dynamic nature of these pathways, one needs to obtain some understanding of how they are shifting over time. This applies to the spectrum of societal sectors which may be affected by CO_2-induced climate changes.

3.1. Models for Tracing the Effects

There exists a broad range of atmospheric, hydrologic, ecological, agricultural, urban, regional, and even global models for examining environmental problems (Holcomb Research Institute, 1976). Many of these have potential for tracing climatic variations through socio-economic systems. For example, one well-developed approach, designed to calculate the ripple effects of changes in regional or national economics, is economic input-output analysis. Input-output models are, essentially, models of pathways and linkages within the economic sector, as between extractive industry, agriculture, manufacturing, etc. Generally, they are used to estimate the indirect economic benefits of increased production or services within a geographic area. In a few instances, however, input-output models have been employed to estimate the pattern of indirect losses from economically disruptive effects. For instance, Cochrane *et al.* (1974) used input-output analysis to estimate the potential economic losses from a hypothetical recurrence of the 1906 earthquake in San Francisco. Conceivably, similar analyses could be conducted of the regional indirect economic benefits and losses from CO_2-induced climate change.

Although input-output models are probably among the most widely used models available, they comprise only a limited set of relationships – all within the economic sector. Components like public policy or climate differences are exogenous. As such, they can only treat selected portions of the pathways and linkages potentially implicated in the flow of effects from climatic change. This is one fundmental drawback of the entire arsenal of models currently at our disposal: they tend to be directed toward particular disciplinary interests, the modelers themselves having difficulty crossing interdisciplinary boundaries (Holcomb Research Institute, 1976).

Thus, referring back to the example of drought pathways laid out in Figure 2, there exists a plethora of models to fill virtually every individual 'box' in the diagram: national economic models, regional economic input-output models, regional climate crop-yield models, local agricultural operations models, etc. A few purport to model entire 'rows' of boxes, as, for example, the global agricultural trade models. But by and large, the linkages – or 'arrows' – in Figure 2 remain unforged. Clearly, these need specification if the full range of consequences of climate change are to be explored. Several important lines of research are suggested.

3.2. Research Opportunities

A very promising research endeavor involves the *linking of major models.* As discussed above, we have models of climate and environmental systems, of agriculture and other resource systems, and of socio-economic systems, at a variety of scales. But we do not have them interconnected in a manner which allows us to estimate easily the full effects of climate fluctuations or to explore the results of alternative polici options.

To illustrate, for the agriculture and food sector, a number of global models have been developed during the last decade which simulate grain production, trade flows, and consumption at the world scale: for example, the Model of International Relation in Agriculture (MOIRA; Linnemann *et al.*, 1979) or the interactive global model of population, food, and policy constructed at the University of Southern California (Enzer *et al.*, 1978). However, neither MOIRA nor the USC model accomodate a direct link to climate and its effects on yields. One possibility is to construct a model that does incorporate a climate-yield component; this approach is currently being pursued at the University of California at Los Angeles in which analytic yield models are being developed for this very purpose (Terjung, 1981). Another approach is simply to use existing climate-yield models and global models in combination, whereby the results of one serve as input to the other. The latter approach has been used, for instance, in determining the international consequences of a global climate change (National Defense University, 1980) and in a preliminary study aimed at tracing the global impacts of a recurrence of a severe drought in the Great Plains of the United States (Warrick and Kates, 1981). The linking of climate and environmental models to several key sectors (like agriculture or energy) at several scales of analysis (regional, national, or global) promises large payoff in exploring the societal effects of climate change.

A second opportunity for research involves *tracing the actual pathways of societal effects of climate variation through empirical case studies.* In part, this work is needed in order to build and refine the models described above and to 'keep them honest'. One important aspect of such research would be identifying how linkages and pathways have shifted over time. The objective of such research would be to gain understanding of the trends in societal sensitivity to climate variation. As argued above, this information is pivotal in attempting to estimate how the full range of societal impacts might unfold given the occurrence of major climate change in the future.

4. What Is the Level and Distribution of Effects From Climatic Change?

The effects, both positive and negative, of climatic variation can be viewed as one major informational component to ameliorative strategy formulation, as we depicted in Figure 1. As society faces policy decisions about CO_2, at least three major questions arise: What is the total *level* of benefits or losses? How are the effects *distributed* in time, space and society? What are the *trends?*

4.1. Level of Effects

There are two very good reasons for compiling information on the level of effects. First, it is an essential ingredient for *evaluation* of alternative strategies. Estimates of aggregate positive and negative impacts provide baseline information by which the benefits of strategies or policies can be assessed. For example, one measure of the agricultural benefits of weather modification for hail suppression is the dollar value of damages prevented. Conventional evaluative methods like benefit-cost analysis or cost-effectiveness analysis demand such data (in commensurable dollar values) for purposes of comparing the costs of strategy implementation to the expected benefits accruing to society.

Second, information on the level of total effects is important in placing societal problems into perspective: How does CO_2 fit amongst the list of *priorities* of problems to be addressed? As Kenneth Boulding suggests (1980), oftentimes society in general, and science in particular, expends a good deal of effort on the seemingly less pressing problems, while the more critical problems (like preventing nuclear war) are neglected. How the CO_2 problem matches up to other societal problems is a fundamental issue at both national and global scales.

With respect to negative impacts arising from short-term climatic episodes, like droughts or other extreme events, the literature on natural hazards contains fairly comprehensive assessments. Nationally and globally, society does a fair job of estimating losses from natural hazards (White and Haas, 1975; White (ed.), 1974), at least in terms of direct dollar losses and lives lost (Table II). We do a worse job at calculating indirect economic losses, environmental effects, and social disruption. Some of these other impacts may be quite significant, but oftentimes we remain unsure of their correct measures or indicators. Displacement of families, abandonment of livelihood, community disruption, and malnutrition are difficult effects to place on a common yardstick. Yet, these are the appropriate descriptions of societal impact in most parts of the world.

TABLE II: Selected estimates of natural Hazard losses (from Kates, 1980b)

Hazard	Country	Total pop.	Pop. at risk	Annual death rate million at risk	Losses and costs per capita at risk: Damages losses	Costs of loss reduction	Total costs	Total costs as % of GNP
Drought	Tanzania	13	12	40	$ 0.70	$ 0.80	$ 1.50	1.84
	Australia	13	1	0	24.00	19.00	43.00	0.10
Floods	Sri Lanka	13	3	5	13.40	1.60	15.00	2.13
	United States	207	25	2	40.00	8.00	48.00	0.11
Tropical cyclone	Bangladesh	72	10	3000	3.00	0.40	3.40	0.73
	United States	207	30	2	13.30	1.20	14.50	0.04

For this reason, we often face a rather difficult task in tabulating or monitoring the impacts of climatic fluctuations, particularly in areas of the world in which slow-onset, climate-related processes exact an insidious, debilitating toll on human populations. This is the case with the problem of desertification on the Sahel, for example. In this region, the ability to recognize clearly the 'early-warning' signals through monitoring of human well-being and livelihood systems would help in combatting the effects of desertification. Development of sound indicators of human impact would be a major contribution toward this goal.

4.2. Distribution of Effects

Who carries the burden of loss from climatic fluctuations? And who benefits? The question can be asked about groups within nations or about nations throughout the global system. If we had better understanding of the social, temporal, and spatial distributions of effects, society would be in a better position to target programs and policies to the most vulnerable parties and to adress explicity the inequities promoted by our social systems. In addition, a solid base of data on social distribution of effects would likely shed light on the reasons for vulnerability. What do we already know?

For a few empirical case studies we have some well-documented research of the *social* distribution of effects, especially with regard to climate episodes like drought or other extreme events. For example, it has been argued convincingly that the major share of impacts of the 1930s Dust Bowl in the U.S. Great Plains was suffered by the poorest – the tenant farmers, sharecroppers, and migrant laborers (Great Plains Committee, 1937). Some of the major government programs designed to relieve drought stress actually exacerbated the impacts on the hardest hit (Stein, 1973). In contrast, many of the well-to-do farmers benefited from the drought in the long run by being able to clear their debts for as little as 10 cents on the dollar with hard-pressed banks and by acquiring bankrupt farms for little or nothing (Worster, 1979; Fossey, 1977). Of course, the fact that someone actually benefited is not surprising; the bulk of climate-society interaction benefits mankind. The question of how the benefits and costs are distributed is the issue.

Similar studies at, say, a national level are few. Dacy and Kunreuther (1969) extend several case studies into an assessment of federal relief policies for disasters. One study by Cochrane (1975) of the distributive efforts of natural hazards in the U.S. concluded that '. . . lower income groups consistently bear a disproportionate share of the losses. . . ' incurred from natural hazards. These groups also receive the least disaster relief, have less insurance, and are more prone to damages. The recent, extended heat wave over the south-central United States exhibited clear-cut differences in impacts vis-à-vis social class. Health effects were severest among the poor and elderly. Monetary losses (i.e., added cooling costs) were borne by middle- and upper-level income groups (CEAS, 1980).

These studies suggest that there may be fundamental social differences in benefits and loss-sharing within societies. Such studies, however, encounter tough sledding with respect to data availability. Presently, in order to associate effects with income groups in the U.S., for instance, one is forced to delve into the files of the Small Business Administration, Red Cross, insurance organizations, etc. As a matter of course, data on impacts from hazards in the U.S. are not collected systematically with respect to income class (or in any way, for that matter). We expect the situation to be no better – probably worse – in the international context. This lack of data on social distribution of effects could be a major constraint to effective strategy formulation with respect to CO_2-induced climate change.

The *temporal* distribution of effects is another subject about which we have relatively little understanding. In the U.S., it is often assumed that lingering secondary impacts of natural disasters, for example, are severe enough to warrant post-disaster programs of recovery. However, two separate studies of long-term disaster impacts in the U.S., one by Friesma *et al.* (1979) and the other by Wright *et al.* (1979), show that such impacts are minimal. The latter study, at census tract level, explored both economic (e.g., retail sales) and social (e.g., population change, income level) indicators and found no evidence of persistent post-disaster disruption. On the other hand, in other social settings, one finds examples of enduring effects long after the initial disaster impact. For instance, the social and cultural impacts of the eruption of Paricutin Volcano in Mexico persisted for decades (Rees, 1970). Why the difference? In which circumstances and socio-cultural settings should we anticipate chronic effects of disruptive climatic (or other environmental) pertubations? And how do we make intertemporal comparisons if impacts (at what social discount rate) for purposes of evaluating the benefits and costs of climate changes in the future? (d'Arge, 1979) These questions relate directly to CO_2 strategy formulation but remain largely unanswered.

A final issue concerns *spatial* distribution of impacts. The most pressing question lies at a global scale: Will CO_2-induced climate change exacerbate the differences between rich nations and poor nations, between the high latitudes and equatorial regions? Unfortunately, this issue is often obscured by focusing solely on the notions of average regional warming, drying, etc. To repeat a point made earlier, it is probably not only the slow average changes in central tendencies that matter to society, but also the changes in frequency of discrete atmospheric events – events which are occurring today. It is relevant to the CO_2 issue to ask: Do major recurring events like droughts bring consistently greater impacts to struggling nations than to developed nations, and further divide the world into 'haves' and 'have-nots'? If, as Garcia and Escudero (1980) argue, the explanation for these impacts lies in the political and economic relationships of nations instead of in the physical systems, the room for remedying the inequities of spatial distribution of impact is large indeed. So while it is true that CO_2-induced climate change may slowly alter the regional frequencies of such events in the future, the basic processes by which the benefits and costs of climatic fluctuations are distributed *are observable today.* We do not have to wait for better information from atmospheric scientists on the exact nature of regional climate shifts. The global laboratory is open for research now. The opportunity to understand the links between climatic events and spatial inequities should be grasped enthusiastically – CO_2-induced climate change or not – if we wish to avoid the pessimistic scenario painted by Heilbroner (1974) of a self-destructing, conflict-ridden world divided and aligned over resources and wealth.

4.3. Research Opportunities

Research can contribute in four ways: First, there is a need to develop a comprehensive set of *indicators of societal impact* from climatic-related events. Conventional measures of dollar damages, while useful, are inappropriate for many purposes and in many socio-cultural contexts. Sensitive indicators which detect alterations in economic, cultural, and human well-being would allow careful monitoring of societies in order to identify signs of societal stress from climatic fluctuations – an early-warning capability.

Second, there exists a need for the development of *methodological frameworks for systematic collection of data on the social distribution of climate effects* (as, for example, by income class). Once applied, knowledge about who shoulders the burdens and who reaps the benefits would provide a solid data base from which to address the issue of inequities – of the processes by which they are maintained and of the strategies or policies which might alleviate them. Consistent, comparable information is not currently available. The need exists at both national and international levels.

Third, a very worthwhile research effort is the *investigation of the global distribution of effects arising from climatic fluctuations.* Do climate-related occurrences like droughts or 'El Niños' act to increase further the discrepancies between rich and poor nations, given the present global economic system? CO_2-induced climate change may change the frequencies of such events in the future, but many of the events themselves – the nature of their effects and their implications for global equity – are available for study now.

Despite all research efforts expended on the CO_2 problem, a large amount of uncertainty will remain. There is a good chance that atmospheric scientists may never be able to predict the average climate changes or the changed frequency distribution of climatic events in key regions of the world. Moreover, it is almost certain that social scientists will fail to predict accurately the nature of social change fifty years hence. Perhaps the alternative to prediction is to *assess the broad trends in climate-society interaction* in order to ascertain the likely direction of effects. For example, two case studies of drought impacts at a time scale of a century, one in the Great Plains and one in the Sahel-Sudanic zone of West Africa, conclude that the local impacts or recurring droughts of similar magnitudes have lessened over time (Bowden *et al.*, 1981). Historical case studies of the trends, utilizing time-series or cross-sectional data on socio-economic effects, could provide valuable clues as to the societal situations in which future climatic alterations may be handled well and those in which the potential for catastrophe may be building.

5. What Is the Range of Mechanisms by Which Societies Adjust to Climatic Fluctuations? And What Are Their Costs and Effects?

As society faces the prospect of a possible climate change from CO_2 or other causes, the issue of what mechanisms or strategies could be employed to cope with the effects has more than just academic interest. Decision-makers will require information on the full range of possible mechanisms and their effects. In part, researchers can help provide this knowledge by drawing upon investigations already conducted on human response to natural hazards and to long-term climate change. Opportunities for new research endeavors also exist, particularly in developing an understanding of the effectiveness of adjustive mechanisms and of the social costs associated with them, as described below.

5.1. The Range of Adjustments

The resiliency and adaptability of a social system to environmental fluctuation or change is linked inextricably to its repertoire of adaptive mechanisms, or adjustments, which can be called upon to buffer society against adverse impacts (or to take advantage of new opportunities). To date, a substantial amount of interdisciplinary research has been devoted to identifying and understanding human adjustments to extreme events in nature. Much less attention has been directed toward learning about adaptation to slow environmental change.

One central goal of research on extreme events in nature is to assess how 'man adjusts to risk and uncertainty in natural systems' (White, 1973). Empirical studies have focused largely on identifying the range of adjustments theoretically possible, delineating the particular adjustments actually adopted by individuals and groups, and understanding the processes of adjustment choice and adoption. For example, one collaborative research project sought explicitly to identify adjustments to natural hazards in an international context (White (ed.), 1974). Twenty-four hazards were investigated, twenty-one of which were atmospheric in origin. Collective and individual adjustments adopted at local, national and global levels were described. Similarly, a study of 15 natural hazards in the United States provides an exhaustive list of adjustments (White and Haas, 1975). These studies, along with anthropological (see Torrey, 1979, for review) and sociological (Dynes, 1970) studies, provide a wealth of information on discrete mechanisms for adjusting to environmental fluctuations.

A body of literature on human impacts of, and response to, short-term climate fluctuations is accumulating rapidly (as evidenced by a recent extensive bibliography compiled by T. Rabb for a DOE-AAAS panel on CO_2 effects). The studies of harsh climate conditions of 1816–19 in Europe (Post, 1977) or the western U.S. drought in the 1970s (Jackson, 1979) are illustrative. These studies deal with environmental changes which have direct applicability to the CO_2 issue. The literature concerning human adaptation to slow environmental change is scanty in comparison. One recent example is a study by McGovern (1981) who examined the relationship between a cooling of Greenland's climate over several centuries and adjustment decisions by Norse Greenlanders. Another example is the work of Baerreis and Bryson (1968) who studied the response of Mill Creek Indians to a steady desiccation of the mid-west prairies of North America in the twelfth century A.D. (also, see Bryson, 1975). But, on the whole, such studies are few in number.

It is unclear at this time whether enough studies of hazards or climate change have been conducted to provide an exhaustive inventory of potential adjustments. But it becomes increasingly clear that we have enough of a sample to offer classifications of adjustments which could serve as common frameworks for systematically assessing the range of possible adjustments to CO_2-induced climate change. For example, Table III draws upon the classificatory scheme offered by Burton *et al.* (1978) and compares human adjustments to a spectrum of climate variations, culled from four studies.

Finally, while we have an abundance of studies which identify adjustments, we know relatively little about the social costs associated with these mechanisms. Although our society performs an adequate job of tabulating the direct, economic costs of adjustments, there is a category of insidious social costs which remain largely unspecified and unmeasured. Yet these may be of critical importance. For example, the apparent lessening of drought impact on the U.S. Great Plains has occurred with the advent of high technology, larger farms, and fewer farmers – along with disintegration of Plains communities, dislocated families, and altered rural lifestyle (Warrick, 1980). As CO_2 strategy decisions are faced in the future, the issue of whether similar sorts of social costs could accompany particular adjustive mechanisms may arise.

Two opportunities for research are suggested by the above discussion.

5.2. Research Opportunities

First, existing research on natural hazards and societal effects of climate change should be canvassed extensively to construct a comprehensive *roster of adjustive mechanisms.* This compilation of mechanisms would benefit from the application of a common classificatory framework appropriate to anticipated CO_2-induced climate impact problems, as noted above. Although some additional new case study work could be carried out, it is felt that such a roster of mechanisms could be mined from the backlog of completed case studies.

TABLE III: Adjustments to climate variation in four case studies (classification from Burton, Kates and White, 1978)

Type of adjustment	Climate variability		Climate change	
	Drought (U.S.: Warrick, 1975)	Frost (U.S.: Huszar, 1975)	Regional Cooling (Norse Greenland, c. 1300: McGovern 1980)	Regional Drying (Central North America, c. 1100: Baerreis and Bryson, 1968)
Modify the physical event	Cloud seeding Irrigation Water storage Evapotranspiration suppressants	Heaters Wind machines Irrigation Artificial clouds		
Modify the loss potential	Resistant crop varieties Diversification	Change planting and harvesting times	Improve sealing techniques Storage of fodder and food Decrease 'cash hunt' for trade Reduce reliance on domesticates	Change diet (hunt)
Change location	Land use regulation Abandon sensitive areas	Change topographic setting	Alter grazing pressure Shift location to the cost	Abandon maize cropping Abandon sensitive areas
Accept or share losses	Accept loss Crop insurance Relief and rehabilitation	Accept loss Crop insurance	Reduce expenditures on ceremonial structures	

Second, *studies of the long-term social costs of adjustment strategies* may allow society to anticipate the possible undesirable side effects associated with strategies contemplated for CO_2-induced climate change. Such studies could focus on climate fluctuations which are potentially related to the CO_2 issue, like droughts, floods, frosts, cooling or warming. The value of this information would lie in avoiding situations in which unanticipated insidious costs eventually outweigh the social benefits of adjustment strategies.

6. How is Information (Scientific or Otherwise) on Climate Change Perceived, Interpreted, Valued, and Channeled Into Strategy Evaluation?

Information on climate change, societal effects, and adjustive mechanisms gets filtered in a variety of ways into strategy and policy formulations. Scientific information on CO_2 and its effects will ultimately leave the hands of the scientific community and will be digested by the media, decision-makers, and the public at large. Unfortunately, we have little understanding of how that information will be interpreted and of the resulting social and economic consequences of its dissemination. The ways in which that information is incorporated into the decision process has enormous implications for eventual strategy or policy choice regarding CO_2-induced climate change.

Within this context, two specific problems arise. First, there is the danger that the information on CO_2 (which, from the societal viewpoint, may be seen as a prediction or forecast) might set in motion a set of behaviors that will lead to unexpected, adverse impacts on society. Clearly, this problem is not specific to CO_2. Within the field of resource management in general, the complications arising from expert information, lay interpretation, and public response are well documented (Sewell and Burton, 1971; White, 1966). In many instances, the development of scientific information progresses at a rate which exceeds society's ability to make best use of it. For example, while enormous efforts have been directed at developing a predictive capability for major U.S. droughts, we have scant knowledge of how the forecast could, or would, be utilized by agriculture and industry (Warrick *et al.*, 1975; Yevjevich *et al.*, 1978). Similarly, if we had prior understanding of the likely perceptions of key decision-makers to state-of-the-art CO_2 information, the scientific community and the political system would be in a much better position to fashion the context, mode of presentation, and timing of such information in order to elicit a more desirable response.

A second problem is that scientific research on climate change, societal effects, and mechanisms for effective response proceeds with little feedback from user groups. It is possible that as atmospheric scientists produce information on mid-latitude average temperature changes, for example, the users – policy decision-makers, farmers, water supply managers, etc. – may desire information on other parameters, like rate of onset, likelihood of catastrophic events, frequency and duration of certain events, and so on. The discrepancy between what the scientific community produces and what the users need could be large indeed.

6.1. Research Opportunities

Two research opportunities flow from the above discussion. The first is an *investigation of the socio-economic consequences of dissemination of scientific information on CO_2*. This assumes that increasing knowledge of the climatic effects of CO_2 enrichment will be available at some future date, and that the information will be regarded publicly as a forecast or prediction – whether intended so or not. What will be the likely reponses of key decision-makers to the information? Within varying social and economic contexts, what consequences (both beneficial and detrimental) might arise from those response patterns? The most appropriate scale at which to address these questions is international.

A second research opportunity is to *assess user needs with respect to information concerning CO_2*. Without getting critical feedback from those who will eventually formulate and adopt strategies and policies, the research community runs the danger of expending tremendous effort on producing inappropriate information. This research endeavor, along with the first, could go far in assuring that the best use is made of the scientific community's role in societal adjustment to a possible CO_2-induced climate change.

7. What Are the Conditions of Choice Which Guide Societal Response to Climatic Change?

Despite input from scientific investigators and careful scrutiny of all alternative strategies by decision-makers, the eventual responses to CO_2 climate change will be guided at all levels by a complex array of economic, political, cultural and legal factors. Together they constitute what we call here the 'conditions of choice' and comprise the context of decision-making which encourages or inhibits particular modes of responses to environmental or resource problems. Such constraints on decisions occur at all levels of social organization.

For example, for decades American communities facing choice about response to flood hazard were enticed into choosing from a narrow range of engineering works (dams, levees, channelization) in lieu of alternative strategies like flood plain regulation or warning systems (White, 1969). In part, this was due to bureaucratic bias and to federal cost-sharing policies. At the national level, efforts to institute effective national land use regulations in geologic hazard areas are severely constrained by cultural values about the rights of private land ownership and by legal entanglements (Baker and McPhee, 1975). Internationally, agreements on strategies for preventing depletion of important ocean fisheries are hampered by the common property nature of the resource and by the lack of international institutional arrangements (Christy and Scott, 1965; McKernan, 1972). The 1972 Stockholm Conference on the Environment discovered that agreement on cooperative strategies for handling global environmental problems is stifled by differences in priorities of national aims, as between economic development and environmental protection.

At all levels, the conditions of choice often whittle away at a theoretically large number of alternative strategies, leaving pitifully few perceived practicable choices. It would be overly sanguine to expect that research which simply delimits the range of alternatives and their consequences will automatically lead to optimal choice. Experience dictates otherwise. Understanding of the ways in which decisions are guided by the conditions of choice is necessary in order to anticipate how societies are apt to select among possible strategies for handling the CO_2-induced climate change.

One source of major influences on choices is found in national policy – in broad national response modes and the priorities of national aims. For instance, global comparison of natural hazards management shows that national *response modes* fall largely into four categories: provision of relief, control of the physical event, comprehensive damage reduction, and multi-hazard management (Burton *et al.*, 1978). In the past, the United States relied heavily on the first two, then switched to the third, and now is taking tentative steps toward the fourth. Other nations display different patterns. Comparative cross-cultural analyses can discover the relative advantages and disadvantages of particular hazard response modes within differing societal contexts. This kind of knowledge can provide clues as to the patterns of response most applicable to CO_2-induced climate change.

Moreover, adjustment decisions are further guided by the relative emphases placed upon particular *national aims*. In the U.S., several national aims enter into decisions regarding natural resources in general and water resource management in particular: economic efficiency, human health, environmental protection, equity in income distribution, and regional development (Water Resources Council, 1976; White, 1969). Choice of adjustment strategies varies as the relative weights attached to particular aims shift over time. For example, the massive river basin development schemes involving large dams and other engineering structures, prevalent in the 1950s and justified on the grounds of economic efficiency and regional development, began to fall into disfavor in the 1960s as greater consideration was given to the national aim of environmental protection.

The point to be emphasized here is that a given set of national aims can be considered the common denominator which underlies all resource-related issues and decisions – CO_2-induced climate change included. This is an important, fundamental connection between responses to CO_2 and responses to other societal problems like air pollution, drought, or energy. In essence, the desirability of any adjustment strategy – to climate change or otherwise can be judged according to the degree to which it contributes to national income, leads to equitable distributions of wealth, meets goals of environmental protection, and so forth. In this way, particular strategies for CO_2 differ only in specific purpose from other resource strategies, but ultimately they contribute to the same set of national aims.

This suggests that we need to step back and view societal response to CO_2 in its larger resource context. This means ceasing to contemplate response to CO_2-induced climate change as a separate problem (or opportunity). We must begin to establish the associations with other societal issues. There are two practical reasons for doing so. First, to the degree that CO_2 strategies can be tactically piggybacked onto other problems or projects which are perceived to be of a more urgent nature (like energy or global food supplies), the greater the likelihood of successful adoption. CO_2 by itself is unlikely to rise to the top of national priority lists. Jointly-designed or dual-purpose strategies promise greater ease of implementation.

Second, CO_2 response strategies might achieve greater benefits at less cost if their adoption is hooked directly into the attainment of specific national aims. For instance, in developing countries CO_2 response could be tied directly to the goal of economic development. Similarly, response to CO_2 in the developed world might be linked intentionally with the broader aim of protecting our environment, as, for example, in reducing both local air pollution and CO_2 emissions by switching away from coal burning power plants. Such linkages could help to sharpen the issues, to guide strategy choice, and to clarify the streams of benefits to be derived nationally from purposeful societal response to CO_2.

In sum, the message of this section is as follows: knowledge of the ways in which particular conditions of choice (like prevailing response modes or national aims) guide, or could guide, societal response to CO_2 is necessary in order to allow careful fashioning of strategies which promise greatest net benefits for society and which have high likelihood of implementation. Several research opportunities are suggested.

7.1. *Research Opportunities*

First, research leading to fuller understanding of the likely *constraints and incentives to CO_2 strategy adoption* is basic. Better descriptive models of choice in resource management would shed light on the CO_2 issue. This includes all levels, from local to global. For some resources and regions, we have already a fairly good understanding of the processes involved and a wealth of existing studies. This is the case with water resource management in the western U.S., for example. But for other areas knowledge is scarce. Perhaps the greatest research payoff would come from studies within the context of the global political economy: how does the capitalist market economy constrain or otherwise guide resource decisions in developing countries at individual, local, or national levels? The global study of the 1972 world food situation by Garcia and Escudero (1980), for example, is enlightening in this regard. A major assumption, of course, is that the same incentives and constraints which are at work to guide societal strategies to droughts, energy shortages, food problems, water management, or the like, are directly applicable to the CO_2 issue. We believe they are.

A second opportunity builds on the first: based on understanding of the conditions of choice, research directed towards indentifying viable *connections between CO_2 strategies and other existing resource problems* could facilitate greater ease of adoption and more explicitly meet the priorities of national aims. How might strategies for adjusting to CO_2 climate change, reducing agricultural drought hazard, and achieving economic development aims be integrated and implemented in the tier of sub-Saharan developing countries? Inasmuch as CO_2 will be perceived as a remote problem in many parts of the world, the chances of formulating patterns of response to benefit the entire global community would be enhanced considerably by addressing such questions.

8. What are the Dynamic Feedback Effects to Nature, Society, and Subsequent Response?

Once adopted and implemented, strategies for adjusting to a situation of climatic change feed back to alter the physical systems or the social systems (refer to Figure 1). The process of response is continuous, changing as social systems themselves change, as thresholds of perception shift, as newly-conceived (or perceived) strategies arise, and as conditions of choice evolve. Thus, we are portraying a dynamic system of climate-society interaction, one which must be studied ultimately in a dynamic – not static – fashion.

Because of the dynamic complexities, every study which attempts to capture the whole set of relationships in one setting over time appears unique and highly descriptive. As Kates (1980a) notes, this is partly why many holistic studies of climate impact seem so idiosyncratic and 'fuzzy' to non-social scientists. On the other hand, the seemingly 'rigorous' studies often focus on isolated aspects of the problem. Thus, we face a dilemma of sorts. Ultimately, we would like to understand, theoretically, the entire pattern and process of human response to climatic variation, but our research procedures usually guide us to specific pieces of the problem (and we are not completely certain that the whole is equal to the sum of its parts). Limited attempts have been made to overcome the dilemma through the use of systems modelling, but the potential for wider applicability of the method to climate impact assessment is unclear at this time. There is a need to investigate further systems modelling and related tools for this purpose.

In terms of actual experience, how effective have various strategies been in helping society adjust to climatic variations? Surprisingly little research has been conducted on this question. In the United States, most research efforts provide prescriptive answers to normative questions (should cloud seeding be widely adopted or water conservation techniques encouraged). Very few post-audit analyses of past adjustment strategies have been conducted to ascertain actual performance (White and Haas, 1975). For example, for nearly 40 yrs the federal government has encouraged certain drought adjustment strategies for the U.S. Great Plains, which include a mix of river basin-wide and groundwater irrigation, soil and water conservation techniques, and so on. Yet, we have little idea if, or to what degree, these practices have achieved their intended aims. One finds many studies which assess such adjustments on an experimental basis (e.g. agricultural experiment station research) but very few which attempt hindsight-evaluation in the real world socio-economic, political, and environmental setting (as did Riebsame, 1981). This represents a major knowledge gap, since many of these same strategies are potentially applicable to problems engendered by CO_2-induced climate change.

8.1. Research Opportunities

Several research areas emerge from the above discussion. First, there needs to be an assessment of the *potential of simulation modelling* as a method for analyzing the effects of and responses to climatic change on society. Simulation models might prove to be a useful means of integrating a number of climate-society relationships, of exploring their interaction over time, and of assessing the possible effects of strategy or policy changes. This is clearly an interdisciplinary endeavor, and incidentally, one which might serve as a useful vehicle for bringing together those with disparate viewpoints.

A second research opportunity lies in conducting empirical *post-audit analyses of past adjustment strategies*. The purpose would be to gain understanding of their effectiveness in actual use beyond theoretical or normative evaluations. The focus should be on studies of both long-term climate change and shorter-term fluctuations which relate directly to the CO_2 issue. The experience in natural resource management or natural hazard management should prove helpful. Knowledge of the efficacy of alternative adjustive mechanisms is a critical informational component to development of strategies for coping with climate change, and should thus receive strong research support.

Summary and Conclusions

Within the time scale of human existence, climate changes are not unusual. The neolithic age was well underway when the Altithermal period of warmer average temperatures prevailed over the globe. Ancient civilizations witnessed the decline of the Altithermal with the change to a cooler global climate about 4500 yrs ago. The Little Ice Age occurred but a minute ago in the lifetime of mankind. Superimposed upon longer-term climate changes were numerous medium- and short-term fluctuations. Some of these apparently coincided with growing, healthy societies, while others found societies troubled and declining. Climate changes presumably can bring boom to some and bust to others, although in hindsight the cause-and-effect nature of the relationship is extremely difficult to establish.

The possibility of a climate change within the next 50 yrs, then, is not so unusual, given the long-term perspective. What *is* unique about the prospect of a CO_2-induced climate change, however, is that: (1) it would be generated largely by human activity through massif combustion of fossil fuels, and (2) it is the first time in human history that we have *prior* scientific information that a climate change is likely. Heretofore, climate changes were phenomena recognized after the fact. The implications are that not only does society (in the global sense of the world) have the option to implement preventative measures if it so chooses, but it also has the opportunity to anticipate the possible outcomes (both benefits and costs) of climate changes and to fashion strategies accordingly. For an environmental change of such a large magnitude and scale, this is unprecedented in the history of human affairs.

The challenges to both the physical and social sciences are enormous. The particular climate impact assessments that are required are extremely demanding because of the far-reaching consequences of a CO_2 climate change. Moreover, society is now requesting answers to direct, applied questions which the scientific community is unused (and often reluctant) to addressing and which ultimately require interdisciplinary cooperation – a formidable hurdle given the tradition and strength of disciplinary barriers. As a result, the scientific community often finds itself lacking the theoretical and conceptual frameworks and the methodologies it needs to answer the socially and economically relevant questions about the shifts in climate. This is especially true for the social sciences. Existing methods have to be re-examined, and new methods and approaches developed and tested. Above all, there is an urgent need to ask what we already *do* know about important aspects of the CO_2 issue and in what broad directions should research now be directed. This paper represents an initial effort to do so.

We first discussed basic assumptions about the nature of climate and society relationships. It was noted that a static deterministic conception of climate's influence on human activity (termed 'neo-environmental determinism' in its extreme form) probably underlies most existing research in climate impact assessment. As a means of identifying opportunities for research, we offered an alternative conceptual framework that portrays climate impacts as a function of the interaction of variations in both the physical and social systems; the framework emphasizes decision-making and societal responses which feed back into the systems in a dynamic fashion. Within that framework, eight key questions were identified that pertain directly to the CO_2 issue. Throughout the paper, we asked what is known about each question and what research could be conducted to advance our knowledge. Altogether, twenty-two areas of research were suggested; these, together with the eight major questions identified in Figure 1, are summarized in Table IV.

As we stand back and reflect on the set of research questions and opportunities, we

TABLE IV: Opportunities for research

1. What are the relationships between *climate variations and sectors* of society?
   (a) Review of basic research on climate-resource sector linkages.
   (b) Climate-crop yield modelling.
   (c) Sector sensitivity analyses.
   (d) Sector resiliency analyses.
2. What are the characteristics of society that determine *vulnerability* to climatic variation?
   (a Critical review of conceptual and methodological approaches to climate impact assessment.
   (b) Networking of research and researchers concerned with societal effects of climate change.
   (c) Systematic inventory of potential case studies.
   (d) Case study investigations of effects of climate change (or analagous events) on society.
3. What are the *pathways and linkages* within social systems through which the effects of climate change are transmitted?
   (a) Linking of major climate-related models with sectoral models.
   (b) Tracing actual pathways of societal effects of climatic variations through case study research.
4. What is the *level and distribution of effects* from climatic change?
   (a) Develop indicators of societal impacts.
   (b) Construct methodologies for systematic collection of data on social distribution of climate effects.
   (c) Investigations of global distributions of effects arising from climatic fluctuations.
   (d) Assess trends in climate-society interactions.
5. What is the range of *mechanisms* by which societies adjust to climatic fluctuations? And what are their costs and effects?
   (a) Construct roster of adjustive mechanisms.
   (b) Studies of long-term social costs of adjustment strategies to short-term climate fluctuations.
6. How is *information* (scientific or otherwise) on climate change *perceived, interpreted, valued, and channeled* into strategy evaluation?
   (a) Investigation of the socio-economic consequences of the dissemination of scientific information on CO_2.
   (b) Assess user needs with respect to CO_2 information.
7. What are the *conditions of choice* which guide societal response?
   (a) Determine potential constraints and incentives to C_2 strategy adoption.
   (b) Determine connections between CO_2 strategies and other existing resource problems.
8. What are the *dynamic feedback effects* to nature, society, and subsequent response?
   (a) Investigate potentials of simulation modelling for climate impact assessment.
   (b) Post-audit analyses of past adjustment strategies.

reach three broad conclusions. First, opportunities for studying the societal effects of a potential climate change lie only secondarily in specifying the likely direct impacts (as in, say, estimating wheat yield declines given a reduction in average precipitation). Although such estimates are useful and practical, the greater opportunities lie in gaining a fuller understanding of the nature and process of societal vulnerability, adaptability, sector sensitivities and resiliencies, and decision-making and response to environmental variation. It is this fundamental knowledge which, in the long run, will prove more valuable than mechanistic delineations of potential impacts.

Second, because of the complexity and holistic character of the CO_2 issue, disciplinary research foci have only limited application. Interdisciplinary communication and research are central to progress in understanding climate-society interaction in general and CO_2-induced climate change in particular. The research opportunities suggested herein reflect this view.

Finally, from a societal standpoint, CO_2-induced climate change is not an isolated problem. Many of the basic processes – of vulnerability, of effects and their distribution, of strategy formulation, etc. – are common to a broad spectrum of resource, environmental, and natural hazards contexts which exist today. The implications are twofold. First, in order to conduct meaningful research, we do *not* have to wait until reasonably precise forecasts of regional climate changes are available. Research related to the societal effects of, and response to, CO_2-induced climate change can proceed now. And second, the eventual strategies which society adopts to deal with climate change will be, and should be, intertwined with a whole set of related environmental and social problems. Many of the issues are similar and amenable to common societal responses. What we learn about a range of social, climatic, and environmental problems will apply directly to an understanding of the societal effects of CO_2-induced climate change. And vice versa.

Acknowledgements

Early drafts were reviewed by F. Kenneth Hare, Ian Burton, and the members of the AAAS/DOE Panel.

Appendix: The Role of Geography

Probably more than any other discipline, geography is extremely wide-ranging in subject matter and approach. Geographers have spent considerable time arguing amongst themselves as to what constitutes the distinctive claims of geography within academia. On the basis of the content, geographers have claimed nothing less than the entire surface of the earth, physical and human systems included. With respect to scale, geographic studies have ranged from investigations of spatial behavior in hospital rooms to global resource patterns. At one time or another, geographers have offered their preoccupation with space as their calling card (but what discipline is without a spatial context in its focus of study?). In terms of content, scale, or dimension, geography always eludes clear definitions.

Perhaps more illuminating is to ask what geographers do. One view (Pattison, 1964; Taaffe, 1974) identifies four traditions in geography: Physical, regional, spatial, and man-environment. Within these traditions, geographers consistently have dipped heavily into related disciplines to acquire theory and methodology and in the process have spread themselves thinly over broad intellectual ground. One result is that geographers have assumed hybrid identities: cultural geographers, social geographers, behavioral geographers, regional geographers, physical geographers, historical geographers, Marxist geographers, economic geographers, geomorphologists, climatologists, human ecologists, and on and on – all within the same bailiwick.

Perhaps it is this characteristic of crossing disciplinary boundaries which gives geography its uniqueness, in two ways. First, operationally, geography seems to come closer to an interdisciplinary field than others. Geographers often provide much-needed synthesis when integration is most needed. (Not that geography has special claim to that role; often, it just turns out that way.) Second, because geographers historically have always kept one foot in the physical sciences (climatology has been a traditional focus in geography), they are noted for their attempts to bridge the gap between the environmental and human realms, between physical science and social science. In this paper, our assessment reflects both interdisciplinary synthesis and a man-environment perspective on the issue of CO_2-induced climate change.

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(Received March 1980; in revised form 14 September, 1981).