THE SCIENCE OF ADAPTATION: A FRAMEWORK FOR ASSESSMENT

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Abstract. This paper outlines what is meant by "adaptation" to climate change, and how it might be addressed in the IPCC Assessments. Two roles of adaptation in the climate change field are identified: adaptation as part of impact assessment (where the key question is: what adaptations are likely?), and adaptation as part of the policy response (where the central question is: what adaptations are recommended?). The concept of adaptation has been adopted in several fields including climate impact assessment and policy development, risk management, and natural hazards research. A framework for systematically defining adaptations is based on three questions: (i) adaptation to what? (ii) who or what adapts? and (iii) how does adaptation occur? The paper demonstrates that, for adaptation purposes, climate extremes and variability are integral parts of climate change, along with shifts in mean conditions. Attributes for differentiating adaptations include purposefulness, timing, temporal and spatial scope, effects, form and performance. The framework provides a guide for the treatment of adaptation in the IPCC assessments, both in the assessment of impacts and in the evaluation of adaptive policy options.

Key words: adaptation, climate change, impact assessment, response options, vulnerability.

1. Introduction

Much of the debate about climate change deals with its implications for natural and human systems, particularly where these are vulnerable to changes in climate, including the associated changes in frequency and intensity of extreme conditions. As a result, adaptation to climatic change and variability is now a fundamental concern, and is receiving increasing attention both in the climate change research community and in the ongoing international negotiations dealing with climate change. While the concept of adaptation is relatively new to the climate change research community, it has a longer history of use in such related fields as ecology, natural hazards and risk management. As analyses of adaptation to climate change and variability have become more common, researchers have proposed numerous types and forms of adaptation, characterized its processes and attributes, and identified a variety of applications. Thus, adaptations have been

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distinguished according to whether they are autonomous or planned, occur in natural or socio-economic systems, are anticipatory or reactive, and take technological, institutional or behavioural forms (Smithers and Smit, 1997a).

This paper outlines what is meant by "adaptation" to climate change and variability, and how it might be addressed in assessments such as the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR). It synthesizes the treatment of adaptation in the literature, and aims to assist analysis and policy development by providing a terminology and a framework for developing the science of adaptation. The paper draws from, and is consistent with, the concepts and terms outlined in Smit *et al.* (1999).

The paper first distinguishes two major roles for adaptation science in the climate change issue, one relating to impact assessment, the other to the evaluation of response options. The framework for defining adaptations is based on three questions: (i) adapt to what? (ii) who or what adapts? and (iii) how does adaptation occur? The paper briefly summarizes analytical approaches to predicting or estimating the likelihood of adaptations and approaches to evaluating potential adaptation measures. The paper concludes by outlining ways in which adaptation might be handled in assessments, such as the IPCC TAR.

2. Roles of Adaptation in the Climate Change Issue

This paper employs the convention adopted in IPCC and elsewhere that distinguishes adaptation from mitigation. Both represent **responses** to climate change and variability. "Mitigation", which means abate, moderate or alleviate, could be (and sometimes is, especially in the environmental hazards literature) applied to impacts, as in mitigate vulnerabilities and effects. In this paper, **mitigation** is a response to the broad issue of climate change and involves reducing or stabilizing greenhouse gas emissions or levels, in order to mitigate changes in climate. "Adaptation" could be (and sometimes is) applied to altering activities related to greenhouse gases. In this paper, **adaptation** refers to adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts.

An understanding of adaptation is necessary as part of climate change impact assessment. This is apparent in both the United Nations Framework Convention on Climate Change (UNFCCC) and the more recent Kyoto Protocol (1997). The ultimate objective of the UNFCCC, as expressed in Article 2 is:

> ...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

An essential element of the determination of what might be regarded as "dangerous" is adaptation. The extent to which natural ecosystems, global food supplies and sustainable development are "in danger" depends partly on the nature of climate change and partly on the ability of the impacted systems to adapt. Thus, in order to judge the degree and nature of the danger of climate change, impact assessments of ecosystems, food production and sustainable development (including systems such as forestry, fisheries, water resources, human settlements and human health) need to address explicitly the capacity for, and the likelihood of, adaptation to potential climatic conditions. The Kyoto Protocol (Article 11) also identifies the need for an improved understanding of climate change impacts, which requires knowledge of adaptations which are likely to occur.

Most impact studies now make assumptions about the expected adaptations in the system of interest (Smit, 1993; Tol *et al.*, 1998). Such adaptations are what distinguish "effects", "potential impacts" or "initial impacts" from "residual impacts". For **impact assessment,** the main interest is in understanding adaptations, predicting the circumstances under which they can be expected, and estimating their implications for the systems or regions of interest. The key question is: what adaptations are **likely**? (Table 1). This is **a positive** analysis; the purpose is to **predict** or **estimate the likelihood** of adaptations.

	Adaptation as part of IMPACT ASSESSMENT	Adaptation as part of POLICY EVALUATION
Analytical Function	Positive	Normative
Purpose	Predict, Estimate Likelihood	Evaluate, Prescribe
Central Question	What Adaptations are Likely?	What Adaptations are Recommended?
UNFCCC Article	Art. 2. are the impacts likely to be dangerous for ecosystems, food production and sustainable economic development?	Art. 4. which measures should be formulated and implemented to facilitate adequate adaptation?

Table 1. Places for Adaptation Analyses in IPCC.

In addition to its role in impact assessments, adaptation is also considered an important response strategy or policy and management option to address climate change (*e.g.*, Fankhauser, 1996; Smith, K., 1996). Adaptation to climate change and its impacts is receiving increasing attention as an alternative or complementary response strategy to reducing net emissions of greenhouse gases (termed "mitigation"). For this policy application, the key question is: what adaptations are **recommended**? (Table 1). This is a **prescriptive** or **normative** exercise, which requires information on possible adaptation strategies or measures, as well as principles to evaluate the merit of adaptation options. The UNFCCC also identifies this role of adaptation - parties are committed to "formulate, implement...national and, where appropriate, regional programmes containing ...measures to facilitate adequate adaptation to climate change" (Article 4.1(b)); and to "cooperate in preparing for adaptation to the impacts of climate change" (Article 4.1(e).)

The Kyoto Protocol (Article 11) also commits parties to promote and facilitate adaptation and deploy adaptation technologies to address climate change.

The formulation and implementation of adaptation measures and policies involves an additional analytical step as compared to the analysis of adaptation as part of impact assessment, namely an **evaluation**. It is not sufficient to specify an adaptation and its likelihood; some judgement as to its appropriateness, effectiveness or acceptability is also required in order to make recommendations as part of a response by governments.

These two roles of adaptation in the assessments of IPCC are indicated in Figure 1. The model on which this is based (Smit, 1993) simply showed that, in response to concerns over climate change impacts on ecological and human systems, actions could be taken to mitigate the changes in climate and/or adapt to their effects. Figure 1 shows that the assessment of climate change impacts includes a consideration of adaptations that are expected to occur. Impact studies (and estimates of impact costs) now commonly use the term "net impacts" to denote the explicit consideration of adaptation in impact assessment (Figure 1). These adaptations have been called "autonomous" and "passive", in that they would **likely** occur in the absence of specific policy initiatives to promote adaptive behaviour.

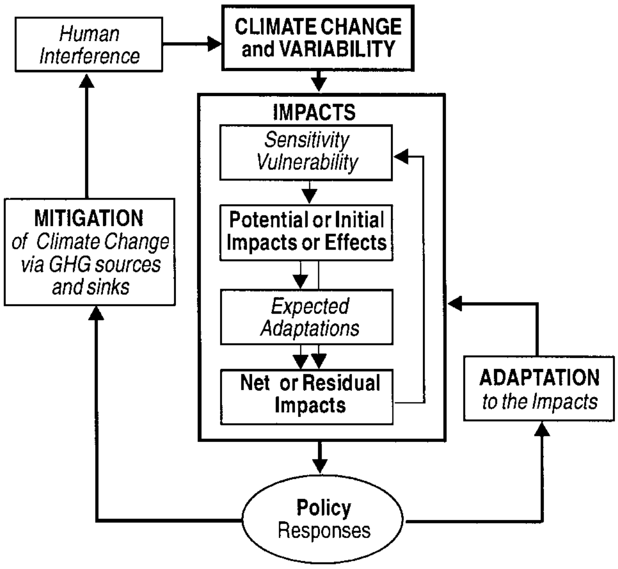

Figure 1. Adaptation in IPCC Assessment.

Most classifications of climate change response strategies and policy, including IPCC (see Jepma *et al.,* 1996), identify both mitigation and adaptation as options. Whereas mitigation policy options address the human influence on climate change via greenhouse gas sources and sinks, adaptation policy options (also called "planned" or "active" adaptations) deal with modifying the impacts or vulnerability of systems to climate change and its effects (Figure 1).

Thus, there are two distinct roles for adaptation science and assessment, but they are not independent; nor do they necessarily occur in any particular sequence. Whether for applications in impact assessment or in development of response options, there is a need for some consistency in concepts and terms. The most common distinctions are captured in the following framework, which provides a structure for the systematic analysis of adaptations. It draws from the "anatomy" of adaptation outlined in Smit (1993) and Smit *et al.* (1999).

3. A Framework for Adaptation Concepts and Terms

"Adapt" means to make more suitable (or to fit some purpose) by altering (or modifying). "Adaptation" refers to both the **process** of adapting and the **condition** of being adapted. The terms have more specific interpretations in particular disciplines. In the climate-change literature, numerous definitions have been proposed. Referring only to societal adaptation to climate, Burton (1992) defines it as "the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides". Similarly, Smith *et al*. (1996) state that "adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system". Also referring to human adaptation, Smit (1993) describes it as involving "adjustments to enhance the viability of social and economic activities and reduce their vulnerability climate, including its current variability and extreme events as well as longer term climate change". To Stakhiv (1993), the term adaptation means "any adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change". Watson *et al.*, (1996) define adaptability as "the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate", and note that "adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions".

These definitions all refer to adjustments in a system in response to (or in light of) climatic stimuli, but they also indicate differences in scope, application and interpretation of the term adaptation. Any scientific analysis of adaptation needs to specify several elements, which are reflected in the questions included in Figure 2. Adaptation can be to climate change, to change and variability, or just to climate. It can be in response to adverse effects or vulnerabilities, but it can also be in response to opportunities. It can be in response to current, actual or projected anticipated conditions, changes or consequences. Thus, analysis of adaptation needs to specify the stimuli to which adaptive responses are being considered, *i.e.*, "adapt to what?" (Figure 2).

The system that does the adapting also needs to be specified. "Who or what adapts?" can be people, social and economic sectors and activities, managed or unmanaged natural or ecological systems, or practices, processes or structures of systems. The systems, once specified, may be distinguished according to such characteristics as their adaptability or vulnerability.

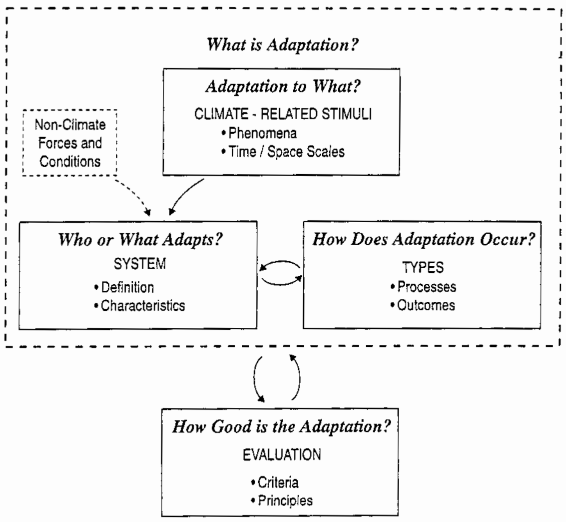

Figure 2. Adaptation to Climate Change and Variability (from Smit *et al.*, 1999).

Adaptations can also be defined according to how they occur. Adaptation can refer both to the process of adapting and to the resulting outcome or condition. Most definitions imply a change "to better suit" the new conditions; changes which fail to reduce vulnerability are sometimes called "maladaptations". Adaptation processes or measures can be reactive or anticipatory, spontaneous or planned, or distinguished in other ways.

A rigorous description of any adaptation would specify the system of interest (who or what adapts?), the climate-related stimulus (adaptation to what?), and the processes and forms involved (how does adaptation occur?). The task of developing or facilitating adaptation options or measures as part of a response strategy (the second role identified above) involves the additional step of evaluation to judge the merit of potential adaptations (how good is the adaptation?) (Figure 2). Evaluations of adaptations can be based on criteria such as costs, benefits, equity, efficiency, urgency and implementability.

The elements in this framework are distinguished to clarify the concepts and treatments of adaptation; obviously, they are not independent of each other. Nonetheless, the details of each element are examined in turn below.

3.1. STIMULI - ADAPTATION TO WHAT?

Climatic stimuli pertinent to adaptation have been called "doses", "stresses", "disturbances", "events", "hazards", and "perturbations" (Burton, 1997; Downing *et al.*, 1996). These stimuli are expressed sometimes as climate or weather conditions (*e.g.*, precipitation), and sometimes as the ecological effects or human impacts of the climatic conditions (*e.g.*, drought, crop failure or income loss). Thus, the **phenomena** to which adaptations are made need to be specified according to the climate characteristics which are relevant and their connection to the system which adapts. For example, an adaptation in agriculture may be in response to income changes, which reflect crop yield changes, which reflect drought, which reflect particular precipitation and moisture conditions. Thus, climate-related stimuli can be distinguished (*e.g.,* Parry, 1986): direct versus indirect, proximate versus distant, effects versus impacts, and various “levels” of impact. The key for adaptation science is that these are **system-relevant** climate-related stimuli, clearly related to the **sensitivity** of systems (Kates, 1985; Kane *et al.*, 1992; Yohe *et al.*, 1996).

The climatic conditions to which adaptations have been considered (either directly or indirectly) generally fall into three broad **temporal** categories: long-term changes in means or norms, inter-annual or decadal **variability**, and isolated **extreme events** or catastrophic weather conditions, such as floods, droughts or storms. These types of climatic stimuli are not independent. Extreme events are part of variability, which is an inherent feature of climate, including changing climate. The mean conditions which have been the focus of the climate change studies are the central tendencies of a distribution of conditions which vary from year to year. Adaptations may be (and perhaps should be) quite different depending on the time frame of the stimuli.

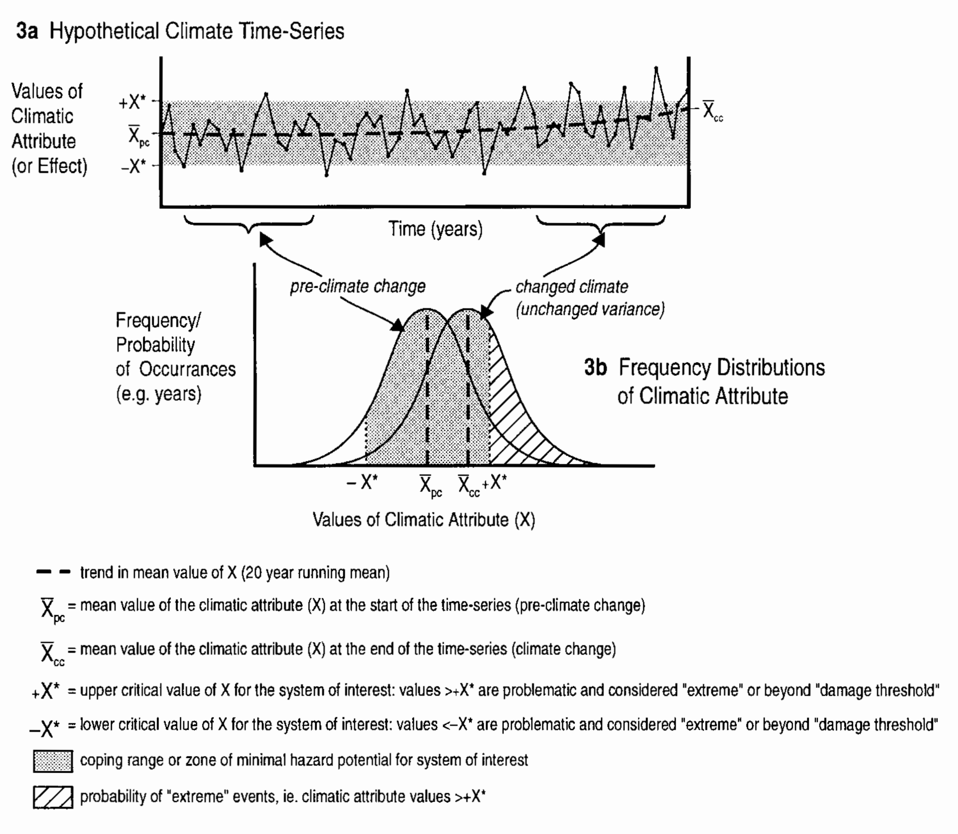

Figure 3. Climate Change, Variability, Extremes and Coping Range (After Hewitt and Burton, 1971; Fukui, 1979; Smit *et al.*, 1999; and others).

As illustrated in Figure 3a, climate change will be experienced via conditions which vary from year to year, and these variabilities are important for ecosystems (Sprengers *et al*., 1994) and for human systems (Downing *et al*., 1996). Adaptation may be to a changing mean, a particular extreme event, or a cumulative effect of conditions beyond some "coping range" (critical value, vulnerability threshold, band of tolerance, damage threshold). The coping range itself (shown as constant in Figure 3a) may change over time (see Hewitt and Burton, 1971; De Vries, 1985; De Freitas, 1989), reflecting adaptations becoming built into the system.

While there is interest in adaptation to variability and extremes in their own right (Smith, K., 1996; Burton, 1996), the focus in this paper is on adaptation to climate change. Yet adaptation to climate change requires consideration of variability. It is well established that, even with no change in variability (*i.e.*, no change in shape or variance of the distribution), a shift in the mean (*i.e.*, climate change) will also move the distribution, as illustrated in Figure 3b. Small changes in the mean may bring major changes in the frequency of occurrence of extreme events (Mearns *et al.*, 1984; Wigley, 1985), with obvious implications for impacts and adaptations (Heathcote, 1985; Warrick *et al*., 1986; Parry, 1986). For example, a drought with a probability of occurring once every 30 years (in Figure 3b: pre-climate change X>+X*) would, with a modest change in mean conditions (X_{pc} to X_{cc}), become a one in three or four year drought (see cross-shaded area in Figure 3b). Such changed frequency, and associated reduced recovery time, would greatly affect the effectiveness of adaptation options.

If climate change also alters the variance of the distribution of a climatic attribute, then the frequency of extremes can be further increased or reduced (Smit *et al*., 1999). Yet, even without **changes** in variability, non-trivial assessments of adaptation to climate change must consider variability as well as mean conditions.

Other temporal characteristics of climate stimuli with implications for adaptation are the speed of onset (or rate of change), the degree of predictability, and the duration of a condition (Sonka, 1992; Smithers and Smit, 1997a). Climate-related stimuli for adaptation can also be differentiated according to their **spatial** characteristics, particularly whether they are experienced locally or over a wide area (Smit, 1993; Tol, 1996). Adaptations are also influenced by non-climate conditions, sometimes called intervening conditions (Figure 2). For example, a series of floods may have similar effects on settlements in two regions, but differing economic and institutional arrangements may result in quite different impacts on residents and in quite different adaptive responses. Non-climatic conditions may dampen or exacerbate a climate stimulus (Lewandrowski and Brazee, 1992; Sonka, 1992; Smit *et al*., 1997). Clearly, any systematic consideration of adaptation needs to specify "adapt to what?".

3.2. SYSTEM DEFINITION - WHO OR WHAT ADAPTS?

Adaptations occur in something, called the "unit of analysis", "exposure unit", "activity of interest", or "sensitive system" (Carter *et al*., 1994). Any analysis of adaptation requires **definition**, or delineation of the system's subject and boundaries (Figure 2). Definition relates partly to scale. Thus, adaptation at the level of a farmer's field might involve planting a new hybrid; at the farm level it might involve diversification or taking out insurance; at the regional or national scales adaptation may relate to the number of farms in a compensation program; and at a global level, it may involve a shift in patterns of international food trade.

Definition also pertains to the nature of the system (*e.g.*, ecological, economic, social, political). It is sometimes held in ecology that organisms and species adapt (*e.g.*, by altering genetic structure or moving) but ecosystems do not (Rose and Hurst, 1991; Peters and Lovejoy, 1992; Markham and Malcolm, 1996). In the ecological field, "adaptation of ecosystems" usually refers to human management practices. Yet ecosystems, comprised of communities and assemblages of species, can and do change in structure, composition, function, and extent as a consequence of adaptations by species. Hence, the UNFCCC statement that "ecosystems adapt...naturally" refers to natural adaptations manifest in ecosystems. Krankina *et al*. (1997) discuss "natural adaptation of long-lived, complex boreal forests", which are complexes of species or ecosystems. They also refer to management and utilization strategies as means "to assist boreal forests in adaptation to a changing global environment".

Adaptation science should distinguish between who takes action and what is modified. For example, actions by coastal zone managers (who) may result in adaptations in a coastal wetland (what). In another coastal wetland system, adaptation may occur via a climate-change induced shift in species distribution (what) without any identifiable who. Any systematic treatment of adaptation requires definition of the system of interest and of the participants in the adaptation process.

Assuming a system has been adequately defined, there exist a host of characteristics analysts have employed to assess prospects for adaptation or adaptability. These include sensitivity, vulnerability, susceptibility, and resilience (Klein and Tol, 1997; Smithers and Smit, 1997b; Sprengers *et al*., 1994). Such characteristics are important both for estimating likely adaptations and for evaluating the merit of adaptive response options (Smit *et al*., 1999).

Particular terms have been suggested to distinguish adaptation in natural systems from that in socio-economic systems, or to differentiate the condition of a system before adaptation from after. Such distinctions are important in the science of adaptation, and can be captured without coining new terms. Hence, "vulnerability of an ecosystem" is different from "vulnerability of a socio-economic system", and "pre-adaptation sensitivity" is different from "post-adaptation sensitivity."

The terms sensitivity, vulnerability and adaptability are probably sufficient to capture the main concepts, especially if the reasons for particular adaptability characteristics are treated as underlying forces, and not included in the adaptability characterization itself. The IPCC (1995) Second Assessment Report (SAR) Summary for Policymakers (pp. 28-29) states: "the most vulnerable systems are those with the greatest sensitivity to climate change and the least adaptability". Not only is agreement on terminology necessary for development of the science of adaptation, but also there is a need for substantive research to test or support such statements.

3.3. PROCESSES AND OUTCOMES: HOW DOES ADAPTATION OCCUR?

The question of how adaptations occur (Figure 2) refers both to the **processes** of adaptation and the **forms** of adaptation which result. Many useful distinctions and typologies have been proposed (Riebsame, 1991; Burton *et al.*, 1993; Stakhiv, 1993; Carter *et al.*, 1994; Bijlsma *et al.*, 1996; Smit *et al.*, 1996; Easterling, 1996; Smithers and Smit, 1997a; Klein and Tol, 1997). Table 2 summarizes some of the common attributes used to differentiate adaptation processes and forms.

General Differentiating Concept or Attribute	Examples of Terms Used	
Purposefulness	autonomous spontaneous automatic natural passive	planned purposeful intentional policy active strategic
Timing	anticipatory proactive *ex ante*	responsive reactive *ex post*
Temporal Scope	short term tactical instantaneous contingency routine	long term strategic cumulative
Spatial Scope	localized	widespread
Function/Effects	retreat - accommodate - protect prevent - tolerate - spread - change - restore	
Form	structural - legal - institutional - regulatory - financial - technological	
Performance	cost - effectiveness - efficiency - implementability - equity	

Table 2. Bases for Differentiating Adaptations.

These processes and forms of adaptation are not independent of “who or what adapts?” and “adaptation to what?”. For example, adaptations in unmanaged natural systems are necessarily autonomous and reactive, whereas adaptations initiated by public agencies are usually planned and may be anticipatory (Smit *et al.*, 1999).

Most of the attributes are descriptive, intended to distinguish one type or form of adaptation from another. The performance attributes are both descriptive and evaluative. For impact assessment, estimates of adaptation costs, for example, are combined with estimates of adaptation-associated changes in impact damages to calculate residual impact costs. Performance attributes are also central features of the evaluation and prescription of adaptation options.

4. Methods for Adaptation Analysis and Evaluation

Previous sections have addressed the main purpose of this paper, namely to outline the roles of adaptation science in the climate change issue, and to present a framework to promote consistency and rigour in the use of concepts and terms. This section briefly notes some of the analytical approaches which contribute to the understanding and management of adaptation.

Conceptual models have been developed to outline expected relationships among stimuli, systems, adaptations and impacts (Klein and Nicholls, 1999; Smit *et al.*, 1996). These theoretical models also provide the structure and hypotheses for numerical impact assessments (*e.g.*, Easterling *et al.*, 1993; Rosenzweig and Parry, 1994). Impact assessment models, whether for ecosystems, economic sectors or integrated regions, necessarily include assumptions about adaptations (or their absence) (Tol *et al*., 1998). The assumptions are reflected in estimates of likely adaptations, which are based upon theoretical principle, observation or speculation. Empirical analyses of adaptive behaviour to climate-related stimuli have provided some insights into the conditions under which certain types of adaptations tend to occur, and in this way inform modelling exercises. Yet there remains a need in the impact assessment field for more systematic treatment of behavioural responses to climatic stresses and risks (*e.g.*, Sonka, 1992).

This research contributes primarily to the role of estimating likely adaptations, and hence net impacts under climate change, thereby addressing the UNFCCC issue of how dangerous are the impacts.

The evaluation of adaptations has received much recent attention. One body of work, summarized by Tol *et al.* (1998), deals with estimating the costs (including both damages and benefits) of adaptations taken "autonomously" rather than in response to government initiatives, and often in reaction to climatic stimuli. The resulting cost estimates are important in the "base case" (reference or do-nothing scenario) for the evaluation of both adaptation and mitigation policy options.

A second body of evaluative work deals with planned adaptations, mainly anticipatory, undertaken or directly influenced by governments as part of their policy response to climate change. The methods are intended to evaluate the merit or utility or acceptability of potential adaptation measures or strategies. Carter *et al.*, (1994) provide some very general steps for such evaluations. Smith and Lenhart (1996) propose net benefits and implementability as central criteria in a more detailed set of procedures proposed to evaluate "anticipatory adaptation policies". Tol (1996) argues that management options be evaluated with respect to economic viability, environmental sustainability, public acceptability and behavioural flexibility. Titus (1990), Goklany (1995), Fankhauser (1997) and Klein and Tol (1997) illustrate the variety of principles and methods which have been proposed for identifying, evaluating and recommending adaptation measures.

5. Adaptation and IPCC Assessments

Any systematic treatment of adaptation to climate change requires specification of three core elements: adaptation to what, who or what adapts, and how does adaptation occur.

This framework provides a structure for improving the science of adaptation and its application to policy. For the assessment of current knowledge about adaptation, and for IPCC Assessments, there is a fundamental distinction to be made between the **prediction** or **estimation of likely** adaptations as part of **impact assessment** on the one hand, and, on the other, the **evaluation** of adaptations as a contribution to the **policy response**.

For impact assessment, the central question is: what and when is “dangerous” anthropogenic interference in the climate system? (UNFCCC, Article 2). The degree to which changes in climate are dangerous for ecological and human systems depends in significant part upon the nature of adaptations which are likely to occur in those systems as a matter of course, and the consequences of those adaptations. Hence, knowledge of adaptations, including an ability to predict the conditions under which they can be expected to occur in given locations and situations, is a necessary ingredient in impact assessment.

For response options or policy evaluations, the central question is: what measures should be undertaken to facilitate adequate adaptation to climate change? (UNFCCC Article 4). The need here is to identify and evaluate potential adaptation measures, and ultimately put in place mechanisms for their implementation.

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