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Human adaptation to climatic variability and change

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Recent developments in both the policy arena and the climate impacts research community point to a growing interest in human adaptation to climatic variability and change. The importance of adaptation in the climate change question is affirmed in the Intergovernmental Panel on Climate Change (IPCC) Technical Guidelines for Assessing Impacts and Adaptations and the IPCC's more recent Second Assessment Report. Yet, the nature and processes of human adaptation to climate are poorly understood and rarely investigated directly. Most often, human responses of one form or another are simply assumed in impacts research. Analyses that do address adaptation use a variety of interpretations and perspectives resulting in an incomplete, and at times inconsistent, understanding of human adaptation to environmental variations. This paper reviews and synthesizes perspectives from an eclectic body of scholarship to develop a framework for characterizing and understanding human adaptation to climatic variability and change. The framework recognizes the characteristics of climatic events, the ecological properties of systems which mediate effects, and the distinctions which are possible among different types of adaptation. A classification scheme is proposed for differentiating adaptation strategies.

Key words: adaption, climate change, climate impact assessment, human–environment interaction, conceptual framework

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Introduction

Amongst the various manifestations of global environmental change the issue of climatic changes, particularly those related to atmospheric accumulation of "greenhouse gases", has attracted the attention of the research community, decision makers, and the public. It is now widely accepted that human-induced changes in climate are likely in the next century if not apparent already, and that they will have or are having significant implications for societies and economies (Houghton *et al.*, 1996; Watson *et al.*, 1996; Bruce *et al.*, 1996). International concerns over global climatic change and its consequences are reflected in the 1992 United Nations Conference on Environment and Development (UNCED) which developed the Framework Convention on Climate Change (FCCC) signed by 154 countries, many of whom now have national plans to address the "problem" of climate change.

Yet there still exist widely differing views, both among and within countries, about the nature and severity of the climate change problem and what, if anything, should be done about it. In some industrialized countries there is a strong lobby for limitation of greenhouse gases; but there are also those who argue that the problem is not sufficiently serious or certain to warrant the costs such policies would entail, and that human activities will adapt in any event (differing views on the adaptability of human systems to climatic changes are discussed in: Nordhaus, 1991; Lave and Vickland, 1989; Chen and Kates, 1994). This latter view reflects an abiding confidence in human ingenuity and adaptability. In recent years the notion of human response or "adaptation" has been more widely incorporated in the climate change debate (Stern *et al.*, 1992; Rosenberg *et al.*, 1989; Goklany, 1995).

Notwithstanding this growing recognition of the role of human agency, relatively few impacts studies have considered the actual processes of adaptation to climate in detail. Most often, it is simply assumed that systems will either adjust or not adjust to the scenarios specified (Delcourt and van Kooten, 1995; Rosenberg *et al.*, 1993; Kaiser *et al.*, 1993; Rosenzweig and Parry, 1994). Some empirical studies have focused more directly on adaptation (e.g. Glantz and Ausubel, 1988; Liverman and O'Brien, 1991; Smit *et al.*, 1996), but there has been little explicit examination of how, when, why, and under what conditions adaptations actually occur in economic and social systems. Such information is now sought by decision-makers and planners attempting to assess the significance of future climatic change, and to prepare for it.

One reason for the assumption-based treatment of adaptation in climate impact assessment is that both the concept and appropriate analytic approaches are still evolving. Although adaptation is frequently referred to in scholarly work and policy discussions related to climate, there is no common understanding of what is meant by the term, let alone how the prospects for adaptation might best be analysed. This paper summarizes the policy relevance of adaptation to climatic variability and change, synthesizes concepts of human adaptation from existing literature, and develops a general framework for classifying and understanding adaptation to climatic stresses.

Climatic variability and change

Climate is inherently variable, and these variations exist at many spatial and temporal scales. Some of this variability, such as from season to season, is well understood. But much of it, including variations over years, decades, centuries and millennia, is poorly understood and largely unpredictable (Hare, 1991). Thus decisions in sectors or activities sensitive to climatic conditions are usually taken under uncertainty or risk, sometimes employing statistical probability, but more often on the basis of heuristics.

Uncertainty is compounded by the fact that human activities in the past and present are causing the earth's climate to change. While there is growing acceptance that the earth's climate, particularly mean temperature, is changing, there are differing views on the rate and ultimate magnitude of these changes. Also uncertain are the potential variations about these new mean conditions (Katz and Brown, 1992; Hare, 1985). Regardless of changes in variability, the difference in the anticipated time frame of global climate change and the planning horizon of most human activities means that any longer term changes will be felt via differences in the frequency and magnitude of extreme events.

The perceived importance of these changes, and the impetus they provide for human response, depends to a large extent upon the forecast rate and magnitude of change and the assessed degree to which human activities will be disrupted (Parry *et al.*, 1996). However, it also depends on the availability and attainability of response options. In some countries, especially in the developing world, longer term global climate change is simply not a priority issue given its long time horizon and inherent uncertainty. In those regions where droughts, floods, cyclones, and other perturbations associated with the current climate regime bring on massive loss of life, human dislocation and suffering, the challenges of coping with today's climatic variations do not allow the luxury of contemplating possible climate changes several decades hence (Chen and Kates, 1994; Glantz, 1992). Thus in many instances, those regions where response is most urgently needed may also be where it is most constrained (Meredith *et al.*, 1991; Parry *et al.*, 1996). Societies and economies function and evolve within this capriciously fluctuating climatic environment, and examples of adaptation to climate are all around us. They are embedded in building construction, transportation systems, agriculture, leisure activities, and many other elements of daily life which are somehow structured or designed to take account of prevailing climatic conditions. Thus the concept of adaptation relates as much to current climatic variability as it does to long term climatic change.

Adaptation to climate does not occur in isolation from the influence of other forces, but instead occurs amid a complex set of economic (micro and macro), social, and institutional circumstances which establish a location-specific context for human–environment interactions. In effect, there are many "non-environmental" factors which impede or mediate change in human systems (e.g. Lewandrowski and Brazee, 1993; Shackley and Wynne, 1995), and consequently there are also examples of "maladaptation" to climate such as the construction of dwellings in flood plains or the planting of moisture sensitive crops in drought prone areas. Such maladaptations are driven largely by non-climatic forces and serve short-term human goals, but often with attendant costs on individuals, communities, and society. In the developed world such costs are often treated as simply "the cost of business" whereas in the developing world the human and ecological consequences of such maladaptations are often more severe (e.g. Haque, 1995).

Adaptation to climate is relevant to both long term global climate change and to current variability in climatic conditions. In the case of global climate change, adaptation is important as an essential ingredient of any estimate of impacts and as one of the possible response options. For current variability, an improved understanding of individual and societal adaptation not only provides insights for estimating future adjustment, but also helps address current problems of sustainable development in light of variable and uncertain environments.

Adaptation, impacts and policy responses

The main elements of the climate change issue are summarized in Figure 1. Changes in climate are expected to have ecological and socio-economic impacts. Concern about these results in consideration of two broad families of response: limitation or mitigation of greenhouse gas emissions so that climate does not change so much or as fast, and adaptation to the changes and their impacts. This structure, which distinguishes impacts, mitigation and adaptation, is reflected in the activities of the Intergovernmental Panel on Climate Change, the Framework Convention on

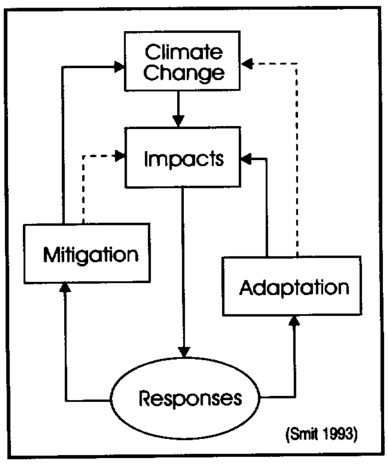

Figure 1. Responses to climate change and impacts.

Climate Change, and in the national programs of many countries including Canada.

While adaptation to climate is most commonly thought of as one of the public policy response options to the concerns about climate change, it is also an integral part of the impacts component because impacted sections or regions will adapt spontaneously (quite apart from policy) to changes in environmental conditions. Estimates of impacts of changing climate are sought for two related reasons: (a) to provide, with information on climate change itself, a basis for assessing the overall severity of the problem, and (b) to provide a bench mark (the "do nothing" option) for evaluating the pros and cons of potential response strategies. The science of assessing human impacts of climate change is still developing (Carter *et al.*, 1994). For the most part, studies have focused on particular scenarios of future climate, essentially representing instantaneous changes in average conditions. Typically, the studies have not considered transient effects or variability and have assumed little or no adaptation to the changed conditions (IPCC, 1996; Smit *et al.*, 1996). However, it is extremely unlikely that social and economic systems would simply collapse in light of climatic changes. Instead, some analysts have assumed that systems will simply adapt spontaneously to a changed environment (Tobey, 1992; Bruce *et al.*, 1996). Unfortunately, we have little basis to support or refute either the "no adaptation" or the "full adaptation" assumption. Without a better appreciation of the adaptations which would occur as a matter of course, we will not have credible assessments of impacts. Thus, an understanding of the spontaneous or autonomous processes of adaptation (Carter *et al.*, 1994; CAST, 1992) is necessary for the evaluation of both the climate change problem and the merits of alternative response options.

It is increasingly accepted that the basic decision facing governments and society is not whether to pursue limitation or adaptation strategies, but rather how to combine these approaches to minimize future change and to adapt to the changes which are now under way (Burton, 1994). Concern that the accelerated rate of human-induced changes in climate may outpace the adaptive mechanisms in natural and socio-economic activities is prompting efforts to plan for possible changes and to promote adaptation (Bruce *et al.*, 1996). Similarly, there is growing interest in identifying public policies and institutional arrangements which currently impede adaptation to environmental conditions, with a view to removing such impediments to adaptation.

Quite apart from the longer term climatic change issue, there is also merit in policy consideration of adaptation to existing climatic variation and uncertainty. Limits to our current levels of adaptation are demonstrated by losses and damages associated with extreme events such as droughts, floods, and unseasonal frosts (Burton, 1994; Niederman, 1996). Such events continue to result in economic losses, and in extreme cases, human suffering, in spite of a growing arsenal of technological and managerial response options. In some cases, social and economic systems may actually be becoming so thoroughly adapted to political, cultural and economic stimuli that they are effectively decoupled from the natural environments in which they operate. As a consequence they are increasingly vulnerable to climatic extremes regardless of the future climate scenario (Blain *et al.*, 1995; Downing, 1992; Dovers and Handmer, 1991). The costs of these damages are borne, at least in part, by society at large. Pay-outs by governments for drought, hurricane, and flood relief alone amount to billions of dollars over recent decades (Wheaton and Arthur, 1990; Smit, 1994; Chagnon, 1996). Thus, there is already a public policy rationale for attention to adaptation as part of a comprehensive response to climatic change and variability.

Conceptual foundations of adaptation

While the concept of adaptation to environment is an increasingly important component of the global climate change question, its origins and development lie elsewhere. According to Winterhalder (1980) its roots are in the natural sciences, namely population biology and evolutionary ecology. Here adaptation refers to genetic characteristics which allow individual organisms to survive and reproduce in the environment they inhabit. Successful adaptation leads to the continued viability of a species or ecosystem, but not necessarily the survival of individuals within a population (Slobodkin and Rappaport, 1974). Ecological concepts such as tolerance, stability, and resilience have been used to describe the propensity of biological systems to adapt to changed conditions, and the processes by which these changes occur (Holling, 1973; Marten, 1988).

The adaptation paradigm has also found wide application in the social sciences, where these ecological principles have been applied in the context of human–environment interaction (e.g. Clark, 1989; Stern *et al.*, 1992; Hawley, 1986; Timmerman, 1981; Dovers and Handmer, 1991). Social and economic systems, and individuals within them, can and do adapt to changing environmental circumstances. An important distinction, however, is that humans possess the ability to plan and "manage" adaptation. Thus, while the responses of biological systems to perturbations are entirely reactive, the responses of human systems are both reactive and proactive, incorporating environmental perception and risk evaluation as important elements of adaptation strategies. Additionally, human systems may adjust in pursuit of goals other than mere species survival, for example, to enhance quality of life or to exploit perceived opportunities.

Social science applications and extensions of the adaptation paradigm are visible in many scholarly fields including human and cultural ecology, natural hazards research, ecological anthropology, cultural geography, ecological economics and, more recently, climate impact research. Applications in these various fields of inquiry have led to some distinct interpretations of the concept of adaptation. For example, some models of cultural adaptation focus on the collective behaviour of systems, while others emphasize the role of individuals as decision makers (Hardesty, 1983). Denevan (1983) argues that there are two levels of cultural-ecological behaviour, a cultural or institutional level which is shared, and an individual level which may differ from the broader collective condition. Thus adaptation, and our understanding of it, is sensitive to scale.

Researchers have considered the capacity of human systems to adapt to global climate change using notions of vulnerability and resilience to understand the potential for damage or loss (Kasperson *et al.*, 1991; Burton, 1991). Drawing on concepts from ecology, it is argued that the nature of response to environmental perturbation is influenced by the degree to which systems are affected, which in turn is described by various properties of the system itself. Some analysts, working from the perspectives of political economy, have examined these characteristics in the context of social, economic and institutional forces that cause some regional variations in exposure to risk (Palm, 1990; Watts, 1983; Chiotti and Johnston, 1995).

Another approach evident in adaptation research focuses on characteristics or properties of the environmental perturbation. These are believed to affect both the degree of impact and the nature of responses. These event characteristics relate primarily to the severity or magnitude of an occurrence, and to its temporal properties such as probability of occurrence (Burton *et al.*, 1993; Kates, 1985). Consideration of such properties of climate is largely absent in most climate impact analyses where the focus is on average conditions for climatic parameters which are assumed to be of key importance for the activity system in question.

Finally, several approaches draw distinctions on the basis of certain characteristics of the action which is undertaken in response to an environmental stimulus. For example, distinctions are made on the basis of whether responses are structural (i.e. technological) or behavioural, whether they are undertaken before or after extreme events occur, and whether they are intended to buffer and sustain current activities or facilitate change to new types and patterns of activity (Burton *et al.*, 1993; Meyer-Abich, 1980; Timmerman, 1992). Some commentators have even drawn distinctions between adaptation strategies on the basis of their availability and ease of implementation. This view contrasts actions which are readily available and implemented within existing structures and institutions with major technological innovations and transformations of institutions, economies and policy regimes (Crosson and Rosenberg, 1991; Clark, 1985).

Do all human responses to environmental change qualify as adaptations? Some definitions distinguish adaptations from other forms of response. For example, Glantz (1992) differentiates adaptation from other responses according to the time of response relative to the time of a perturbation: adaptation refers to the unplanned reactive response to an event or condition which has already been experienced, as distinct from what is termed "mitigative" actions which seek to avoid negative impacts through anticipatory actions. Burton *et al.* (1993) distinguish adaptations from adjustments according to the persistence of the response, where short term measures are not deemed to be adaptations. Bryant (1994) has applied concepts from the adoption of innovations paradigm and the field of strategic planning to draw a similar distinction between actions of a managerial nature, which are short lived and consistent with existing management practices, and strategic or entrepreneurial actions which result in a fundamental change in the nature or structure of an activity system. The latter type of change is deemed to be adaptive.

Adaptation has even been cast as one of the emergent properties of human systems. In this interpretation, adaptation or adaptability is not something which is determined by various ecological properties of systems, it is itself regarded as an ecological property of a system. For example, Riebsame (1991) contrasts adaptation with resilience, where the former is equated with change and the latter with entrenchment.

These distinctions demonstrate the wide usage of the concept of adaptation by researchers interested in global environmental change, but they also paint a somewhat confused picture. The notion of human or societal adaptation to the natural environment is not just a product of our current interest in global environmental change. It has been widely, if not uniformly, applied in many scholarly fields with interest in society–environment interactions. Rather than attempting to invent yet another interpretation of adaptation we propose to synthesize several of these existing concepts into a framework to categorize the many different types and forms of human responses to environmental conditions. Our intent is not to judge whether given actions are definitively adaptive or otherwise, but to clarify and make explicit the dimensions of the adaptation issue via a framework or "anatomy" of adaptation and a model of human responses to climatic variations.

A framework for understanding climate adaptation

Adaptation involves change in a system in response to some force or perturbation, in our case related to climate. Analyses of adaptation can begin by addressing the attributes of the perturbation, the characteristics of the impacted system, or the nature of the response. These foci represent the major dimensions of adaptation and together serve as a framework for adaptation research (Figure 2). Drawing on the various interpretations and distinctions noted earlier, we develop each of these dimensions in turn and, in the case of responses, offer a schema by which adaptation strategies can be classified and described.

Climatic disturbances

Previous work has identified several characteristics of events, or environmental parameters, which influence the impact of environmental disturbances on society, and hence the pace and the nature of adaptation. Much scholarly effort has been devoted to assessing effects of sudden shocks (e.g. floods, tornados). The use of the term "event" in the context of climate change includes not only short-term extremes, but also a number of other conditions. Climate change may involve gradual changes in long term average conditions, greater variability within the range of "normal conditions", changes in the types of extreme events which are possible or probable, changes in the frequency, magnitude, and distribution of extreme events, or most likely some combination of all of these (Hare, 1991). Consequently, climate change may be regarded as an event in its own right, or as a broader phenomenon within which particular climatic conditions will occur at some changed frequency and/or magnitude. The latter interpretation is most relevant to the following characteristics of disturbances, which are drawn largely from the work of hazards researchers.

The scale of events, both in terms of magnitude and areal extent, is relevant in any consideration of environmental impact and adaptation. Events of greater *magnitude*, especially those which exceed a system's "absorptive capacity", are expected to have a greater impact on human systems, and thus would be expected to necessitate and accelerate adaptation. A related consideration is the spatial scale or *areal extent* over which climatic events or changes are experienced. While some disturbances may be highly localized, others may occur over large areas. The types of responses selected for localized or concentrated events may differ greatly from strategies which might be directed toward conditions that are more widespread across regions.

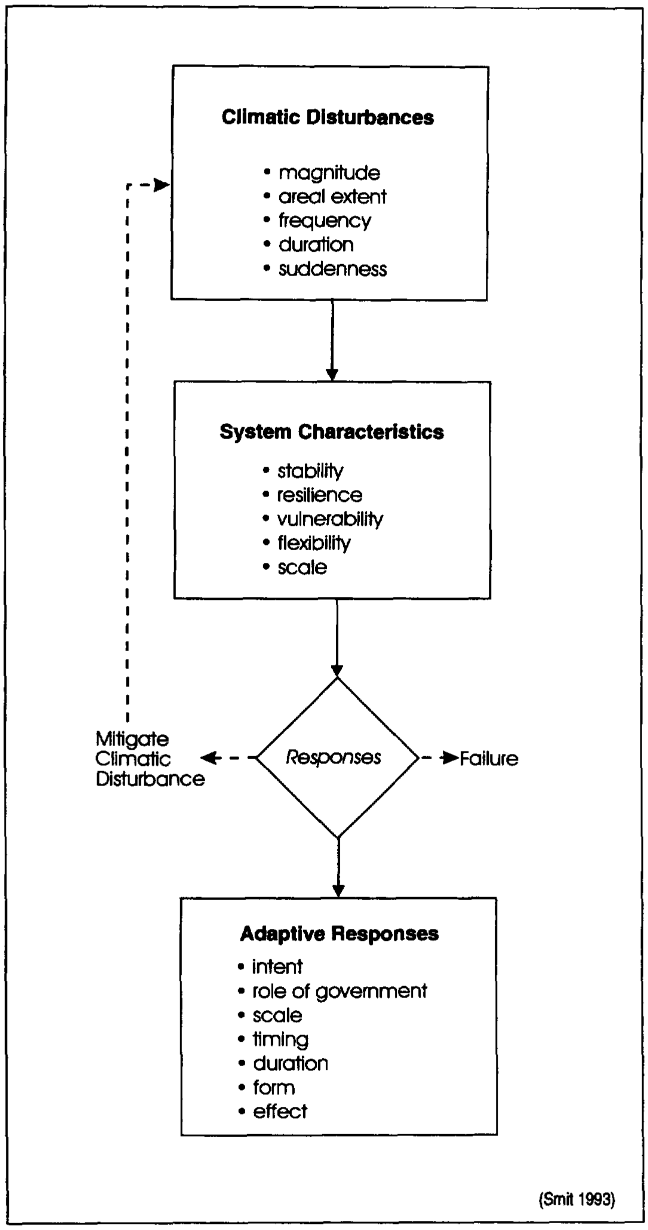

Figure 2. Dimensions of adaptation.

The temporal properties (frequency, duration and suddenness) of climatic events have significant potential to influence adaptation. The *frequency* of occurrence of climatic events of a given type and magnitude is a potentially influential factor in the human adaptation process. Here we recognize the importance of cumulative impacts and their role in adaptation. Increased frequency of harmful climate events will also heighten decision makers' awareness of climate and perception of risk (Schweger and Hooey, 1991). In an agricultural region, for instance, single year dry spells may evoke a very different type of response than a series of repeated dry years (Blain *et al.*, 1995). The combined influence of frequency and magnitude affect the time needed for system recovery after perturbation and the time available before another stress is added to the system.

Similarly, the *duration* of the stress is noteworthy. Climate events which extend over a comparatively lengthy period of time should, *ceteris paribus*, be expected to inflict greater damage or disruption to human activities than will like conditions of shorter duration. Events of longer duration may also permit greater opportunity for adaptation during the occurrence than do events of shorter duration. For example, the curtailment of municipal water use during problematic dry spells represents and adjustment during a climatic stress.

A third temporal attribute, *suddenness*, describes the speed of onset of particular climate conditions (or of climate change itself). For example, some climate related perturbations such as flooding may vary in their rate of onset. While a steady rise in water levels as a result of seasonal rains or snow melt usually provides some opportunities for "preventive" forms of adaptation, a flash flood necessitates a different set of responses. In contrast, global climate change is a slow and incremental process and provides a different context for adaptation altogether.

A final point on sources of disturbance. Human systems respond not only to environmental conditions but also to economic, technological, institutional, political and social conditions—and changes in any of these domains are capable of perturbing human systems. The relative importance and role of these potential influences on adaptation and their synergistic effects with climate are not well understood (Smit *et al.*, 1996). Estimations of both impacts and human responses would be improved though a better accounting of this issue.

System characteristics

Several system characteristics have been identified, especially in ecology and general systems theory, as affecting the ability of environmental systems to sustain shocks or stresses. More recently, the fields of thermodynamics and chaos theory have contributed to a growing understanding of the behaviour of complex systems in the face of largely unpredictable environmental stresses (Kay and Schneider, 1994; Funtowicz and Ravetz, 1994). While much of this research is oriented toward natural systems, these concepts are well suited to work on human systems. Understanding the prospects for adaptation to environmental change requires some qualitative understanding of the sensitivity of the impacted region or system (IPCC, 1996). The following properties or characteristics of human activity systems (see Figure 2) seem especially relevant to this task.

The *stability* of a system refers to its ability to remain fixed and unchanged in the face of disturbance; the less the fluctuation in response to climatic events, the more stable the system. Thus the notion of stability pertains to the steadfastness of systems and the lack of fluctuation about an equilibrium state (Holling, 1973; Kay, 1991). The related notion of *resilience* refers to the "elasticity" or recuperative power of a system, its ability to recover or rebound, or the degree of impact that can be experienced without moving the system away from a previous equilibrium and onto what Kay and Schneider have termed a new attractor (Kay and Schneider, 1994). For example, a farming system which produces a consistent yield over time through resistance to impact or quick recuperative power is stable, while an agricultural system which can sustain itself despite large fluctuations in yields or prices etc. is resilient. Both attributes prompt thinking about thresholds of tolerance in human systems. Indeed, one of the most important and most difficult research challenges lies in identifying these impact thresholds.

The notion of *vulnerability* refers to the degree to which a system or "exposure unit" may be adversely affected by a hazardous event (Timmerman, 1992; Carter *et al.*, 1994). In the context of climate change, vulnerability relates to the susceptibility of a human or economic system to the disruption, wound or damage resulting from environmental change. At present there are efforts to identify regions of the earth that are inherently and acutely vulnerable to environmental perturbation, and thus at greater risk of disruption (Kasperson *et al.*, 1991; Meredith *et al.*, 1994). It is noteworthy that efforts to reduce vulnerability have often been pursued via attempts to increase the stability of socio-economic systems. While most would agree that a stable system is appealing, at least on intuitive grounds, it is held by some that past efforts to buffer and entrench human systems, while making them more resistant to damage from small to medium scale (i.e. routine) perturbations, have also had the effect of increasing their vulnerability and loss potential in the event of major environmental perturbations (Bowden *et al.*, 1981; Riebsame, 1990). The IPCC (1996) concluded that vulnerability depends upon economic circumstances and institutional infrastructure, and that systems are typically more vulnerable in developing countries where economic conditions and institutional arrangements are less favourable.

Flexibility refers to the degree of manoeuvrability which exists within systems or activities. It has been suggested that, in responding to current environmental stress and uncertain future conditions, the preservation of future options is as important as the immediate response (Goldberg, 1986; Waggoner, 1992). Some socio-economic activities, sectors or regions are more flexible, and therefore more adaptable, than others. For example, it might be argued that specialized monoculture farming systems, found in many parts of Canada today, are less flexible, and therefore less adaptable, than were the smaller-scale diversified systems which preceded them because of their dependence on technology, capital and marketing structures.

Finally, the issue of system *scale* is fundamental to understanding human adaptation to environmental change. Human–environment interactions can be considered at the level of an individual (Smit *et al.*, 1996), a community (Izac and Swift, 1994), a sector (Rosenberg, 1992), a region (Koshida *et al.*, 1993) and so on. Yet, depending upon the scale at which a system is defined, a change may or may not represent an adaptation. For example, actions designed to sustain the viability of individuals in a system may actually retard the long term adaptation of the system itself (consider the adaptation of a farmer versus a regional farming system). Such actions are sometimes referred to as maladaptations (Carter *et al.*, 1994; Smit, 1993). Similarly, the losses to individuals may be regarded, at the more aggregate scale of regional economy of community, as an adaptation of the system generally.

Adaptive responses

The characteristics of human systems and the nature of climatic events together establish conditions which stimulate and influence responsive adjustments. The third dimension of our framework focuses on the characteristics of adaptive responses themselves. One set of possible responses addresses the environmental change itself, with activities to prevent or mitigate climatic disturbances (Figure 2). Although (as noted as the outset) these actions are important in the climate change issue, they are beyond the scope of this paper. Another type of change or response in the human system is the outright collapse or failure of some activity (Figure 2). While we have not attempted to rigidly specify conditions that represent adaptation, we suggest that this type of change cannot be considered an adaptation—at least at the scale where the collapse has occurred. For our purposes, adaptation involves change, in response to environmental conditions, which maintains, preserves or enhances viability of the system of interest.

Previous research and commentary has highlighted several distinctions amongst the varied components of the environmental adaptation issue. This scholarship forms the basis for a schema to describe, differentiate, and understand adaptation strategies. Human adaptive responses can be summarized according to seven broad attributes (Figure 2).

Adaptations can be distinguished according to their *intent*, i.e. whether they occur incidentally or are the result of purposeful decisions (e.g. Waggoner, 1992; Carter *et al.*, 1994; Smit, 1993). Adaptation is often regarded as being the outcome of a conscious and deliberate response to stress, with a commonly understood (though often not stated) goal. However, it is sometimes the case that actions taken for some other purpose have the unintended or incidental effect of reducing the impact of climatic events. For example, a policy decision to discourage housing developments close to shorelines in order to preserve access and aesthetics may also incidentally make those developments less vulnerable to climate-induced changes in water levels and storms.

The question of intent often becomes less clear when attention shifts from adaptations by individuals to system-wide adaptations. A regional agricultural system subjected to a series of droughts may experience changes with a reduction in the number of operators and an increase in the debt load of farmers generally. This system-wide adaptation results not so much from a conscious decision or goal to reduce operators and increase debt, but rather this is what transpired over time given the prevailing climatic conditions and the economic and policy situation. However, it is more often the case that adaptation is the result of a deliberate attempt to avoid, or respond to, the impacts of an environmental change. Purposeful adaptation to climate implies an assessment of climatic conditions and a decision to act, i.e. something done with the intent of responding directly to climate. The resulting plan of attack represents an adaptation strategy.

The second broad basis for distinguishing responses concerns the *role of government*. Adaptation strategies may be distinguished according to whether they are undertaken privately, via public agency, or through a combination of both (Tobey, 1992). In support of private sector adaptation, there are those who possess an abiding faith in the ability of individuals and societies to adapt to environmental change on their own from a suite of existing options and emerging or anticipated technological developments. Agriculture is one sector in which it is often assumed that many of the necessary adaptations, especially in industrialized world, will occur privately or autonomously (Waggoner, 1992) (and given the impressive track record of industrialized agriculture in the area of crop productivity over past 50 years this is not an altogether unwarranted assumption). Nevertheless, the role of government is an important one, both in an anticipatory planning sense and in a *post-hoc* manner following environmental perturbations.

The potential roles of government in stimulating, imposing, and/or underwriting adaptation initiatives may be direct or indirect. In some cases governments directly implement the adaptive actions, for example, modifying port facilities or water control structures, building standards, Coast Guard practices, emergency responses, land use controls, disaster relief, and so on. Direct actions of governments may be proactive or reactive, and may be undertaken over the short term or long term. In addition, governments may also adopt an indirect supporting function via research, information dissemination, public education, or the provision of financial or other incentives. We might even question the true autonomy of private sector adaptations, especially those that derive from publicly funded research and development.

For many situations, the distinction between public and private adaptation is not clear. A very common case is where the adaptive behaviour is undertaken by private individuals or companies, but there exist government policies or programs which influence the nature or prospect of adaptation. Thus, the degree to which farmers will take risks with climatic variations depends in part upon government policies and programs in crop insurance, price supports, drought relief, and international trade agreements which promote certain types of production (Smit, 1994; Burton, 1994; Reilly *et al.*, 1994). In some cases government programs can impede adaptation; for example, subsidies to produce specific crops may discourage changes to other crops which are less vulnerable to climatic variability (Smit, 1994).

Adaptation to climate can range from local to national levels, and it is possible to distinguish both the type of adaptation and various adaptation strategies on the basis of both spatial and social *scale*. Some forms of climate adaptation may be in response to localized risks from particular types of perturbation and thus are site specific in nature (e.g. the threat to certain vulnerable coastal communities from increased sea levels or storms). Other types of adaptation may occur at broader scales because of changes in regional climatic conditions and their effects on economic sectors such as tourism, forestry or agriculture. Still other adaptations, and the strategies developed to achieve them, may occur at a national scale; e.g. the potential modification of national building code standards to reflect the increased (or reduced) stresses posed to buildings and infrastructure from an altered climate. Of course, there is also the prospect of international adaptation, such as agreements to accommodate "environmental refugees" or to address climate-induced food shortages or distribution problems.

It is also important to consider the social scale of adaptation. At one extreme is adaptation to climate change on the part of individual decision-makers. In agriculture, for example, such individual adaptation might involve farm level changes such as the modification of tillage practices under a new soil climate regime. In cases where sufficient numbers of individuals within a system have adapted to an existing or anticipated perturbation to have fundamentally changed the character of the system, adaptation may be described at the aggregate, or societal/community, scale as well.

A further distinguishing feature concerns the *timing* of adaptive responses. Adaptations may be classified according to their time of initiation relative to the time of the climatic perturbation. Incidental adaptation, by its nature, usually occurs either during or after a climatic event. In contrast, purposeful adaptations vary in their timing. Strategies designed to compensate loss or alleviate suffering caused by a climatic event may be conceived and initiated before, during or after the occurrence (e.g. disaster relief funding). Some forms of adaptation will require considerable lead time, especially where major institutional changes or innovations are required. These would need to be devised and implemented well in advance of the expected event.

Adaptations may also be distinguished according to their *duration*. Some adaptations may be very short term responses to climatic conditions, while others may remain for many years, and essentially become parts of modified or transformed human systems. Elsewhere this has been the basis of a distinction between short term "adjustment" and more permanent "adaptations" (Burton *et al.*, 1993; Parry, 1986. The notion of duration also relates to the common distinction between tactical and strategic adjustments in an activity system. Tactical actions comprise the daily or weekly management decisions made in response to an immediate stimulus. Strategic actions represent more enduring, often anticipatory, actions which are made with a view to the longer term and which alter the nature of the activity in some way. To illustrate, in agriculture a tactical adaptation may be a change in the rate of fertilizer application in one growing season whereas a strategic decision could involve change to a different type of farming entirely.

The final two attributes proposed in the framework are those related most closely to the nature of adaptations themselves, namely the form that they take, and their intended effect. While some changes are quintessentially technological or "engineered" in *form*, others are more behavioural and/or institutional. This distinction is apparent in many of the adaptation strategies already noted in this section. Technological responses to climate change and variability involve attempts to "manage" the impact of environment on humans, whether it be in the construction of new coastal infrastructure, the design of energy efficient housing, or the development of drought resistant cultivars. In these types of approaches technology is used both to buffer against climate's effects and to facilitate a change in society's practices under an altered climate.

Behavioural adaptation strategies include those activities which are undertaken through modification of the practices of individuals, groups, or institutions. It is likely that many adaptations to climate change will not involve the use of a "technological fix", but will instead be achieved through adoption of new practices, shifts to different types of activities or locations, and the restructuring of institutional arrangements. While some of these adaptations may take the form of tactical "fine tuning" responses at a micro-scale (e.g. changing the time of planting for field crops, amending zoning by-laws etc.), behavioural adaptations may also be evident and important in more dramatic ways, such as broad-scale shifts to new types of regional economic activity or changed patterns of human habitation. Indeed, such adaptations are the basis of many assumed responses in analyses of climate impacts.

Adaptation strategies, regardless of their type, may also differ according to their intended outcome or *effect*. A fundamental distinction exists between strategies or actions which seek to buffer a system from an environmental perturbation, and those which attempt to facilitate a shift or evolution to a new state. The former aims to protect current activity in the face of environmental change (enhancing stability), while the latter might be described as changing to meet altered conditions (enhancing resilience or flexibility). An example of buffering strategies in agriculture might be the development of irrigation systems to sustain existing types of production in the face of possible climate-related water shortages. A non-structural example of buffering is the use of various insurance or compensation packages to spread the financial costs of climate related losses. While the "first order" impacts of the event are experienced, those most directly affected are protected or buffered against its economic consequences. Hence, the impetus for other types of adaptation is reduced or removed altogether. In contrast, change-oriented adaptation strategies are directed toward a deliberate transformation of the *status quo*. Such strategies attempt to alter the nature of human activity in order to achieve a desired or better "match" with environmental conditions. Consider, for example, a program of land use planning which freezes development in areas likely to be adversely affected by climate change, or which protects areas which are likely to become important in the migration of ecosystems, or which encourages changes in land use practices to reduce vulnerability to certain conditions.

Thus the framework outlined in Figure 2 identifies dimensions and attributes by which adaptation to climatic change and variability can be systematically described and analysed.

Conclusion

Human adaptation to environmental change has been addressed in several disciplines, some of which are not well represented in climate impacts research to date. The resulting variety of terms, interpretations, and assumptions is somewhat confusing, especially for those attempting to integrate across disciplines. This paper has attempted to synthesize these concepts, and organize them in a comprehensive framework which identifies dimensions and attributes by which adaptation to climatic change and variability can be systematically described and analysed.

The framework accommodates three dimensions of adaptation to climate or other environmental stimuli: the nature of the disturbance stimulus, or force of change; the properties of the system which may influence its sensitivity; and the type of adaptation which is undertaken. Of course, there are feedbacks within and between the dimensions. For example, efforts to buffer an agricultural system from the effects of climatic variations, thus increasing its stability, may also affect other properties of the system such as its resilience, flexibility, and ultimately its vulnerability. Such adjustments also influence the nature of sensitivity to future variations in climate, and thus the type of adaptation taken.

The conceptual framework provides an organizing tool for continuing research on climate adaptation. Further research on adaptation would provide substance to the rather generic "anatomy" of adaptation outlined in this paper. Key gaps and information needs exist with respect to the forms which adaptations take, the conditions (or triggers) for adaptive action, and on the situations which influence the success or failure of adaptation strategies—including the institutional and economic forces which directly or indirectly promote or impede adaptation. Not only is such information essential for the development and promotion of adaptation strategies, it also provides direction for climate modelling, monitoring and impact assessment. Those attributes of climatic regimes to which human activities are sensitive are the ones for which data needs to be available for both research and decision making.

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