IPCC WG II Fourth Assessment Report − Draft for Government and Expert Review

Chapter 2 – New Assessment Methods and the Characterisation of Future Conditions

Coordinating Lead Authors
Timothy Carter (Finland), Roger Jones (Australia), Xianfu Lu (China)

Lead Authors
Suruchi Bhadwal (India), Cecilia Conde (Mexico), Linda Mearns (USA), Brian O'Neill (IIASA), Mark Rounsevell (Belgium), Monika Zurek (FAO),

Contributing Authors
Jacqueline de Chazal (Belgium), Stephane Hallegatte (France), Milind Kandlikar (Canada), Robert Nicholls (United Kingdom), Michael Oppenheimer (USA), Anthony Patt (USA), Kimmo Ruosteenoja (Finland), Claudia Tebaldi (USA), Detlef van Vuuren (Netherlands)

Review Editors
Hans-Martin Füssel (Germany), Yihui Ding (China), Geoff Love (Australia)

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Executive Summary

This chapter describes the significant developments in methods of climate change impact, adaptation and vulnerability (CCIAV) assessment since the Third Assessment Report (TAR). It also introduces the main scenarios and approaches to scenario construction that are used to characterise future conditions in the studies reported in this volume.

Assessment methods for CCIAV have expanded. Since the TAR, the demand for policy-relevant information concerning climate change impacts, adaptation and vulnerability (CCIAV) has seen the number of different methods in use expand significantly. Although the standard climate scenario-driven approach dominates the assessments described in this report, the use of other approaches is increasing. They include assessments of current and future adaptations to climate, of adaptive capacity, of social vulnerability, and of adaptation in the context of sustainable development. [2.2.1.1] [2.2.1.2]

Risk management is a useful framework for decision-making. There is an emerging recognition that risk management is a useful unifying framework for decision-making on climate change related threats and opportunities. The advantages of risk management methods include the flexibility to incorporate a range of mental models, formalised methods to manage uncertainty, stakeholder involvement, methods for evaluating policy options without being policy prescriptive and integration of different disciplinary approaches. [2.2.1.3] [2.2.1.4]

Assessments of appropriate responses to future climate risks require knowledge about current climate risks, and this involves stakeholders. An understanding of how a group or system can cope with current climate risks is an important part of undertaking CCIAV assessments for the future. Stakeholder participation is vital to the assessment process, and an increasing number of vulnerability and adaptation assessments include an active stakeholder component. This is crucial both for establishing credibility and for placing an assessment in a problem-driven context, which is a pre-requisite for effective risk management. [2.2.1.3] [2.2.3.3]

Vulnerability to climate change can be strongly conditioned by non-climate factors. Many new studies have applied non-climate scenarios at regional scale derived from the global scenarios developed in the IPCC Special Report on Emissions Scenarios (SRES). These studies demonstrate how the large differences in regional population, income and technological development implied under alternative SRES storylines can produce sharp contrasts in exposure to climate change, in adaptive capacity and vulnerability. Such studies also emphasise that it is not sufficient to rely on a single characterisation of future conditions.[2.2.2.8] [2.2.2.9]

Scenarios are being applied in CCIAV studies at a range of scales. Since the TAR there has been more quantification of the SRES storylines. With some regional exceptions, the original SRES assumptions for population and economic development largely remain credible. A range of methods have been applied to downscale and interpret the SRES storylines to regions, including stakeholder participation, expert judgement, modelling, and disaggregation. New regional scenarios have been developed of socio-economic development, land use and land cover, atmospheric composition, climate and sea level. Many have been applied in impact studies reported in this volume. [2.3.1.1] [2.3.1.2] [2.3.1.3] [2.3.1.4] [2.3.1.5] [2.3.1.6]

Improved understanding of the processes of adaptation and technological change will be essential for many future CCIAV studies. Technology scenarios are increasingly recognised as important for CCIAV studies, but there is a lack of theories and process knowledge about how future technology will evolve, and this has limited scenario development. Similarly, few CCIAV studies have developed scenarios of future adaptation, and the process and costs of adaptation are rarely accounted for in most global scenario exercises. [2.2.2.10] [2.2.2.11]

GCMs are still widely used for developing climate scenarios in CCIAV studies, but regionalisation methods are increasingly adopted, especially for treating extreme events. Coupled atmosphere-ocean general circulation models (AOGCMs) continue to be the primary resource for characterising future regional climate but regionalisation methods have increasingly been employed to obtain high resolution climate scenarios. The added value of regionalisation is context-specific, but it can provide new information about climatic variability and extreme climate events, and in some cases has revealed systematic differences to AOGCM projections. The range of uncertainties in regional projections from AOGCMs remains little changed from the TAR, but the importance of regional aerosol emissions and land use change to regional climate change has become more evident. [2.2.2.5] [2.3.1.2]

Non-SRES scenarios, incorporating climate policies or representing singular events, are gradually being adopted. SRES-based scenarios do not adequately address all concerns of policy makers. CCIAV studies assuming mitigated or stabilised futures, not considered in SRES, are beginning to assess the benefits (through impacts ameliorated or avoided) of climate policy decisions. Characterisations of singular events with potentially widespread consequences have also been developed, though questions remain over the plausibility (e.g. timing, magnitude) of projections that deal with surprises and shocks.[2.3.2] [2.2.2.12]

Probabilistic characterisations are being developed that can be applied to climate-related risks. Probabilistic characterisations of future climate and non-climate conditions are increasingly becoming available. Emerging methods of developing and applying probabilities to climate-related risks now indicate, for a limited range of examples, the probability of exceeding predefined thresholds of impact and the timing associated with this exceedence. However, many characteristics of the future are still inherently too uncertain to be handled probabilistically. [2.2.2.14]

2.1 Introduction

Assessments of climate change impacts, adaptation and vulnerability are carried out to inform decision making in an environment of uncertainty. The management of this uncertainty drives the development of new and improved methods of assessment. It also defines the requirements for characterisations of future conditions (scenarios) that are required in applying many of these methods. It is important that assessments deliver their findings and recommendations based on up-to-date knowledge, accounting for all major uncertainties affecting those findings in a transparent and informative manner. This chapter describes the significant developments in climate change impacts, adaptation and vulnerability (CCIAV) assessment methods since the IPCC Third Assessment Report (TAR). Also introduced are the main approaches used to characterise future conditions in the studies reported in this volume, with prominent examples of these highlighted.

In previous years, IPCC Working Group II[1] has devoted a Special Report and two chapters to assessment methods (Carter *et al.* 1996; IPCC 1994; Ahmad *et al.* 2001). Moreover, recognising the fundamental importance of scenario development in most CCIAV assessments, the TAR included a broad treatment of this topic (Carter *et al.* 2001; Mearns *et al.* 2001), which built on earlier descriptions of climate scenario development (IPCC-TGCIA 1999). These contributions provide detailed descriptions of assessment methods and scenarios, which are not repeated in the current assessment.

The range of approaches and methods in use has expanded since the TAR. Starting as the straightforward application of climate scenarios to assess impacts and potential adaptations, CCIAV methods have expanded to treat the management of uncertainty by addressing a variety of spatial scales, assessment directions and temporal aspects. These advances have also challenged some of the concepts and definitions associated with climate change (e.g. adaptation and vulnerability), which have had to become more inclusive to account for their uses in other disciplines. In particular, the development and application of risk management frameworks to CCIAV assessment is a major advance and is described in detail.

Managing uncertainty refers to taking account of uncertainty and integrating it into policy and decision-making processes (Schneider and Kuntz-Duriseti 2002). Appropriate characterisation of uncertainty is part of that process. Thus, uncertainty management is a prominent driver of the development of new modelling approaches, such as those involving probabilistic analysis. Conditional likelihoods are being developed to describe projections of future climate, and are being used in integrated assessment and impact assessment. However, process-based methods, such as those for managing the interactions between researchers and stakeholders, for developing and comparing conceptual models of risk and for constructing and assessing thresholds, are also being developed and applied. These improvements are interrelated and the integration of both models and processes is an important part of the new developments.

Many methodological developments and applications are hampered by insufficient data describing past trends and present conditions required for model calibration and testing. While data paucity continues to impede research in many parts of the developing world, in particular, the emergence of new methods for evaluating adaptation options and assessing vulnerability has highlighted a more universal need for new types of information; for example: understanding the processes and practice of current adaptation, the adoption and diffusion of new technologies, and the costing of impacts and adaptation.

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[1] Hereafter, IPCC Working Groups I, II and III are referred to as WG I, WG II and WG III, respectively.

The characterisation of climate and non-climate futures continues to be prominent in assessments, specifying the main drivers for estimating future impacts and providing a context for considering future vulnerability and adaptive capacity. Methods of developing socio-economic and land use change scenarios have advanced considerably since the TAR, and new methods are emerging for quantifying future conditions probabilistically, for addressing extreme climate events, and for treating singular events with indeterminate likelihood but potentially widespread consequences.

Many of the more recent studies evaluated in this Report have adopted scenarios based on the IPCC Special Report on Emissions Scenarios (SRES) and derivative studies. These are compared with representations of the future developed to serve other research and policy communities, which have also been applied in some CCIAV studies. The SRES scenarios assume no explicit climate policies, and other studies have begun to explore the implications of policy interventions aimed at mitigating greenhouse gas emissions, including those targeting stabilisation of atmospheric GHG concentrations.

The structure of information presented in this chapter follows a hierarchy of approaches, methods and results. An approach describes the overall orientation of a range of assessments, providing a framework that utilises a common set of methods. In that sense, vulnerability, adaptation and risk assessment can all be described as (not unrelated) approaches. A method is a particular procedure designed to carry out a limited number of tasks; therefore, a number of different methods may be applied within a single approach. Results of new or improved approaches and methods are illustrated where possible.

We begin the chapter with a description of different methodological approaches, concentrating especially on the development of risk assessment for CCIAV (section 2.2.1). Most CCIAV approaches have a scenario component, so section 2.2.2 details recent advances in methods of characterising future conditions. Section 2.2.3 then describes a range of new and improved methods that have been applied in CCIAV assessments since the TAR, with the critical issue of data needs for assessment treated in the following section (2.2.4). Given the wide adoption of SRES-based scenarios as well as increasing application of mitigation and stabilisation scenarios, section 2.3 provides a short summary of these as an introduction to the remaining chapters of the report. Finally, in section 2.4 we address key new findings and future directions.

2.2 Developments in methods

2.2.1 Towards a suitable framework for assessment

2.2.1.1 Conventional approaches to assessment

Since the TAR, the range of approaches and methods available for CCIAV assessments has been significantly expanded. Factors that distinguish a particular approach take into account the purpose of an assessment, its focus (who, what and at what scale), the methods available and the management of uncertainty. Stemming from the standard approach, which has its origins in the seven-step approach of IPCC (IPCC 1994), other approaches include inverse methods (e.g. those that focus on a specific outcome and assess the conditions under which that outcome may be realised or avoided), risk management approaches and integrated assessment. Constructing a taxonomy of approaches is difficult because of the many terms in use and the interdependence of different approaches; in this chapter we focus on the standard climate scenario-driven, adaptation, vulnerability, and risk management approaches.

Two of the most common terms describing assessment types are "top-down" and "bottom-up", which can variously describe the approach to scale, to subject matter (e.g. stress-impact-response; physical to socio-economic disciplines) and to policy (national as opposed to local policy); sometime mixing two or more of these. Note that some more integrated assessments combine top-down and bottom-up aspects, preventing any definitive conclusion as to what constitutes a top-down and bottom-up assessment. In this chapter, terminology is intended to communicate a general principle or purpose unless specifically defined otherwise. Application of the standard IPCC approach has expanded significantly since the TAR. For example, the context of input scenarios has risen in importance with impacts assessed from non-greenhouse policy emission scenarios being contrasted with those derived from stabilisation scenarios(e.g. Parry *et al.* 2001). The use of probabilities in impact assessments, presented as proof-of-concept examples in the TAR (Mearns *et al.* 2001), have contributed to concrete adaptations (see chapter 11), though examples remain limited (section 2.2.2.14). Adaptation and vulnerability assessments, once the outputs of impact assessments, are now being conducted in a broader socio-economic context.

The development of other approaches has been necessary to overcome the limitations of the standard climate scenario-driven approach. While for some purposes it remains the most suitable approach, a broader range of techniques is required to fulfil the following objectives: assessing current vulnerabilities and experience in adaptation; stakeholder involvement in dealing with extreme events; capacity-building needs for future vulnerability and adaptation assessments; potential adaptation measures; prioritization and costing of adaptation measures; interrelationships between vulnerability and adaptation assessments and national development priorities and actions to integrate adaptation options into existing or future sustainable development plans (e.g. SBI 2001; COP 2005).

Addressing these needs has prompted the development of risk assessment approaches, ranging from those that deal exclusively with adaptation, to those that aim to integrate the management of both adaptation and mitigation under climate change.

2.2.1.2 Climate change assessment in the context of risk

Although the enhanced greenhouse effect has previously been linked to the management of risk (Shlyakhter *et al.* 1995; Beer 1997) only recently have formal risk management frameworks for climate change been developed. This includes frameworks for adaptation (Jones 2001; Willows and Connell 2003; UNDP 2005), mitigation (e.g. Heal 2002) and integrated approaches suitable for addressing Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC Jones 2001; Mastrandrea and Schneider 2004). Article 2 itself is compatible with risk management (e.g. Lorenzoni *et al.* 2005). The requirement to stabilise "greenhouse gas concentrations … at a level that would prevent dangerous anthropogenic interference with the climate system" sets the objective for risk management, while ensuring that food security is not threatened, facilitating sustainable economic development and allowing ecosystems to adapt naturally set the criteria for management (United Nations 1999).

Climate change assessments have evolved from relatively straightforward scientific assessments − applying greenhouse gas scenarios to model the response of the climate system and then assessing the ensuing impacts of the changed climate − to those addressing the many factors listed in the previous section (e.g. Lorenzoni *et al.* 2005). Three iterations of risk assessment can be linked to successive IPCC assessments (Table 2.1).

The two major forms of climate risk management are the mitigation of climate change through the abatement of greenhouse gas emissions and sequestration of greenhouse gases, and adaptation to the consequences of a changing climate. Mitigation reduces the rate and magnitude of changing climate hazards whereas adaptation reduces the consequences of those hazards (Jones 2004). Mitigation also reduces the upper bounds of the potential climate change, whereas adaptation will have to cope with the lower bounds (Yohe and Toth 2000). Therefore, adaptation and mitigation treat different elements of climate change risk (consequences and hazards, respectively) and act on the upper and lower bounds of the plausible range of climate change, so are complementary processes. However, the benefits will appreciate at different time scales and, in many cases, they can be assessed and implemented separately (Klein *et al.* 2005). These aspects of complementarity and difference are discussed in chapter 18.

Table 2.1: *Evolution of risk assessments over time.*

Assessment	Policy question	IPCC process	Methodological approach	Scenario requirement
First iteration	Is climate change really a problem?	IPCC (1988) IPCC FAR (1990)	Sensitivity analysis	Incremental scenarios for primary climate variables
Second iteration	What are the potential impacts of unmanaged climate change?	IPCC IS92a-f scenarios (1992) IPCC SAR (1996) IPCC SRES emissions (2000) IPCC TAR (2001)	Scenario-driven impact assessments	Climate model derived scenarios for a large number of variables, at global and regional levels
Third iteration	How do we effectively manage climate change?	IPCC AR4 (2007)	Risk assessment framework	Model derived scenarios for a large number of variables, consistent with other scenario components; integration of scenarios at varying scales

To date, most CCIAV studies have assessed climate change without specific regard to how mitigation policy will influence those impacts. However, the certainty that some climate change will occur (and is already occurring − see chapter 1) is driving adaptation assessment beyond the limits of what scenario-driven methods can provide. The issues to be appended include linking current adaptation to climate variability and extremes with those to future climate, linking adaptation to sustainable development, engaging stakeholders and decision-making under uncertainty. Risk management has been identified as a framework that can deal with all of these issues in a manner consistent with existing methodologies. However, risk assessment frameworks introduce a new lexicon that needs to be reconciled with terms used in conventional CCIAV assessment. This is a difficult task – the climate change lexicon needs to be updated to encompass broader meanings consistent with mainstream activities, while the language surrounding risk is highly inconsistent, employing different nomenclature across a range of applications (Beer 2003). Box 2.1 outlines a range of broadly used, but not exclusive, terms and meanings from the literature.

2.2.1.3 Reconciling conventional assessment approaches with risk management

As the aims of CCIAV assessment have expanded in range and sophistication, so too have the approaches and methods used to address these aims. Although the purpose of an assessment has the greatest influence on which approach may be the most suitable for addressing that purpose, assessments share a number of common elements summarised in Table 2.2.

The standard climate scenario-driven approach is often described as top-down because it combines scenarios down-scaled from global climate models (GCMs) to the local scale with a process that begins with the climate system and moves towards socio-economic assessment. Bottom-up methods are those that commence at the local scale by addressing socio-economic responses to climate, which tend to be location specific (Dessai and Hulme 2004). Assessments that combine bottom-up and top-down approaches can seem complex because of the need to switch between frames of reference, the involvement of multidisciplinary approaches, stakeholder involvement and the presence of multiple uncertainties. However, such combined approaches are much more relevant to the adaptation process. The United Nations Development Programme's Adaptation Policy Framework (UNDP APF – UNDP 2005) has also identified a third major assessment approach – a policy-based approach, which assesses current policy and plans for their effectiveness under climate change.

Box 2.1: Definitions of risk and climate change terms

This box provides generic definitions for risk and selected climate change terms designed for readers to extract the core meaning encompassed within each term and use it in different contexts without deforming that core meaning (Sources: AS/NZS 2004; ISO/IEC 2002; Renn 2005)

Acceptable risk – insignificant or acceptably controlled risk

Consequence – the outcome of an event; can be single or multiple, range from positive to negative, be expressed qualitatively or quantitatively and be considered in relation to objectives.

Coping range – a range of climate variability or derived variable or set of variables with which an identifiable group, body, species or community can cope. The coping range serves both as a mental model and analytic tool that can be used to relate consequences to a pattern of varying climate

Critical threshold – denoting where an impact or risk exceeds a stated level of tolerance. A critical threshold can define a state change or set management criteria.

Exposure – duration of time subject to a harmful substance or process.

Hazard – a source of potential harm or situation with the potential to cause loss

Likelihood – a measure of probability expressed qualitatively or quantitatively

Probability – the extent to which an event is likely to occur. Probability can be related to a long-run relative frequency of occurrence or to a degree of belief that an event may occur

Residual risk – the risk remaining after the implementation of risk management/treatment

Risk – the chance of something happening that will have an impact on something that humans value. Most often measured as likelihood times consequence.

Risk analysis – systematic process to understand the nature of and deduce the level of risk

Risk assessment –the initial part of the process of identifying and quantifying risk (but sometimes used to describe the entire risk process; see risk management).

Risk criteria – terms of reference by which the significance of risk is assessed

Risk evaluation – process of comparing the level of risk against risk criteria (i.e. weighing up likelihood with consequence in order to make a decision on risk).

Risk management – the culture, processes and structures directed towards realizing potential opportunities whilst managing adverse effects. In some jurisdictions this term is restricted to the evaluation and implementation of options to control risk.

Risk reduction – actions to reduce the likelihood, negative consequences or both associated with a risk.

Risk sharing – the act of sharing a burden of loss or benefit of gain from a particular risk between entities.

Risk treatment – process of selection and implementation of measures to modify risk. The two major risk treatments for the enhanced greenhouse effect are adaptation and mitigation measures.

Vulnerability – the extent to which a person or group is susceptible to harm or loss from exposure

Table 2.2: *Common Elements of approaches to undertaking CCIAV assessments*

Elements	**Description**
Spatial scale	
Global (top-down)	Begins at the global scale, yields results at a regional or local scale
Local (bottom-up)	Begins at the local scale, results can be aggregated to a larger scale
Subject matter	
(Natural) Hazard (scenario-driven)	Begins with the drivers of change moving through to stresses on system functioning, , impacts and responses; Drivers-Pressure-State-Impact-Response (DPSIR) framework
Vulnerability/critical threshold (downside)	Assesses vulnerability (e.g. critical thresholds) then assesses likelihood of exceedence and/or measures to reduce vulnerability
Resilience/sustainable state (upside)	Defines a successful outcome or state, then establishes how to achieve that under climate change
Policy	Assesses an existing policy or set of actions, then determines how they fare under climate change
Temporal	
Exploratory (projection/ conditional forecast)	Projects forward in time (transient and time slice methods)
Normative (goal-oriented)	Explores a goal then diagnoses pathways towards that goal
Research methods	
Qualitative	Mathematical modelling approaches, data collection
Quantitative	Stakeholder elicitation, narrative approaches, risk perception
Involvement	
Stakeholders	May range from stakeholder information sessions through to stakeholders initiating and conducting assessments
Public at large	Communication strategy to disseminate results and lessons learnt

A further development is the linking of current climate, impacts, adaptations and vulnerability to potential future climate, impacts, adaptations and vulnerability. This recognises that adaptation to current climate is the basis from which future adaptations will take place (Mirza 2003b; Jones and Boer 2005). Figure 2.1 shows the major elements of the CCIAV assessment process, and relates the three major approaches described above to both current and future climate. The left-hand side of the figure emphasises the importance of assessing a range of historical and current factors, progressing well beyond the construction of baseline climate data. Baseline adaptation, existing adaptive capacity and adaptations to historically experienced climate risks are all utilised, especially when they have been developed to deal with climate variability and extremes.

The first, standard approach is labelled a natural hazards approach, where climate scenarios are projected through impact models to assess outcomes. The natural hazards approach is so named after the process used in the discipline of the same name, which identifies the hazard, assesses its likelihood and impact before going on to define vulnerability. Treatment can then reduce the consequences of an event (e.g. adaptation), or modify the event itself (e.g. mitigation). The second, vulnerability-based approach addresses the socio-economic context in which climate change occurs, then seeks to maximise potential benefits and minimise or reverse potential losses. Vulnerability concentrates on the downside of risk (see Table 2.2) whereas a resilience-based approach focuses on adaptation and adaptive capacity. The third, policy-based or normative approach focuses on how current or proposed policies and plans may be able to cope with climate change and how they may be modified to better meet their objectives (Table 2.3). Chapters 17 (adaptation options) and 20 (climate change and sustainability) are mainly concerned with these approaches at the local level, whereas chapter 19 looks at key vulnerabilities and risks.

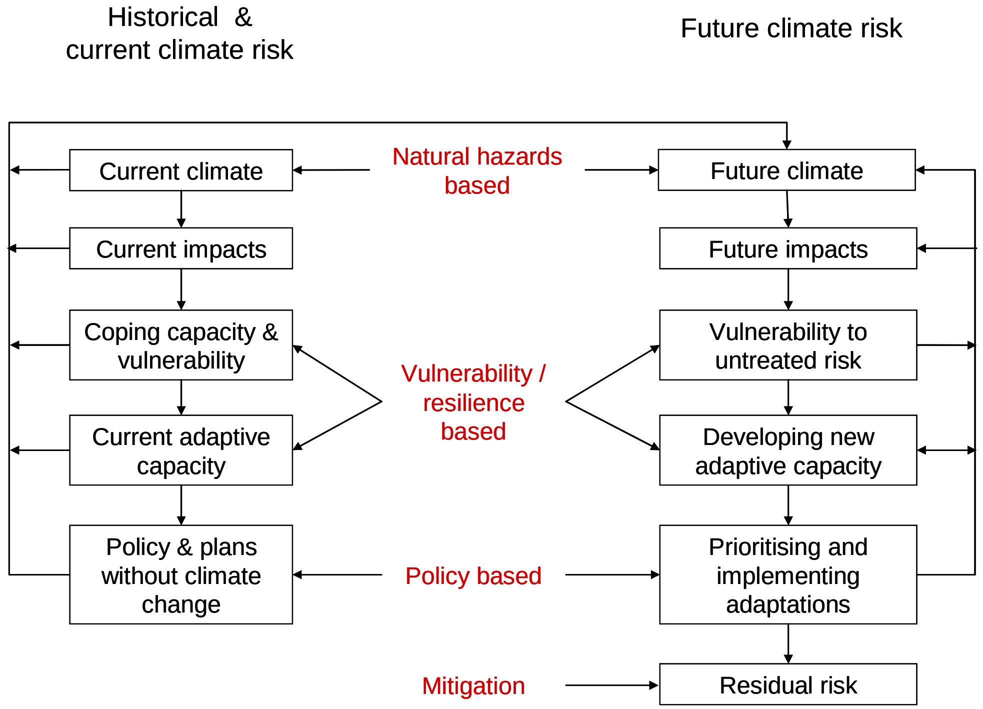


Figure 2.1: *Flow chart showing relationship of different assessment approaches with the process of assessing current and future climate risks. Though highly simplified, the arrows aim to highlight how simple pathways through the assessment, cross-links and inverse methods are all possible, depending on the scope and context of the assessment.*

Table 2.3: *Summary of approaches to CCIAV assessments showing characteristics of the assessment and criteria affecting the choice of approach (based on UNDP 2005).*

Approach	**Natural hazard-driven**	**Vulnerability/Resilience-driven**	**Policy-driven**
Objectives	What risks may we face under this projected scenario(s)?	What is the likelihood that a specific place, process, group or activity may be harmed and how do we reduce that level of harm?	How will our current plans for the future be affected by climate change?
Analytical method	Analyse possible outcomes from a given climate hazard(s) ± other drivers of change. Assess actions that may reduce consequences.	Determine the likelihood that current or desired vulnerability may be affected by future climate hazards. Assess ability to withstand shocks, recover from setbacks and manage change.	Assess the efficacy of an existing or proposed policy under climate change. Assess actions that will improve policy effectiveness.
Outcomes	An understanding of current/future climate-related risks and measures to manage those risk	Understanding of exposure to harm and harmful processes. Better knowledge of coping mechanisms and socio-political institutions, barriers to adaptation, increased benefits	Fitter policy under climate change
Scenario types	Exploratory scenarios of climate with other biophysical and socio-economic conditions	Characterisation of socio-economic states; can use scenarios or assess drivers through inverse methods. Baseline adaptation, adaptation analogues from history, other locations other activities	Unmanaged climate change impacts and vulnerability
Criteria influencing choice of method	• Probabilities of hazard constrained • Main drivers known • Chain of consequences understood • P(Hazard) × Consequences • Largely exploratory	• Probabilities of hazard not constrained • Many drivers resulting in vulnerability • Multiple pathways and feedbacks • P(Vulnerability)/Hazard (e.g. critical threshold exceedence) • Largely normative	• Policy aims sensitive to climate change • Desire to "mainstream" adaptation

2.2.1.4 Formalising the risk management approach for use in CCIAV

Risk management is defined as the culture, processes and structures directed towards realising potential opportunities whilst managing adverse effects (AS/NZS 2004). Risk is generally measured as likelihood × consequence (Box 2.1). This definition is also appropriate in guiding adaptation to climate change-related risks. There may be more than one event, while consequences can range from positive to negative and probabilities and consequences can be measured qualitatively or quantitatively (ISO/IEC 2002).

Risk management frameworks contain all of the characteristics that have also been deemed necessary for CCIAV assessment. Frameworks for adaptation assessment that utilise a risk management framework have been produced by Jones (2001), Willows (2003) and UNDP (2005). Figure 2.2 shows the UNDP Adaptation Policy Framework and the UKCIP Risk Assessment Framework (Willows and Connell 2003).

Some of the standard elements within the risk management process that can be linked to parallel CCIAV methods are:

- A scoping exercise, where the context of the assessment is established. This identifies the overall approach to be used.
- Risk identification, where the system of interest (exposure unit), its key elements considered to be at risk, the main climate and non-climate factors to which the receptors are sensitive (scenarios) and levels of acceptable risk are identified.
- Risk analysis, where the consequences and their likelihood are analysed. This is a highly developed area with a wide range of available methods to undertake impact analysis.
- Risk evaluation, where adaptation and/or mitigation methods are prioritised.
- Risk treatment, where selected adaptation and/or mitigation measures are applied, with follow-up monitoring and review.

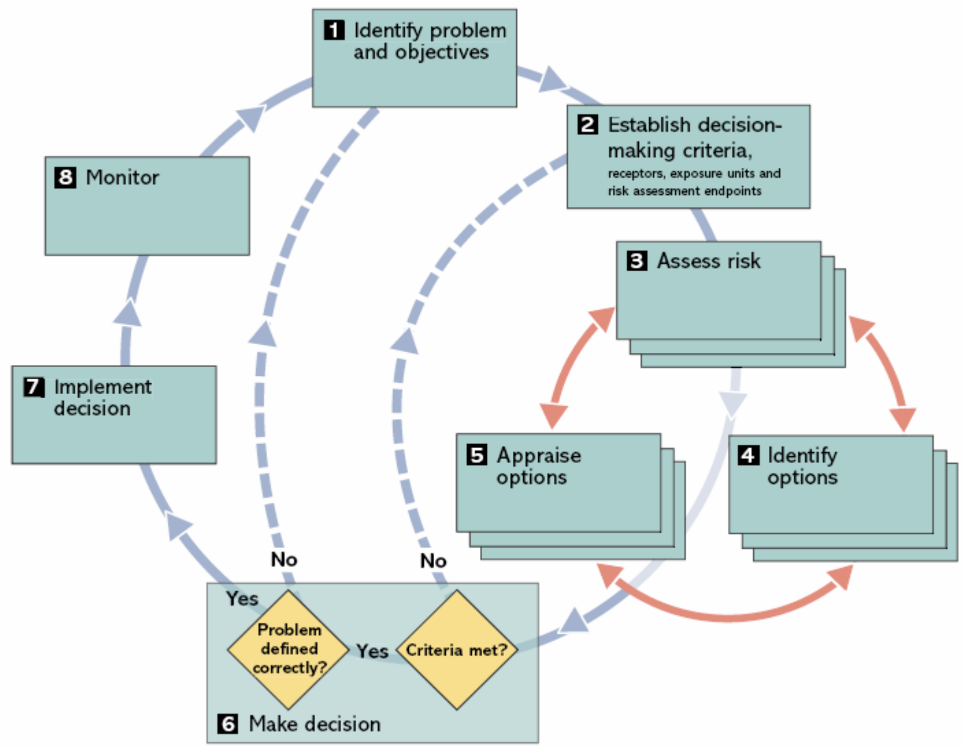
Two over-arching activities are communication and consultation with stakeholders and monitoring and review, which in CCIAV assessments are largely concerned with addressing the needs for uncertainty management and ensuring clarity and transparency surrounding the assumptions and concepts being used.

2.2.2 Methods for characterising the future

2.2.2.1 Why and how do we characterise future conditions?

Evaluations of future climate change impacts, adaptation and vulnerability require assumptions about how future socio-economic and biophysical conditions will develop, whether explicit or implicit. Literature in the CCIAV field and methods of characterising the future have grown in tandem, but these methods have not been defined consistently across different research communities. Box 2.2 presents a consistent typology of characterisations that expands on the definitions presented in the TAR (Carter *et al.* 2001). Although they may overlap, different types of characterisations of the future can be usefully distinguished in terms of their plausibility and ascription of likelihood on the one hand, and the comprehensiveness of their representation on the other (see Box 2.2 for definitions). Since the TAR, comprehensiveness has increased and ascriptions of likelihood have become more common.

(a) UKCIP Framework



(b) UNDP Adaptation Policy Framework

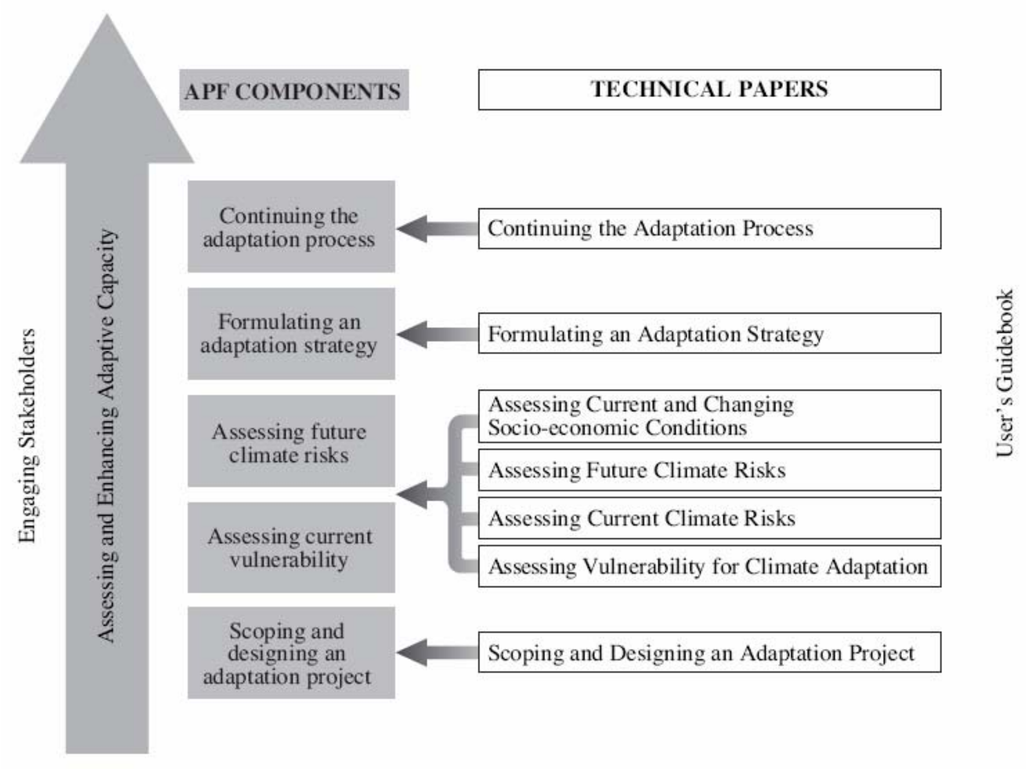


Figure 2.2: *Comparison of (a) UKCIP decision-making framework for climate change risk (Willows and Connell 2003) with (b) the UNDP Adaptation Policy Framework (UNDP 2005). Note: the analysis is iterative in the former and builds upwards in the latter.*

Box 2.2: Definitions of characterisations of the future

Figure B2.2.1 illustrates the categories of characterisations of the future most commonly used in CCIAV studies. They are distinguished according to comprehensiveness and plausibility.

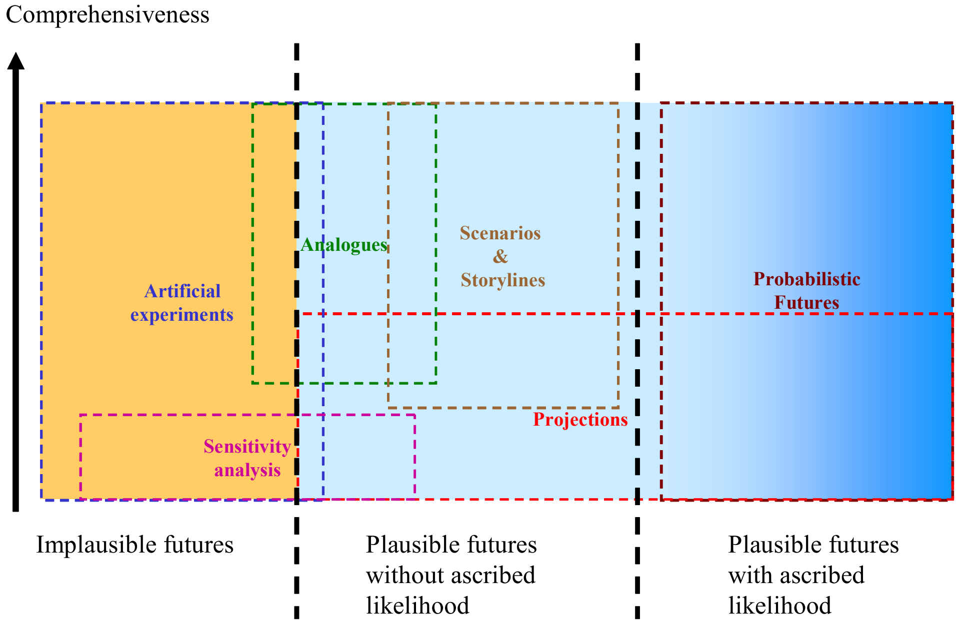


***Figure B2.2.1**: Characterisations of the future*

Comprehensiveness primarily indicates the degree to which a characterisation of the future captures the various aspects of the integrated socio-economic-biophysical system it aims to represent. Secondarily, it indicates the detail with which any single element is characterised.

Plausibility is a subjective measure of whether a characterisation of the future is possible. Implausible futures are assumed to have zero or negligible likelihood. Plausible futures can be further distinguished by whether a specific likelihood is ascribed or not.

Artificial experiment. A characterisation of the future constructed without regard to plausibility (and hence often implausible), but that still follows a coherent logic in order to study a process or communicate an insight. Such artificial experiments range in comprehensiveness from simple thought experiments to detailed integrated modelling studies.

Sensitivity analysis. Sensitivity analyses employ characterisations that involve arbitrary or mechanical adjustments of one or several variables relative to a reference case. These characterisations may be implausible or within plausible limits, but the primary intention is to explore model sensitivity to inputs, possibly to help assess the uncertainty in an outcome.

Analogues. Analogues are based on current or past conditions that exhibit similarities to characterisations of the future obtained for a study region using other methods. These may have plausibility in respect to a limited set of details but may be implausible in other respects.

Scenarios. A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (IPCC 1994; Nakićenović *et al.* 2000; Carter *et al.* 2001; Raskin *et al.* 2005). Scenarios are not predictions or forecasts but are alternative images without ascribed likelihoods, of how the future might unfold. They may be qualitative, quantitative, or both. An over-arching logic often relates several components of a scenario, for example a *storyline* and/or *projections* of particular elements of a system. E*xploratory (or descriptive)* scenarios describe how the future might unfold according to known processes of change, or as extrapolations of past trends (Carter *et al.* 2001). *Normative (or prescriptive)* scenarios describe a pre-specified future, either optimistic, pessimistic or neutral (Alcamo 2001), and a set of actions that might be required to achieve (or avoid) it. Such scenarios are often developed using an *inverse modelling approach,* by defining constraints not to be exceeded and then diagnosing plausible combinations of the underlying conditions that satisfy those constraints (see chapter 3, WG III).

Storylines. Storylines are qualitative, but internally consistent, narratives of how future worlds may evolve and describe the principal trends in socio-political-economic drivers of change and the relationships between these drivers. Storylines may be self standing, but more often they underpin quantitative projections of future change that, together with the storyline, constitute a scenario.

Projection. In general usage a projection is regarded as any description of the future and the pathway leading to it. However, here we define a projection as a model-derived estimate of future conditions related to one element of an integrated system (e.g., an emissions projection, a climate projection, an economic growth projection). Projections are thus, by definition, generally less comprehensive than scenarios, even if the projection of an element is influenced by other elements. In addition, projections may be probabilistic while scenarios do not ascribe likelihoods.

Probabilistic futures. Futures with ascribed likelihoods are probabilistic. The degree to which the future is characterised in probabilistic terms can vary widely. For example, conditional probabilistic futures treat some uncertainties probabilistically, conditional on deterministic assumptions about the future of other uncertain elements of the system. Assigned probabilities may be partial and can also be qualitative rather than quantitative.

The following sections make use of the typology in Box 2.2 to address notable advances in methods of characterising the future.

2.2.2.2 Artificial experiments

The most significant advance in artificial experiments since the TAR is the development of a new set of *commitment runs*. These are climate change projections that assume that the radiative forcing at a particular point in time (often the current forcing) is held constant into the future (see chapter 10, WG I). The projections demonstrate time lags in the climate system: under conditions of changing radiative forcing, some fraction of the climate change that would eventually result has not yet been realized. This lag in climate response is induced by the delayed penetration of heat into the oceans (Hoffert *et al.* 1980; Hansen *et al.* 1985; Wigley and Raper 1993; Church *et al.* 2001) and, for sea level response, the dynamics of ice sheets. Recent experiments estimate the global mean annual warming commitment associated with radiative forcing in 2000 of about 0.5°C by 2100 (WG I, chapter 10). Sea level rise due to thermal expansion of the oceans responds much more slowly, on a timescale of millennia; committed sea level rise to 2300 has been estimated at between 5 and 25 cm per century (WG I, chapter 10), not including contributions from glaciers, ice caps, and ice sheets. However, commitment runs are unrealistic because they exceed the limits of plausible mitigation scenarios (see chapter 3, WG III). They are therefore inappropriate baselines for impact assessment, except to assess impacts seen as inevitable (Parry *et al.* 1998).

2.2.2.3 Sensitivity analysis

Sensitivity analysis is commonly applied in many model-based CCIAV studies to investigate the behaviour of a system assuming arbitrary, often regularly spaced, adjustments in important driving variables. It has become a standard technique in assessing sensitivity to climatic variations, enabling the construction of impact response surfaces over multivariate climate space (e.g. van Minnen *et al.* 2000; Miller *et al.* 2003). Response surfaces are increasingly constructed in combination with probabilistic representations of future climate to assess risk of impact (see section 2.2.3.1). Sensitivity analysis has also been used as a device for studying land use change, by applying arbitrary adjustments to areas, such as + 10% forest, -10% cropland, where these area changes are either spatially explicit (Shackley and Deanwood 2003) or not (Ott and Uhlenbrook 2004; van Beek and van Asch 2004; Vaze *et al.* 2004).

2.2.2.4 Analogues

Temporal and spatial analogues are applied in a range of CCIAV studies. The most common of recently reported analogues are historical extreme weather-related events. These correspond to events that may recur more frequently under anthropogenic climate change requiring some form of adaptation measure. Examples of such analogues judged likely or very likely by the end of the century (Table 11.3, chapter 11, WG I) include: the European 2003 heatwave (see Box 2.2), wildfires associated with continental summer drying in Colorado in 2002 (see chapter 14) and the Iberian peninsula in 2005 (Moreno *et al.* 2005), flooding (related to more intense summer precipitation) in Bangladesh (Mirza 2003a) and Norway (Næss *et al.* 2005). Examples of potential analogues for which supporting evidence is currently uncertain (chapters 10 and 11, WG I) include intense precipitation and flooding events in central Europe (Kundzewicz *et al.* in press) and El Niño-Southern Oscillation (ENSO)-related events (Glantz 2001; Heslop-Thomas *et al.* submitted; Desanker *et al.* submitted; Sanjak *et al.* submitted).

Spatial analogues have also been applied in CCIAV analysis. For example, projected climates by the end of the 21st century in selected European cities have been likened to current climates in analogue cities as a heuristic device for analysing economic impacts and adaptation requirements under a changing climate (Hallegatte *et al.* submitted). A variant of the approach is to seek projected climates that have no present-day climatic analogues (novel climates) or regions where present-day climates are no longer to be found in the future (disappearing climates – Williams *et al.* submitted). Using recent global AOGCM projections (e.g. see chapter 10, WG I), novel climates were found in 18% of land areas for the A2 scenario and 5% for the B1 scenario, with the highest incidence in Africa and South America and the lowest in Eurasia and North America. Disappearing climates were found on tropical mountains and the poleward side of continents. These results were linked to possible risks to ecological systems and biodiversity.

2.2.2.5 Scenarios and storylines

Advances in scenario development since the TAR address issues of consistency and comparability between global drivers of change, and regional scenarios required for CCIAV assessment. Numerous methods of downscaling from global to sub-global scale are emerging (see later sections), some relying on the narrative storylines underpinning the global scenarios.

Storylines for CCIAV studies are increasingly adopting a multi-sectoral and multi-stressor approach (Holman *et al.* 2005b; Holman *et al.* 2005a) over multiple scales (Kok *et al.* 2006a; Alcamo *et al.* 2005; Lebel *et al.* 2005; Westhoek *et al.* 2006b) and including stakeholder elicitation (Kok *et al.* 2006b). As they have become more comprehensive, the increased complexity and richness of the information they contain has assisted in the interpretation of adaptive capacity and vulnerability

(Metzger *et al.* 2006). Storyline development is also subjective, however, so more comprehensive storylines can have alternative interpretations that are equally plausible (Rounsevell *et al.* 2006). The concept of a "region", for example, may be interpreted within a storyline in different ways − as world regions, nation states or sub-national administrative units. This may have profound implications for how storylines are characterised at local scale, limiting their reproducibility and credibility (Abildtrup *et al.* 2006). The alternative is to link a locally sourced storyline, regarded as credible at that scale, to a global scenario.

Storylines can be an endpoint in their own right (e.g. Rotmans *et al.* 2000), but often provide the basis for quantitative scenarios. Models using input parameters interpreted from the qualitative storylines follow the SAS (storyline and simulation) approach (Alcamo 2001). Parameter estimation is often subjective, using expert judgment, although more objective methods, such as pairwise comparison, have been used to improve internal consistency (Abildtrup *et al.* 2006). Analogues and stakeholder elicitation have also been used for parameter estimation (e.g. Berger and Bolte 2004; Kok *et al.* 2006a; Rotmans *et al.* 2000). Participatory approaches are important in reconciling a given long-term scenario framework with the shorter-term and particular policy-driven requirements of stakeholders (Shackley and Deanwood 2003; Velázquez *et al.* 2001; Lebel *et al.* 2005).

Five classes of scenarios relevant to CCIAV analysis were distinguished in the TAR: climate, sea level, socio-economic, land use and land cover, and other (non climatic) environmental scenarios (Carter *et al.* 2001), with climate scenarios covered in more depth by (Mearns *et al.* 2001). The following sections describe recent progress in the methods applied in each of these classes as well as in three new categories on future technology, adaptation scenarios and singular events with widespread consequences.

2.2.2.6 Development and application of high resolution climate scenarios

The development and application of scenarios from high resolution climate models since the TAR confirms that improved resolution allows a more realistic representation of the response of climate to fine scale topographic features (lakes, mountains, coastlines), and that impact models will often produce different results depending on whether scenarios are based on high resolution or direct GCM outputs (e.g. Arnell *et al.* 2003; Mearns *et al.* 2003; Leung *et al.* 2004; Stone *et al.* 2003; Wood *et al.* 2004). However, most experiments still rely on only one driving AOGCM and only one or two regional climate models (RCMs).

The recent development of more elaborate and extensive AOGCM-RCM programmes permits the exploration of multiple uncertainties (across different RCMs, AOGCMs, and emissions scenarios) and the effects of those uncertainties on ensuing impacts. The PRUDENCE project in Europe produced multiple RCM simulations based on two different AOGCM or AGCM simulations and two different emissions scenarios (Christensen *et al.* submitted). In the impact studies that used these simulations (e.g. Ekstrom *et al.* in press; Graham *et al.* submitted; Fronzek and Carter submitted; Hingray *et al.* in press; Olesen *et al.* submitted) uncertainties due to the spatial scale of the scenarios and resulting from different RCMS versus different GCMs were elaborated on. For example, Oleson *et al.* (submitted), using scenarios from a range of RCMs and GCMs, and two emissions scenarios, found that the variation in simulated impacts (agricultural) was smaller across RCMs nested in a single GCM than those across different GCMs or across the different emissions scenarios. Similar results were found in other PRUDENCE impact studies. However, these conclusions were drawn from an unbalanced set of experiments, i.e., most RCM groups used only one GCM (HadAM3H), for which the contrast in the scale of the GCM to the RCMs (150 km down to 50 km) was relatively small. Fewer RCM groups used the other AOGCM or both emissions scenarios. Nevertheless, these types of analyses can indicate more efficient use of resources for scenario development based on where the largest uncertainties are found. For example, using the experience of PRUDENCE, a North American climate scenarios program (NARCCAP) is producing a more balanced set of experiments across four GCMs and six RCMs (Mearns *et al.* 2005).

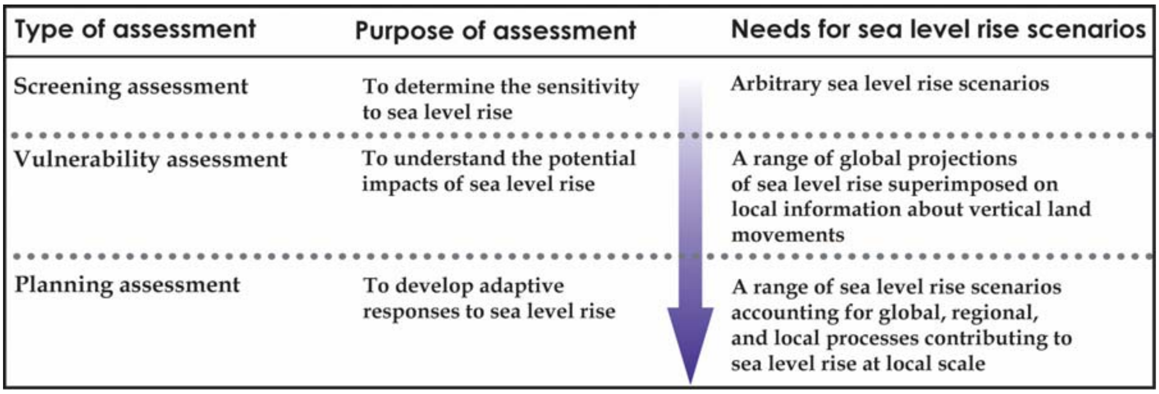
The construction of higher resolution scenarios (now often finer than 50 km), has encouraged new types of impact studies to be undertaken. For example, studies examining the combined impacts of increased heat stress and air pollution are now more feasible because the resolution of regional climate models is converging with that of air quality models (e.g. Hogrefe *et al.* 2004). Finally, scenarios developed from RCMs (e.g. UKMO 2001) are now being used in many more regions of the world, particularly the developing world (e.g. Gao *et al.* 2003; Anyah and Semazzi 2004; Arnell *et al.* 2003; Rupa Kumar *et al.* 2006; Government of India 2004). Results of these regional modelling experiments are found in WG I, chapter 11.

Much additional work has been produced using methods of statistical downscaling (SD) for climate scenario generation (Wilby *et al.* 2004 and see WG I, chapter 11). Various SD techniques have been used in downscaling directly to (physically based) impacts and to a greater variety of climate variables, including extremes of variables. For example, Wang (2004) and Caires (2005) have developed non-stationary extreme value models for projecting changes in wave height.

While statistical downscaling has mostly been used to develop climate change scenarios at single locations, Hewitson (2003) developed empirical downscaling for point scale precipitation at numerous sites across the continent of Africa and on a 0.1 degree resolution grid over Africa. Finally, the wider availability of statistical downscaling tools is being reflected in wider application; for example the Statistical Downscaling Model (SDSM) tool of Wilby (2002), which has been used to produce scenarios for islands in the Caribbean (Chen *et al.* 2004) and for the River Thames basin (Wilby and Harris 2006).

2.2.2.7 Sea level scenarios

One of the major impacts projected under global warming is sea-level rise. Klein (1999) suggested three levels of analysis for sea-level rise impacts, which demand increasingly sophisticated scenarios (Figure 2.3).



Type of assessment	Purpose of assessment	Needs for sea level rise scenarios
Screening assessment	To determine the sensitivity to sea level rise	Arbitrary sea level rise scenarios
Vulnerability assessment	To understand the potential impacts of sea level rise	A range of global projections of sea level rise superimposed on local information about vertical land movements
Planning assessment	To develop adaptive responses to sea level rise	A range of sea level rise scenarios accounting for global, regional, and local processes contributing to sea level rise at local scale

Figure 2.3*: Types of assessment and their requirements for sea-level rise scenarios (after Klein and Nicholls 1999)*

Basic techniques for developing sea level scenarios were described in the TAR (Carter *et al.* 2001).

Since the TAR, there have been refinements to methods that account more effectively for regional and local factors affecting sea level and in so doing, presenting scenarios that are more relevant for planning purposes. Two main types of scenarios are distinguished here: regional sea level scenarios and scenarios of storm surges. A third type, characterising abrupt sea level rise, is described in section 2.2.2.12. Analogue approaches have also been reported (e.g. Arenstam Gibbons and Nicholls 2006). More details on sea level and sea level scenarios can be found in chapters 5 and 10 of the WG I report and chapter 6 of this report.

Regional sea level scenarios. Sea level does not change uniformly across the world due to climate change: different rates of oceanic thermal expansion and region-specific changes in oceanic and atmospheric circulation affect the level of the sea surface differently, giving rise in AOGCM simulations to regional departures of up to 50% from global-mean sea-level rise (Church *et al.* 2001). Moreover, account also needs to be taken of the long-term, non-climate related trend, usually associated with vertical land movements that affect relative sea level.

To account for regional variations, Hulme (2002) recommends applying the range of global-mean scenarios ±50% change. Alternative approaches utilise scenario generators. The Dynamic Interactive Vulnerability Assessment (DIVA) model computes relative sea-level rise scenarios using either global-mean or regional patterns of sea-level rise scenarios from a climate model of intermediate complexity, CLIMBER–2 (Petoukhov *et al.* 2000; Ganopolski *et al.* 2001). CLIMsystems (2005) have developed a software tool that rapidly generates place-based future scenarios of sea-level change during the 21st century, accounting for contributing factors at global, regional, and local scales. Spatial patterns of sea-level rise from thermal expansion and ocean processes taken from AOGCM simulations with global-mean sea-level rise projections from simple climate models through the pattern-scaling technique (Santer *et al.* 1990). Users are required to input a value for the local sea-level trends to account for local land movements.

Storm surge scenarios. Several studies stress the importance of characterising high impact, extreme sea level events. In many locations, the risk of extreme sea levels is poorly constrained even under present-day climatic conditions, due to sparse tide gauge networks and relatively short records of high measurement frequency. Where such records do exist, detectable trends are highly dependent on local conditions (Woodworth and Blackman 2004). Chapter 6 of this report summarises several recent studies, one method using a combination of stochastic sampling and dynamical modelling (Box 6.2).. Scenarios may also be developed by downscaled regional climate predictions from global climate models which are used to drive barotropic storm surge models (Lowe and Gregory 2005). These analyses suggest that extreme water level scenarios may differ from relative sea-level rise scenarios.

2.2.2.8 Socio-economic scenarios

Socio-economic changes are key drivers of projected changes in future emissions and climate so are key determinants of most climate change impacts, potential adaptations and vulnerability (Malone and La Rovere 2005). CCIAV studies increasingly include scenarios of changing socio-economic conditions, which can substantially alter assessments of the effects of future climate change (Parry 2004; Schröter *et al.* 2005; Alcamo *et al.* submitted). Typically these assessments require information at the sub-national level, whereas many scenarios are developed at a broader scale, thereby necessitating downscaling of aggregate socio-economic scenario information.

Guidelines are presented for the analysis of current and projected socio-economic conditions as part of the UNDP APF (Malone and La Rovere 2005). They advocate the use of indicators to characterise socio-economic conditions and prospects, concepts which can often be too abstract to be easily measured. Five categories of indicators are suggested: demographic analysis economic analysis, natural resource use, analysis of governance and policy, and cultural analysis. Most recent studies have focused on the first two of these.

The sensitivity of climate change effects to socio-economic conditions was highlighted by a series of multi-sector impact assessments (Parry *et al.* 1999; Parry *et al.* 2001; Parry 2004 – Table 2.4). The first two relied on only a single representation of future socio-economic conditions (IS92a), comparing effects of mitigated versus unmitigated climate change (Arnell *et al.* 2002; Nicholls and Lowe 2004). The third set considered four alternative SRES-based development pathways (see section 2.3.1.1, below), finding that these assumptions are often a stronger determinant of impacts than climate change itself (Arnell *et al.* 2004; Levy *et al.* 2004; Arnell 2004; Parry *et al.* 2004; Nicholls 2004; van Lieshout *et al.* 2004). For example, the number of people estimated to be living in water stressed areas (Arnell 2004) or at risk of hunger (Parry *et al.* 2004; Goklany 2005) depends much more on the assumed development pathway than it does on the effect of climate change. Furthermore, climate impacts can themselves depend on the development pathway (see chapters 17 and 20), emphasising the limited value of impact assessments of human systems that do not account for possible socio-economic changes.

Table 2.4: *Key features of scenarios underlying three global-scale multi-scale assessments (Parry et al. 1999; Arnell et al. 2002; Parry 2004).*

	Impacts of unmitigated emissions	**Impacts of stabilisation of CO_2 concentrations**	**Impacts of SRES emissions scenarios**
Emissions scenarios	IS92a (1% per increase in CO_2-equivalent concentrations per year from 1990)	S750 and S550	Four SRES emissions scenarios: A1FI, A2, B1 and B2
Climate scenarios	Derived from four ensemble HadCM2 simulations and one HadCM3 simulation forced with IS92a emissions scenarios	Derived from HadCM2 experiments assuming stabilisation of CO_2 at 550 and 750 ppm; comparison with IS92a.	Derived from HadCM3 ensemble experiments (number in brackets): A1FI (1), A2 (3), B1 (1) and B2 (2)
Socio-economic scenarios	IS92a consistent GDP and population projections	IS92a consistent GDP and population projections	SRES-based socio-economic projections

The advantages of being able to directly link regional socio-economic futures to scenarios and storylines are being recognised. For example, the SRES scenarios have been used as a basis for developing storylines and quantitative scenarios at national(Carter *et al.* 2004; Carter *et al.* 2005; van Vuuren *et al.* submitted) and sub-national (Berkhout *et al.* 2002; Shackley and Deanwood 2003; Solecki and Oliveri 2004; Heslop-Thomas and Bailey 2004) scales. The content of downscaled storylines depends on information needs for a particular application. For example, four sub-national storylines for northern Nigeria that included qualitative demographic and economic trends, the nature of governance, policy, and social and cultural values were developed (Nyong *et al.* 2004). In contrast, most regional studies in the AIACC (Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors) research programme[2] adopted a participatory, sometimes *ad hoc*, approach to socio-economic scenario development utilising current trends in key socio-economic indicators and stakeholder consultation (e.g. Heslop-Thomas and Bailey 2004; Pulhin *et al.* 2004).

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[2] http://www.aiaccproject.org

Methods for downscaling quantitative socio-economic information have focused on population and gross domestic product (GDP). Initial but crude methods to downscale population growth have been replaced by methods of regional differentiation (van Vuuren and O'Neill submitted; Grübler *et al.* submitted). Methods of downscaling to the sub-national level have included: unrealistic assumptions that population changes everywhere within a country at the same rate (Gaffin *et al.* 2004; van Vuuren and O'Neill submitted), simple rules for preferential growth in coastal areas (Nicholls 2004), extrapolations of recent trends at the grid cell level (Gaffin *et al.* submitted), and scenario-dependent algorithms leading to preferential growth in urban areas (Grübler *et al.* submitted).

Downscaling approaches for GDP are also evolving. The first downscaled SRES GDP assumptions applied regional growth rates uniformly to all countries within the region (Gaffin *et al.* 2004) without accounting for country-specific differences in initial conditions and growth expectations. New methods specify scenario-dependent convergence assumptions across countries, an approach that avoids implausibly high growth for rich countries in developing regions (van Vuuren and O'Neill submitted; Grübler *et al.* submitted). GDP scenarios have also been downscaled to the grid level, either by assuming constant shares of GDP in each grid cell (Gaffin *et al.* 2004; van Vuuren and O'Neill submitted) or through scenario dependent sub-national algorithms (Grübler *et al.* submitted).

2.2.2.9 Land use scenarios

Many CCIAV studies need to account for future changes in land use and land cover. This is especially important for regional studies of agriculture and water resources (Barlage *et al.* 2002; Klöcking *et al.* 2003), forestry (Bhadwal and Singh 2002) and ecosystems (Bennett *et al.* 2003; Cumming *et al.* 2005; Dirnbock *et al.* 2003; Zebisch *et al.* 2004), but also has a large influence on regional patterns of demography and economic activity (Geurs and van Eck 2003) and associated problems of environmental degradation (Yang *et al.* 2003) and pollution (Bathurst *et al.* 2005). Land use and land cover change scenarios have also been used to analyse forcing to the climate system (DeFries *et al.* 2002; Leemans *et al.* 2002; Maynard and Royer 2004) and the emissions of GHGs (El-Fadel *et al.* 2002; Fearnside 2000; Sands and Leimbach 2003).

The TAR concluded that Integrated Assessment Models (IAMS) were the most appropriate method for the development of land use change scenarios, and this remains the case for global scale studies. Since the TAR, however, a number of new models have emerged that provide new insights into regional land use change. Comparative studies across similar scenarios (e.g. Busch 2006) have shown that IAMs can generate land use changes that are very different to those from regional land use models, often with opposing directions of change. This is analogous to the observation for global and regional climate models discussed in section 2.2.2.6. The need, however, to define exogenous input variables to regional scale land use scenario analyses remains a challenge (e.g. Alcamo *et al.* 2006; Sands and Edmonds 2005) and IAMS have an important role to play in characterising the global boundary conditions for regional land use change assessments (van Meijl *et al.* 2006).

Regional scale land use models often adopt a two-phase (nested scale) approach with an assessment of aggregate quantities of land use for the entire region followed by ‘downscaling’ procedures to create regional land-use patterns. Aggregate quantities are often based on IAMS or economic models such as General Equilibrium models (van Meijl *et al.* 2006) or input/output approaches (Fischer and Sun 2001). Methods of downscaling vary considerably and include proportional approaches to estimate regional from global scenarios (Arnell *et al.* 2004), regional scale economic models (Fischer and Sun 2001), spatial allocation procedures based on rules (Rounsevell *et al.* 2006), micro-simulation with cellular automata (de Nijs *et al.* 2004; Solecki and Oliveri 2004), linear programming models (Holman *et al.* 2005b; Holman *et al.* 2005a) or empirical-statistical techniques (Verburg *et al.* in press; de Koning *et al.* 1999; Verburg *et al.* 2002). An emerging method is the use of Agent-Based Models (ABM) to address climate change impacts on land use, as well as decision processes of adaptation and vulnerability assessment (Alcamo *et al.* 2006; Acosta-Michlik and Rounsevell 2005).

Most land use scenario assessments are based on mean trends in socio-economic and climate change baselines, although responses to extreme weather events such as hurricane Mitch in Central America have also been assessed (Kok and Winograd 2002). Probabilistic approaches in the development of land use futures are rare with the exception being the effects of uncertainty in alternative representations of land use change for hydrological variables (Eckhardt *et al.* 2003). Not all land use scenario exercises have addressed the effects of climate change even though they consider time frames over which a changing climate would be important. This may reflect a perceived lack of sensitivity to climate variables (e.g. studies on urban land use Allen and Lu 2003; Barredo *et al.* 2003; Barredo *et al.* 2004; Loukopoulos and Scholz 2004), or is an omission within the analysis (Ahn *et al.* 2002; Berger and Bolte 2004).

2.2.2.10 Scenarios of future technology

The importance of technology has been highlighted specifically for land use change (Ewert *et al.* 2005; Rounsevell *et al.* 2005; Rounsevell *et al.* 2006; Abildtrup *et al.* 2006) and for ecosystem service changes, such as agricultural production, water management or climate regulation (Nelson *et al.* 2005). Technological change is also a principal driver of change for GHG emissions. Since the TAR, scenarios addressing different technology pathways for climate change mitigation and adaptation have increased in number (see chapter 3, WG III). Technological change can be treated as an exogenous factor to the economic system or be endogenously driven through economic and political incentives. More work is needed, but recent modelling exercises are representing theories on technical and institutional innovation, such as the "Induced Innovation Theory", in scenario development (Grübler *et al.* 1999; Grubb *et al.* 2002).

For integrated global scenario exercises, the rate and magnitude of technological development is often based on expert judgements and mental models. Storyline assumptions are then used to modify the input parameters of environmental models (e.g. for ecosystems, land use or climate) prior to conducting model simulations (e.g. Millennium Ecosystem Assessment 2005; Ewert *et al.* 2005). Such an approach is useful in demonstrating the relative sensitivity of different systems to technological change, but the role of technology remains a key uncertainty in characterisations of the future. In particular, questions such as the uptake and diffusion of new technologies deserve greater attention. Only a few studies have tackled technology, suggesting an imbalance in the treatment of environmental change drivers within many CCIAV scenario studies which future work should seek to redress.

2.2.2.11 Adaptation scenarios

Limited attention has been paid to characterising alternative pathways of future adaptation. Narrative information within scenarios can assist in characterising potential adaptive responses to climate change. For instance, the ATEAM project (Schröter *et al.* 2005) identified determinants and their indicators of adaptive capacity in Europe through questionnaire survey. Empirical relationships between these indicators and population and GDP over 1960–2000 were then established. Scenarios of adaptive capacity were then inferred by applying these empirical relationships to downscaled, SRES-based GDP and population projections (see section 2.3.1, below). Nicholls(2004) also interpreted the SRES storylines to estimate the exposure of human populations to coastal flooding, using GDP per capita scenarios to estimate the future standards of coastal defences. Hijioka (2002) used the narrative description of SRES worlds in conjunction with quantitative scenarios of GDP per capita to assume future changes in access to safe water in a study to estimate diarrheal incidence under climate change.

Parry (2004) estimated future risk of hunger using a food model that makes assumptions about yield changes, food demands and trade liberalisation. Two types of adaptation strategy were incorporated: farm-level adaptation strategies, such as changes in planting date, and application of additional fertilization and irrigation, and regional-scale adaptation, where production functions in developed countries simulated yield increases due to innovations such as new cultivars and irrigation infrastructure. Other economic adjustments to the modelled yield changes were tested by a world food trade model, including increased agricultural investment, re-allocation of agricultural resources according to economic returns, and reclamation of additional arable land as a response to higher cereal prices. Future studies, following consultation with key stakeholders, are more likely to include adaptation explicitly as part of socio-economic scenario development, hence offering the possibility to gauge the effectiveness of adaptation options in comparison with baseline scenarios (Holman *et al.* 2005b).

2.2.2.12 Singular events with widespread consequences

Singular events with widespread consequences are extreme, often irreversible changes in the earth system such as an abrupt cessation of the Atlantic meridional overturning circulation (MOC) or the melting of ice sheets in Greenland or West Antarctica (see chapters 8 and 10, WG I). Artificial experiments have been applied to test the impacts of the Atlantic MOC. "Hosing" experiments assuming the injection of large amounts of freshwater at high latitudes, have been conducted using AOGCMS (e.g. Vellinga and Wood 2002; Wood *et al.* 2003), inducing a MOC shutdown. Substantial reduction of greenhouse warming occurred in the Northern Hemisphere, with a net cooling occurring mostly in the North Atlantic region (Wood *et al.* 2003). Such scenarios have subsequently been applied in impact studies (Higgins and Vellinga 2004; Higgins and Schneider 2005 and see chapter 19).

Complete deglaciation of Greenland and the West Antarctica Ice Sheet (WAIS) would raise sea level by 7 m and about 5 m, respectively. One recent study assumed an extreme rate of sea level rise, 5m by 2100 (Nicholls *et al.* submitted), to test the limits of adaptation (Toth and Hizsnyik submitted; Dawson submitted; Poumadère *et al.* submitted; Olsthoorn *et al.* submitted; Tol *et al.* submitted) and decision making (Guillerminet and Tol submitted; Lonsdale *et al.* submitted; Kasperson and Bohn submitted). A second study employed a scenario of rapid sea-level rise of 2.2m by 2100 by adding an ice-sheet contribution to the highest IPCC projection for the period (Cubasch *et al.* 2001), with the increase continuing unabated after 2100 (Arnell *et al.* 2005). Both studies describe the potential impacts of such a scenario in Europe, based on expert assessments.

2.2.2.13 Integrating scenarios

The widespread adoption of SRES-based scenarios in studies described in this report (see section 2.3.1, below) acknowledges the desirability of seeking consistent scenario application across different studies and regions. For instance, SRES-based downscaled socio-economic projections were used in conjunction with SRES-derived climate scenarios in a set of global impact studies (Arnell *et al.* 2004 see section 2.2.2.8). At a regional scale, the European ATEAM project developed multiple scenarios for the main global change drivers (socio-economic factors, atmospheric CO_2 concentration, climate factors, land use and technology), based on interpretations of the global IPCC SRES storylines (Schröter *et al.* 2005 − see section 2.3.1.6, below).

Nationally, scenarios of socio-economic development (Kaivo-oja *et al.* 2004), climate (Jylhä *et al.*

2004), sea level (Johansson *et al.* 2004), surface ozone exposure (Laurila *et al.* 2004), and sulphur and nitrogen deposition (Syri *et al.* 2004) were developed for Finland in the FINSKEN project. Though the SRES driving factors were used as an integrating framework, downscaling from global scenarios alone was not sufficient to ensure mutual consistency between scenario types, as this ignored important regional dependencies (e.g. between climate change and air pollution and between air pressure and sea level Carter *et al.* 2004). Similar exercises have also been conducted at sub-national scale in the east (Lorenzoni *et al.* 2000) and north-west (Holman *et al.* 2005b) of England.

Integration across scales was emphasised in the scenarios developed for the Millennium Ecosystem Assessment (MA). A SAS approach (see section 2.2.5) was followed in developing scenarios at scales ranging from regional through national, basin and local (Lebel *et al.* 2005). Many differ greatly from the set of global MA scenarios that were also constructed (Alcamo *et al.* 2005). This is due, in part, to different stakeholders being involved in the development of scenarios at each scale, but also reflects an absence of feedbacks from the sub-global to global scales (Lebel *et al.* 2005).

2.2.2.14 Probabilistic futures

Since the TAR, many studies have produced probabilistic representations of future climate change and socio-economic conditions suitable for use in impact assessment. Some key choices faced in these studies include which components of climate change and socio-economic inputs to quantify and how to define the input probability density functions (pdfs) for each component. Integrated approaches derive pdfs of climate change from input pdfs for emissions and for key parameters in models of greenhouse gas cycles, radiative forcing, and the climate system. The models then sample repeatedly from the uncertainty distributions for inputs and model parameters, in order to produce a pdf of outcomes, e.g. global temperature and precipitation change. Either simple climate models (e.g. Wigley and Raper 2001) or climate models of intermediate complexity (Forest *et al.* 2002) have been applied.

The most important uncertainties to be represented in pdfs of regional climate change, the scale of greatest relevance for impact assessments, are greenhouse gas emissions, climate sensitivity and inter-model differences in climatic variables at the regional scale. Of those, pdfs for emissions have not been explicitly calculated due to the controversial nature of quantifying socio-economic futures (Grübler and Nakicenovic 2001; Lempert and Schlesinger 2001), although integrated methods contain implicit distributions (e.g. Wigley and Raper 2001; Dessai and Hulme 2001; New and Hulme 2000). All of these studies refer back to the SRES emissions scenarios, for which likelihoods were not explicitly assigned. However, probabilistic projections have also been produced independent of SRES based on expert judgment, leading to both wider (Webster *et al.* 2002) and narrower (Richels *et al.* 2004)ranges of future emissions as compared to SRES. A rapidly growing literature reporting pdfs of climate sensitivity is challenging the long-held IPCC estimate of 1.5–4.5°C for the range of global mean annual temperature change for a doubling of atmospheric CO_2 (see WG I, chapter 10 for a detailed description).

For regional change, early work on generating regional probabilities was covered in the TAR (e.g. Jones 2000; New and Hulme 2000). A number of methods applying different weighting schemes to multi-model ensemble projections of climate have since been developed based on model performance and degree of convergence (Giorgi and Mearns 2002; Giorgi and Mearns 2003), Bayesian methods (Tebaldi *et al.* 2004 Tebaldi, 2005, Regional probabilities of precipitation; Greene *et al.* in press), and weighting models equally (Räisänen 2005) − see chapter 11, WG I for more details. Dessai (2005) sampled a wider range of uncertainty by scaling the normalized regional patterns of change from a large suite of GCMs by global mean temperature changes simulated using a simple climate model. They tested the sensitivity of probabilistic regional climate changes to a range of uncertainty sources including climate sensitivity, GCM simulations, and emissions scenarios. Other groups are developing additional methods of establishing probabilities of regional climate change. For example, the ENSEMBLES research project[3] is producing regional probabilities of climate change for Europe.

Methods to translate probabilistic climate changes for use in impacts assessment (e.g. New and Hulme 2000; Yates *et al.* submitted; Wilby and Harris 2006)include those assessing probabilities of impact threshold exceedences (e.g. Jones 2000; Jones 2004; Jones *et al.* in press). Wilby and Harris (2006), combined information from various sources of uncertainty (emissions scenarios, GCMs, statistical downscaling and hydrological model parameters) to estimate probabilities of low flows in the River Thames basin, finding that the most important uncertainty was the difference among the GCMs, a conclusion supported in water resources assessments in Australia (Jones and Page 2001; Jones *et al.* 2005). Probabilistic impact studies sampling across emissions, climate sensitivity and regional climate change uncertainties have been conducted for wheat yield (Howden and Jones 2005; Luo *et al.* 2005), coral bleaching (Jones 2004; Wooldridge *et al.* 2005), water resources (Jones and Page 2001; Jones *et al.* 2005) and freshwater ecology (Preston in press).

Probabilistic scenario approaches to emissions futures have also been explored. SRES storylines have been used to assign probability distributions to drivers such as population (O'Neill 2004). The resulting conditional probability distributions for emissions demonstrate a much wider range of emissions uncertainty for some SRES storylines than represented in SRES. Fully probabilistic projections have also been used to identify scenarios of emissions and drivers (Webster and Reilly submitted) or for population and its determinants for use in integrated scenario assessments (O'Neill 2005).

The use of subjective probability assignments for future emissions has been debated. Some argue that decision makers will estimate the relative likelihood of different possible outcomes themselves, so it is better to explore underlying assumptions through decision analytic techniques and communicate the results (Schneider 2001, 2002; Webster *et al.* 2002; Webster *et al.* 2003). Others argue that the climate change issue is characterised by "deep uncertainty" – i.e. system models, parameter values, and interactions are unknown or contested – and therefore elicited probabilities may not represent well the nature of the uncertainties faced (Lempert *et al.* 2004; Grübler and Nakicenovic 2001). Adaptation strategies may benefit more from understanding and enhancing adaptive capacity than from improving probabilistic projections of climate change, and probabilities may not be essential for making mitigation decisions (Dessai and Hulme 2004). Non-probabilistic approaches to addressing uncertainty propose the use of model-based test beds to search for robust strategies that are relatively insensitive to a wide range of possible outcomes (Casman *et al.* 1999; Lempert and Schlesinger 2001; Lempert *et al.* 2004). However, many impacts such as those for water resources and coral bleaching, which may require substantial adaptation within planning horizons of several decades, are relatively insensitive to underlying uncertainties in emissions (e.g. Jones 2001). In this regard, probabilistic impact assessments carried out on water resources in Australia have already led to adaptation actions being taken (see chapter 11).

2.2.3 Methods for measuring and interpreting CCIAV

2.2.3.1 Thresholds and criteria for risk

The development of criteria, especially those setting the limits of tolerable risk, set the terms of

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[3] http://www.ensembles-eu.org/

reference by which the significance of a risk is assessed. This allows a risk to be analysed and management options to be evaluated, prioritised and implemented. In CCIAV, this requires linking climate impacts to potential outcomes. The most significant criterion is that of dangerous anthropogenic interference with the climate system (see section 2.2.1.2) but most criteria are context specific, relating to a given activity at a particular location, so can be representative on all scales from local to global.

In climate change assessments, the setting of criteria involves the use of thresholds; in particular critical thresholds that denote the lower limit of tolerable risk. A threshold is a non-linear response of a variable, activity or system to an internal or external stress. Thresholds are used in assessing change in two ways:

1. A non-linear change in state, where a system shifts from one identifiable set of conditions to another.
2. A criterion on a linear measurement scale denoting a change in condition that invites some form of response; e.g. a management threshold.

Thresholds used to assess risk are a value-laden, or normative, concept, where crossing a boundary meets a given criterion. A threshold may represent a state change that can be objectively measured, to which a value judgement is attached, for example many of the key vulnerabilities listed in chapter 19. A threshold can also be attached to a given value on a linear, gradational scale, where the response is the non-linear aspect; for example, a management threshold (Kenny *et al.* 2000). Exceeding a management threshold will result in a change of legal, regulatory, economic or cultural behaviour. This gives rise to the concept of the critical threshold (IPCC 1994; Parry *et al.* 1996; Pittock and Jones 2000), where criticality exceeds, in risk assessment terms, the level of tolerable risk. Critical thresholds are used to define the coping range (section 2.2.3.4).

Thresholds derived with stakeholders avoid the pitfall of researchers ascribing their own values to an assessment (Pittock and Jones 2000; Kenny *et al.* 2000; Conde and Lonsdale 2005). Stakeholders thus become responsible for the management of the uncertainties associated with that threshold through ownership of the assessment process and its outcomes (Jones 2001).

The probability of threshold exceedence is being used in risk analyses (Jones 2001, 2004) on local and global scales. For example, probabilities of critical thresholds for coral bleaching and mortality for sites in the Great Barrier Reef as a function of global warming show that catastrophic bleaching will occur biennially with a warming of ~2°C (Jones 2004). Mastrandrea and Schneider (2004) assess the likelihood of exceeding a thresholds of DAI derived from the TAR (Smith *et al.* 2001) under probabilistic representations of climate projections also derived from the TAR, estimating the reductions in emissions that would be required to reduce the probability of exceeding DAI to acceptable levels using a simple integrated model of the climate and economy.

2.2.3.2 Advances in impact assessment

Major advances in impact assessment since the TAR are: meta-analyses summarising a range of assessments; integrated impact analysis across one or more sectors at the national or global scale; the vertical integration of impacts to address social and economic outcomes; and probabilistic impact analyses (see section 2.2.2.14). More specific descriptions of recent developments in impact modelling can be found in the sectoral chapters of this report (3-8). However, there are many regions and sectors, especially in developing countries, where detailed impact assessments of climate-sensitive resources have not yet been carried out.

A global scale analysis of a range of studies for different sectors, involving a range of impacts models and levels of climate was conducted by Hitz and Smith (Hitz and Smith 2004). For some sectors and regions, such as agriculture and the coastal zone, sufficient studies were available to construct a summary of sectoral impacts as a function of increase in global mean temperature. For other sectors, such as marine biodiversity and energy, only broad conclusions of low confidence were possible because of limited information.

Aggregated climate change damages have been estimated by Mendelsohn and Williams (2004) and Nordhaus (in press), using statistical relationships between climate variables (mean temperature and annual precipitation) and economic variables (e.g., farm values, energy expenditures and others for the former; local GDP for the latter). Mendelsohn and Williams, working at the national scale, found the impact of climate change to be quasi-neutral, with total impacts lower than 0.1% of GWP, but with significant consequences for developing countries. Nordhaus, working in more detail on a 1°x1° latitude x longitude grid, suggests higher damages than past studies, with impacts between 1 and 3% of gross world product (GWP) for a doubling of CO_2 concentration.

A range of recent economic studies utilise processes models that assess the cost of uncertainty and consider adaptation. Fischer *et al.* (2002) extensively analysed climate change consequences for global agriculture, finding no global disruption of food production, but identified growing regional imbalances with possible consequences for food security and large economic consequences for developing country economies. This result is consistent with findings by Mendelsohn and Williams (2004), who assume perfect adaptation. Neumann *et al.* (2000) and Nicholls and Tol (in press) investigate the consequences of sea-level rise, finding lower estimates than past studies. Hallegatte *et al.* (in press) suggest that altered extreme event distributions producing short-term reconstruction constraints may increase significantly the long-term costs of natural disasters. Hamilton *et al.* (2005) found the influence of climate change on tourism to be significant but lower than the impact of drivers like population and economic growth. Hallegatte *et al.* (submitted) concluded that low-cost adaptation in European cities to higher temperatures is impeded by climate uncertainty, possibly leading to adaptation costs that ultimately reach several percent of GDP. The role of economic dynamics has also been emphasized (Fankhauser and Tol 2005; Hallegatte 2005; Hallegatte *et al.* in press). Some new studies suggest damage overestimations by previous assessments, while others suggest underestimations, leading to the conclusion that uncertainty is likely to be larger than suggested by the range of previous estimates.

2.2.3.3 Stakeholder involvement

Stakeholder involvement is crucial to risk, adaptation and vulnerability assessments because it is they who will be most affected and thus may need to adapt (Burton *et al.* 2002; UNDP 2005). Stakeholders are characterised as individuals or groups who have anything of value (both monetary and non-monetary) that may be affected by climate change or by the actions taken to manage the ensuing risks of climate. They might be policymakers, scientists, communities, and/or managers in the sectors and regions most at risk now and in the future (Conde and Lonsdale 2005). Stakeholder engagement in climate change initiatives has been reinforced since the TAR.

People's and institutional knowledge and expertise comprise the principal resource for adapting to the impacts of climate change. Adaptive capacity is developed if people have time to strengthen networks, knowledge, resources and the willingness to find solutions (Cebon *et al.* 1999; Cohen 1997; Ivey *et al.* 2004). Through an ongoing process of negotiation and modification, stakeholders can assess the viability of adaptive measures, by integrating scientific information into their own social, economic, cultural and environmental context (van Asselt and Rotmans 2002). However, stakeholder involvement may occur in a context where political differences, inequalities, or conflicts may be raised; researchers must accept that it is not their role to solve those conflicts, unless they want to be part of them (Conde and Lonsdale 2005). Approaches to stakeholder engagement vary from passive interactions, where the stakeholders only provide information, to a level where the stakeholders themselves initiate and design the process (Figure 2.4).

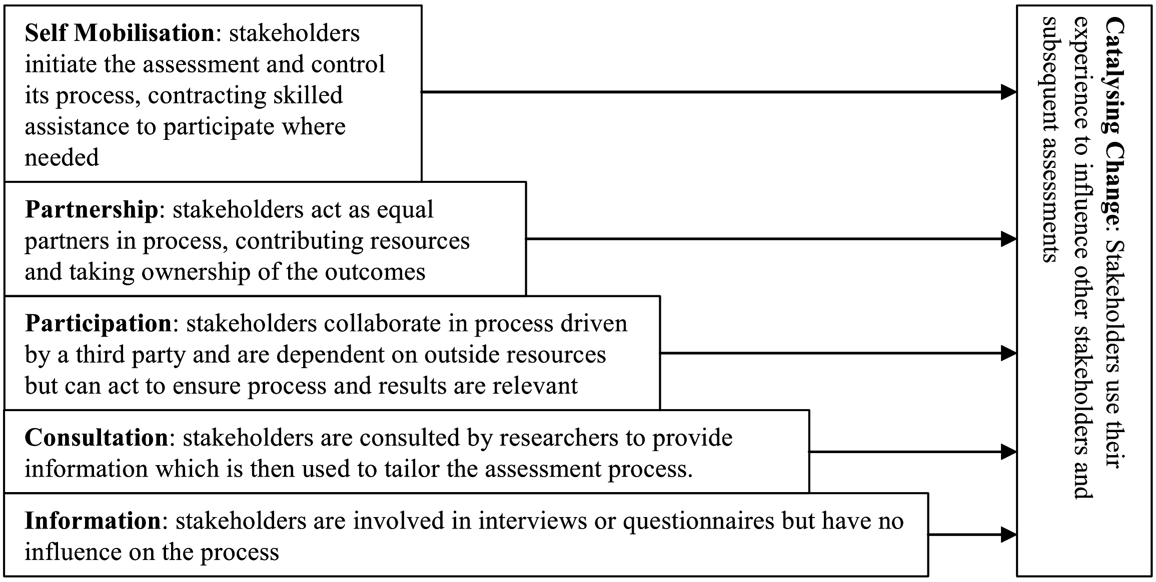

Figure 2.4: *Ladder of stakeholder participation (based on Pretty 1994; Conde and Lonsdale 2005)*

Current adaptation practices for climate risks are being developed by communities, governments, NGOs and other organised stakeholders to increase their adaptive capacity (Thomalla *et al.* 2005; Ford and Smit 2004; Conde *et al.* in press). Indigenous knowledge studies are a valuable source of information for CCIAV assessments, especially where formally collected and recorded data is sparse (Huntington and Fox 2005). Stakeholders have a part to play in scenario development (Bärlund and Carter 2002; Lorenzoni *et al.* 2000) and participatory modelling (e.g. Welp 2001; van Asselt and Rijkens-Klomp 2002).

Stakeholders are also central in assessing future needs for developing policies and measures to adapt (Nadarajah and Rankin 2005). These needs have been recognised in regional and national approaches to assessing climate impacts and adaptation, including the UK Climate Impacts Programme (UKCIP) (West and Gawith 2005), the US National Assessment (Parson *et al.* 2003; National Assessment Synthesis Team 2000), the Arctic Climate Impact Assessment (ACIA 2005) the Finnish National Climate Change Adaptation Strategy (Marttila *et al.* 2005) and related FINADAPT research consortium (Kankaanpää *et al.* 2005), and the Mackenzie Basin Impact Study (Cohen 1997).

2.2.3.4 Defining coping ranges

The coping range of climate (Hewitt and Burton 1971) is described in the TAR as the capacity of systems to accommodate variations in climatic conditions (Smith *et al.* 2001), so serves as a suitable template for understanding the relationship between changing climate hazards and society. The concept of the coping range has since been expanded to incorporate concepts of current and future adaptation, planning and policy horizons, and likelihood (Yohe and Tol 2002; Willows and Connell 2003; UNDP 2005). It can thus serve as a conceptual model (Morgan *et al.* 2001) which can be used to integrate analytical techniques with a broader understanding of climate-society relationships (Jones and Mearns 2005).

The coping range is used to link the understanding of current adaptation to climate with adaptation needs under climate change. It is a useful mental model to use with stakeholders who often have an intuitive understanding of which risks can be coped with and those which cannot, that can be developed into a quantitative model (Jones and Boer 2005). It can be depicted as one or more climatic or climate-related variables upon which socio-economic responses are mapped (Figure 2.5). The core of the coping range contains beneficial outcomes. Towards one or both edges of the coping range, outcomes become negative but tolerable. Beyond the coping range, the damages or losses are no longer tolerable and denote a vulnerable state, the limits of tolerance describing a critical threshold. A coping range is usually specific to an activity, group and/or sector, though society-wide coping ranges have been proposed (Yohe and Tol 2002).

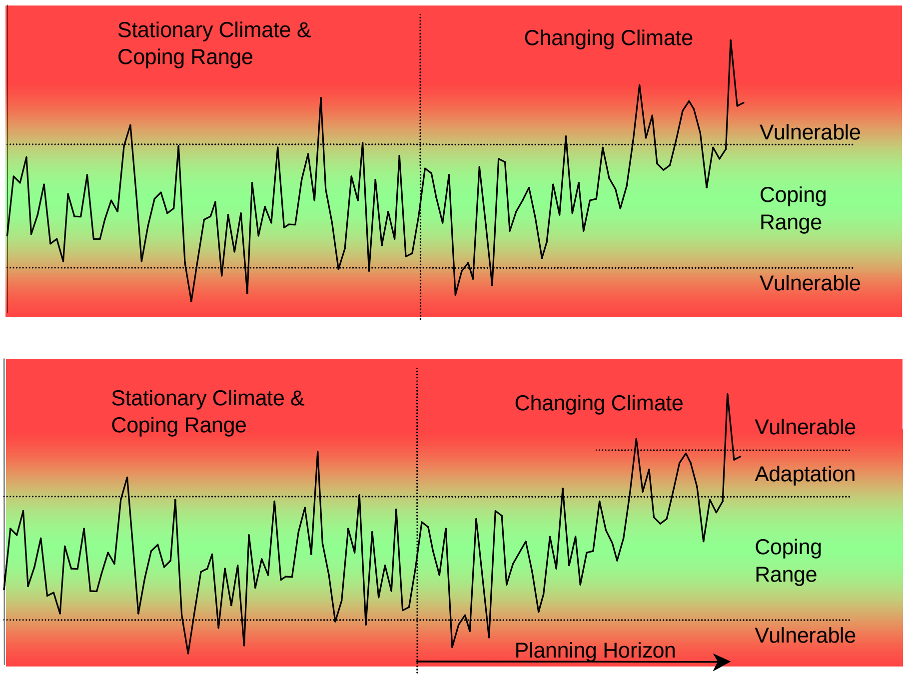

Figure 2.5: *Coping range showing (a) the relationship between climate change and threshold exceedence, and (b) how adaptation can establish a new critical threshold, reducing vulnerability to climate change. (Jones and Mearns 2005)*

Risk is assessed by calculating how often the coping range is exceeded under given conditions. For example, Jones (2001) constructed two separate critical thresholds for the Macquarie River catchment in Australia irrigation allocation and environmental flows. The probability of exceeding these thresholds was a function of both natural climate variability and climate change. Yohe (2002) explored hypothetical upper and lower critical thresholds for the Nile River using current and historical streamflow data. The upper threshold denoted serious flooding, and the lower threshold the minimum flow required to supply water demand. Historical frequency of exceedence served as a baseline from which to measure changing risks using a range of climate scenarios.

2.2.3.5 Adaptation assessment

The evaluation of specific adaptation options is likely to benefit from the use of formal methods for selection and prioritisation (Niang-Diop and Bosch 2004). Often, because of issues such as institutional reform, legislation and regulation, the benefits or impacts of a measure cannot be quantified and expert judgements are made on the basis of diverse criteria using existing institutional or informal structures. Many options currently appear to be selected on this basis, reflecting the limited experience with such assessments. Further research on both formal and informal methods is urgently needed.

Niang-Diop(2004) discuss the following four methods, which range from measures that are almost exclusively monetary, to those that can use a variety of metrics:

- Cost Benefit Analysis (CBA): compares costs and benefits of a measure with a view to deciding whether it is attractive to undertake an activity (a project or a project-type adaptation measure).
- Cost Effectiveness Analysis (CEA): once a course is chosen, this technique evaluates different options that achieve the same objective, and compares them to determine how a well-defined objective can be met with least cost.
- Multi-criteria Analysis (MCA): assesses between three and eight criteria (seldom more, for practical reasons), sometimes with different weightings, orders and other methods of uncertainty analysis.
- Expert judgement: employs structured methods to elicit information from experts (often stakeholders) who utilise their experience to prioritise different measures.

Guidance for methods and tools to use in prioritising adaptations include the Compendium of Decision Tools (UNFCCC 2004), the Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Feenstra *et al.* 1998) and Costing the Impacts of Climate Change (Econometrica 2004). A range of different methods can also be used with stakeholders (e.g. van Asselt and Rotmans 2002; Rowe and Frewer 2000; Renn 2004).

For instance, a successful application of cost benefit analysis was applied to a risk assessment approach using critical thresholds of damage due to storm surges on a proposed coastal road in the Pacific (ADB 2005). It showed a net benefit of US$2.8 million over 50 years for an investment in adaptation costs of US$3.3 million using a discount rate of 3%. Retrofitting an existing roadway also showed a net benefit. Several more case studies in the same report show wide benefits of allowing for climate change when investing in sustainable development.

The financing of adaptation has received minimal attention. Bouwer and Vellinga (2005) suggest applying a more structured decision-making framework to decisions affecting disaster management and adaptation to climate change, sharing risk between private and public sources. Quiggin and Horowitz (2003) argue that the economic costs will be dominated by the costs of adaptation, which depend on the rate of change, especially that of climate extremes. By treating the result of economic analyses as an optimal result and not factoring in such adjustments, many methods under-estimate the true costs. Impact assessments that account for adaptation costs are also described in section 2.2.3.2.

2.2.3.6 Advances in vulnerability assessment

Since the TAR, the IPCC definition of vulnerability has been challenged, both by a broadening of the remit of vulnerability assessments to include social vulnerability, which is influenced by a whole range of stressors, and by risk assessment. Vulnerability to climate change within a risk assessment framework depends on whether risk has or has not been reduced. Different states of vulnerability to climate include vulnerability to current climate, vulnerability to unmanaged climate change, where adaptation and mitigation options have not yet been exercised, and residual vulnerability, where adaptive and mitigative capacity are unlikely to be sufficient to keep an activity from harm (e.g. Jones *et al.* in press). Chapter 19 defines a key vulnerability as having the potential for significant adverse affects on both natural and human systems as outlined in the UNFCCC, which may contribute to dangerous anthropogenic interference with the climate system.

Therefore, vulnerability is highly dependent on context and scale. Downing and Patwardhan (2004) surveyed different meanings of vulnerability in the literature, advising that when the term is used, care should be taken to clearly describe its derivation and meaning. There have been calls for frameworks that are able to integrate the social and biophysical dimensions of vulnerability to climate change (Klein and Nicholls 1999; Polsky *et al.* 2003; Turner *et al.* 2003a). This includes the need to place vulnerability of biophysical systems within a social context, as these assessments involve value judgements about the identification of important ecosystem services and of the acceptability or otherwise of ecosystem change (e.g. Neudoerffer and Waltner-Toews submitted; de Chazal submitted). There is also a recognised need to develop formal methods for vulnerability assessment (Metzger and Schröter submitted; Ionescu *et al.* submitted) and to address the uncertainties inherent in vulnerability assessments (Patt *et al.* 2005).

Vulnerability assessment offers a frame for policy measures that focus less on technical aspects and more on social aspects, including poverty reduction, diversification of livelihoods, protection of common property resources, and strengthening of collective action (O'Brien *et al.* 2004). Such measures enhance the ability to respond to stressors and secure livelihoods under present stress, which can also reduce vulnerability to future climate conditions. One way of operationalising this is by first understanding the distribution of vulnerability and identification of "hotspots" through vulnerability mapping. At a more local scale, however, community based interactive approaches on coping potentials provide insights into the underlying causes and structures that shape vulnerability (O'Brien *et al.* 2004). Two recent projects − ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling[4]) and VISTA (Vulnerability of ecosystem services to land use change in traditional agricultural landscapes[5]) − assessed ecosystem vulnerability by downscaling global scenarios to a regional level. Both projects involved stakeholder participation to assess vulnerability (Schröter *et al.* 2005; de Chazal submitted).

Most regional studies in the AIACC programme were vulnerability assessments applying a bottom-up approach. Methods included in the programme included using stakeholder elicitation and survey (Eakin and Wehbe 2004; Pulhin *et al.* 2004; Rawlins 2004), sustainable livelihood frameworks (Zakieldin 2004), multi-criteria modelling (Wehbe *et al.* 2004), policy assessment (Gichangi and Toteng 2004) and vulnerability indices (Kokot *et al.* 2004; Norbis *et al.* 2004).

Traditional knowledge of local communities represents an important, yet currently largely under-used resource for CCIAV assessment (Huntington and Fox 2005). Empirical knowledge from past experience in dealing with climate-related natural disasters such as droughts and floods (Desanker *et al.* submitted), health crises (Wandiga *et al.* 2005) as well as longer-term trends in mean conditions (Huntington and Fox 2005; McCarthy and Long Martello 2005) can be particularly helpful in understanding the coping strategies and adaptive capacity of vulnerable communities.

2.2.3.7 Integrated assessment

Integrated assessment represents complex interactions across spatial and temporal scales, processes and activities, requiring the integration of different research disciplines. Integrated assessments are a process that may involve one or more mathematical models, which may themselves be integrated. Integrated models range from simple models linking large-scale processes, through models of

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[4] http://www.pik-potsdam.de/ateam

[5] http://lotus5.vitamib.com/hnb/vista/vista.nsf/Web/Frame?openform

intermediate complexity to the complex, physically explicit representation of Earth systems. These different levels involve a trade-off between realism and flexibility, where simple models better represent uncertainty and are less accurate, whereas scenarios and projections from complex models offer more detail and a greater range of output. However, no single theory describes and explains dynamic behaviour across scales in socio-economic and ecological systems (Rotmans and Rothman 2003), nor can a single model represent all interactions within a single entity, or provide responses to questions in a rapid turn-around time (Schellnhuber *et al.* 2004). Therefore, integration at all these scales is required to comprehensively assess CCIAV.

Cross-sectoral integration

Cross-sectoral integration is required for purposes such as national assessments, analysis of economic and trade effects, and joint population and climate studies. National assessments can utilise nationally integrated models (e.g. Hurd *et al.* 2004; Rosenberg *et al.* 2003; Izaurralde *et al.* 2003), or can synthesise a number of disparate studies for policy makers (e.g. West and Gawith 2005). Markets and trade can have significant effects on outcomes. For example, a study assessing the global impacts of climate change on forests and forest products showed that trade can affect efforts to stabilise carbon dioxide in the atmosphere. Trade can also significantly affect regional welfare, with adverse effects on those regions with high production costs (Perez-Garcia *et al.* 2002).

Integration of climate with other stressors and processes

Integration yields results that can often not be produced in isolation. For example, the Millennium Ecosystem Assessment assessed the impact of a broad range of stresses on ecosystem services, of which climate change was only one (Millennium Ecosystem Assessment 2005). Linked impact and vulnerability assessments can also benefit from taking the multiple stressors approach. For example, the AIR-CLIM Project integrated climate and air pollution impacts covering Europe between 1995 and 2100, concluding that that while the physical impacts were weakly coupled in the policy environment, air pollution and climate change were strongly coupled. The indirect effects of climate policies were found to reduce the costs of controlling air pollution emissions by more than 50% (Alcamo *et al.* 2002).

Coupling of impacts, adaptation and vulnerability assessments with Earth System Models

Earth System Models of intermediate complexity that link the atmosphere, oceans, cryosphere, land system and biosphere are being developed to assess impacts, particularly global scale singular events that may be considered dangerous, within a risk and vulnerability framework (Rial *et al.* 2004 − see section 2.2.2.12). Global climate models are also moving towards a more complete representation of the Earth system; recent simulations integrating the atmosphere with the biosphere via a complete carbon cycle showing the potential of the Amazon rainforest to suffer large-scale dieback, leading towards a positive feedback decreasing the carbon sink and increasing atmospheric CO_2 concentrations (Cox *et al.* 2004; Betts *et al.* 2004).

Integrating adaptation and mitigation to assess climate policy benefits

The assessment of climate policy benefits has arisen out of the need to assess the complementary but different benefits of adaptation and mitigation and balance these against the risks associated with various policy options. This type of integrated assessment modelling integrates simple to intermediate models of the climate, impacts and the economy. To date, the impacts of climate change and the benefits of avoiding consequent damages have been overlooked in favour of asymmetric attention being paid to the costs of mitigation commitments on the one hand, and, more recently, the potential benefits of adaptation on the other (Corfee-Morlot and Agrawala 2004). This is because of the relatively crude state of impact damage functions and the limited ability of such models to provide realistic simulations of impacts under a wide range of scenarios. Analyses of the costs of adaptation within these frameworks are also rare.

The benefits of avoided damage can be assessed in a risk assessment framework, providing a means to assess the trade-offs associated with decisions about mitigation (O'Neill and Oppenheimer 2002; Arnell *et al.* 2002; Jacoby 2004). Impact analyses are carried out for a range of scenarios with unmanaged greenhouse gas emissions and contrasted with scenarios where some type of management has been imposed. The range of key vulnerabilities summarised in chapter 19 allows thresholds to be set where the risk of abrupt and irreversible change is high. The aggregation of smaller local and regional thresholds will also help identify thresholds for global mean temperature change or rates of change that limit the risk of irreversible damage to vital natural or human systems (Jones 2004). In turn, such thresholds provide a means to establish boundaries for near-term actions consistent with emission pathways that lead to stabilisation of greenhouse gas concentrations.

The risk of exceeding critical thresholds can also be estimated within a Bayesian framework, by expressing global warming and sea level rise as cumulative distribution functions that are much more likely to be exceeded at lower levels than higher levels (Jones 2004; Mastrandrea and Schneider 2004; Yohe 2004). However, although this may be achieved for key global vulnerabilities there is often no straightforward way to integrate local critical thresholds into a "mass" damage function of many different metrics across the wide range of potential (Jacoby 2004). IAMs may do so, but it is difficult to run them within a probabilistic framework. Webster *et al.* (2003)use an integrated model of moderate complexity to link selected critical outcomes to different levels of forcing under both SRES and stabilisation scenarios.

2.2.3.8 Communicating uncertainty and risk

Communicating risk and uncertainty is a vital part of helping people respond to climate change. However, people often rely on intuitive decision-making processes, or heuristics, in solving complicated problems of judgment and decision-making (Tversky and Kahneman 1974). In many cases, these heuristics are surprisingly successful at leading to successful decisions under information and time constraints (Gigerenzer 2000; Muramatsu and Hanich 2005). In other cases, heuristics can lead to predictable inconsistencies or errors of judgment. For example, people consistently overestimate the likelihood of low probability events (Kahneman and Tversky 1979; Kammen *et al.* 1994), or events that have a strong emotional impact (Tversky and Kahneman 1973; Elster 1998) often resulting in choices that increase their exposure to harm (Thaler and Johnson 1990).

Participatory approaches establish a dialogue between stakeholders and experts, where the experts can explain the uncertainty and the ways it is likely to be misinterpreted, the stakeholders can explain their decision-making criteria, and the two parties can work together to design a risk management strategy (Fischoff 1996; NRC 2002; Jacobs 2002). Because stakeholders are often the decision-makers themselves (Kelly and Adger 2000) the communication of impact, adaptation, and vulnerability assessment has risen in importance (Jacobs 2002; Füssel and Klein in press). Adaptation decisions also depend on changes outside the climate change arena (Turner *et al.* 2003b).

If factors that give rise to the uncertainty in the first place are described (Willows and Connell 2003) stakeholders will view that information as more credible because they can make their own judgments about its quality and accuracy (Funtowicz 1993; Funtowicz and Ravetz 1990). People will remember and use uncertainty assessments when they can mentally link the uncertainty and events in the world with which they are familiar; assessments of climate change uncertainty are more memorable, and hence more influential, when they fit into people's pre-existing mental maps of experiences of climate variability, or when sufficient detail is provided to help people to form new mental models (Hansen 2004).

Finally, there are a number of common pitfalls stakeholders have in understanding and responding to uncertainty (Morgan *et al.* 2001; Nicholls 1999). The perception of risk and deficiencies in human judgement in the face of uncertainty are discussed at length in the TAR chapter on methods (Ahmad *et al.* 2001).

2.2.4 Data needs for assessment

The two main areas of need regarding data and information for use in CCIAV assessments are: the collection and dissemination of environmental and socio-economic data in ongoing programmes and the context-specific data and information required for a project (e.g. Briassoulis 1997). Context-specific data and information can come from existing sources or through stakeholder elicitation. Types of information elicited from stakeholders include, for example, past adaptation actions, thresholds denoting limits of coping capacity and past vulnerability to climate.

Monitored data includes traditional sources of data, such as climate data, but as the range and complexity of CCIAV methods increases, so too do their data requirements (Basher 1999):

- The climatic influencing factors (e.g. temperature, rain, wind);
- The non-climatic influences (e.g. population, prices, pests, policies);
- The internal functions of the system, and their climatic and other sensitivities;
- The interactions (physical, biological and social) with other systems and resultant integrated behaviours.

As discussed in section 2.2.1, this will require integrated data on current climate risks and how they have been responded to, along with model projections and scenarios if numerical studies are to be undertaken, or even if projections are to be communicated to stakeholders.

However, instrumental data and records of human systems can be difficult to access and validate, particularly in developing countries where financial support is low and/or decreasing. In many jurisdictions, long-term monitoring is decreasing, jeopardising future assessments (Basher 1999). Also, in developing countries, formal observations of natural and human behaviour are scarce, given the small scientific communities and limited resources. Many assessments are now obtaining data through stakeholder elicitation and survey methods. For example, in many traditional societies a large number of social interactions may not be recorded by bureaucratic processes, but records of how societies adapt to climate change, how they perceive risk and measure their vulnerability exist with community members (e.g. Cohen 1997; ACIA 2005 − see Section 2.2.3.6). Even in data rich situations it is likely that some additional data from stakeholders will be required. However, this also requires adequate resourcing.

New programmes to record human-environment interactions are being implemented. For example, the recent history past climatic disasters in Latin America[6], highlights not only climatic adverse events, but also the actors and consequences of those events. Information on local coping strategies applied by different communities and sectors is being recorded by the UNFCCC[7].

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[6] http://www.desinventar.org/desinventar.html

[7] http://maindb.unfccc.int/public/adaptation

New sources of data are also becoming available from remote sensing (e.g. Justice *et al.* 2002) and theoretically could fill the gaps where no ground-based data are available but would also need to be resourced for developing country access. Lastly, the coverage of different sectors is very different. Agriculture and water resources are relatively well served areas, whereas information on coastal and marine environments and stock and materials in the built environment is difficult to obtain in useable form.

2.3 Characterising the future in this assessment

Recent methodological advances in the characterisation of future climatic and non-climate conditions were outlined in section 2.2.2. They are directed towards developing scenarios, storylines and other representations of the future, based on the best available knowledge. At the time of the TAR, most CCIAV studies utilised climate scenarios (many based on the IS92 emissions scenarios), but very few applied contemporaneous scenarios of socio-economic, land use or other environmental changes, and those that did used a range of sources to develop them.

The publication of the IPCC Special Report on Emissions Scenarios (SRES − Nakićenović *et al.* 2000) presented the opportunity to construct a range of mutually consistent climate and non-climatic scenarios. Originally developed to provide scenarios of future greenhouse gas emissions, the SRES scenarios are also accompanied by storylines of social, economic and technological development that can be used in CCIAV studies. They are discussed in section 2.3.1. The SRES storylines assume that no specific climate policies are implemented, and thus form a baseline against which narratives with specific mitigation and adaptation measures can be compared. Mitigation scenarios are described in section 2.3.2. As yet, there are few examples of scenarios that account for feedbacks from impacts and adaptation to the global economy and in future a new generation of integrated scenarios, covering a range of spatial scales, will be required to address more adequately the varied needs of the CCIAV community.

2.3.1 SRES-based characterisations of the 21st century

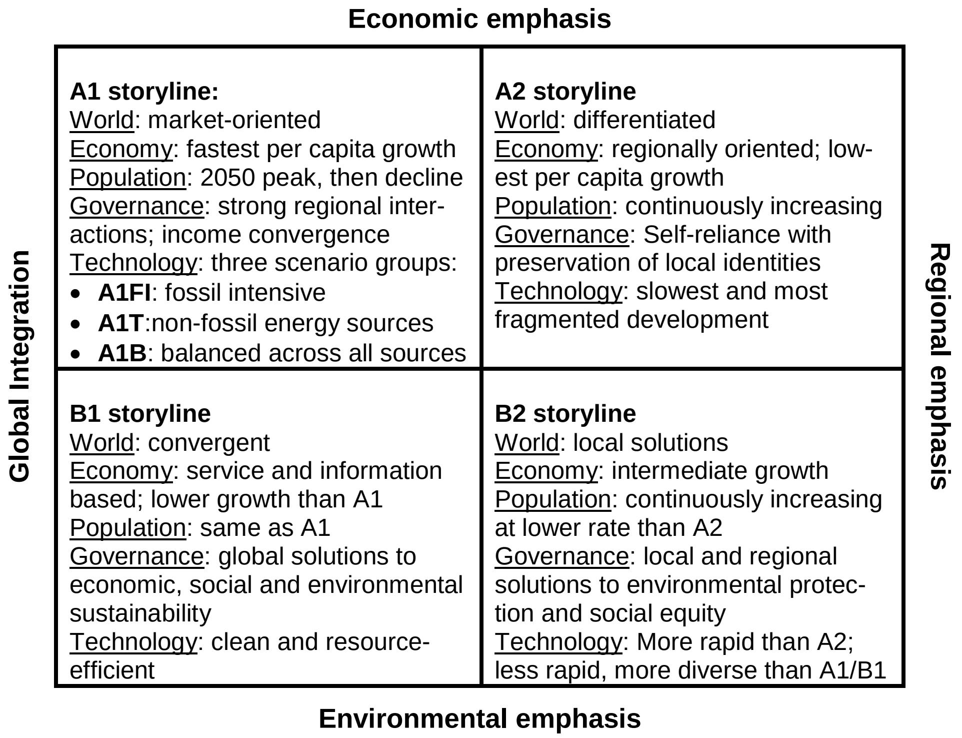
2.3.1.1 The SRES global storylines and scenarios

SRES presented four narrative storylines, labelled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally (Figure 2.6). Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways and result in different levels of greenhouse gas emissions.

The SRES storylines formed the basis for the development of derivative quantitative scenarios using various numerical models that were presented in the TAR. Emissions scenarios were converted to projections of changing atmospheric greenhouse gas and aerosol concentrations, radiative forcing of the climate, effects on regional climate, and climatic effects on global sea level (IPCC 2001). However, little regional detail of these projections and no CCIAV studies that made use of them were available for the TAR. Subsequent work is described below, with examples given of SRES-based regional scenarios applied in CCIAV studies and assessed elsewhere in this report.

2.3.1.2 SRES-based climate characterisations

Not all of the impact studies reported in this assessment employed SRES-based climate scenarios. Earlier scenarios are described in previous IPCC reports (IPCC 1992, 1996; Greco *et al.* 1994). The remaining discussion focuses on SRES-based projections, which are applied in most CCIAV studies currently undertaken.



A1 storyline:
World: market-oriented
Economy: fastest per capita growth
Population: 2050 peak, then decline
Governance: strong regional interactions; income convergence
Technology: three scenario groups:
- **A1FI**: fossil intensive
- **A1T**:non-fossil energy sources
- **A1B**: balanced across all sources

A2 storyline
World: differentiated
Economy: regionally oriented; lowest per capita growth
Population: continuously increasing
Governance: Self-reliance with preservation of local identities
Technology: slowest and most fragmented development

B1 storyline
World: convergent
Economy: service and information based; lower growth than A1
Population: same as A1
Governance: global solutions to economic, social and environmental sustainability
Technology: clean and resource-efficient

B2 storyline
World: local solutions
Economy: intermediate growth
Population: continuously increasing at lower rate than A2
Governance: local and regional solutions to environmental protection and social equity
Technology: More rapid than A2; less rapid, more diverse than A1/B1

Figure 2.6: *Summary characteristics of the four SRES storylines (based on Nakićenović et al. 2000)*

Projections of regional mean changes assessed in this report

Global mean annual temperature is the measure most commonly employed by the IPCC and adopted in the international policy arena to summarise future changes in global climate and its likely impacts. In the TAR, a projected range of global mean temperature change by 2100 (relative to 1990) of 1.4 to 5.8ºC was reported for the range of SRES emissions scenarios (IPCC 2001). This is very similar to the 65% probability range cited by WG I (chapter 10) of 1.5 to 5.8°C. While this measure is adopted in some global assessments of the aggregate costs and damages of climate change (Hitz and Smith 2004), it is of little use for CCIAV studies conducted at a regional scale. These studies require more detailed spatial and temporal projections of the key climate variables to which natural and human systems are exposed (see section 2.2.2.6).

Since publication of the TAR, a large number of simulations of the global climate response to the SRES emission scenarios have been completed with AOGCMs. Early runs (labelled "pre-TAR") were reported in the TAR (Cubasch *et al.* 2001) and are available from the IPCC Data Distribution Centre (DDC)[8]. Many have been employed in CCIAV studies reported in this volume. A new generation of AOGCMs, some of which incorporate improved representations of climate system processes and land surface forcing, are now utilising the SRES scenarios in addition to other emissions scenarios of relevance for impacts and policy. These were unavailable for use in the CCIAV studies reported here. The new models and their projections are evaluated in Chapters 8, 10 and 11 of the WG I report and compared with the pre-TAR results below.

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[8] http://ipcc-ddc.cru.uea.ac.uk/

Pre-TAR AOGCM results held at the DDC were included in a model inter-comparison of seasonal mean temperature and precipitation change for 32 world regions (Ruosteenoja *et al.* 2003)[9]. The range of changes by the end of the 21st century are summarised in Figure 2.7 across the four SRES emissions scenarios (B1, B2, A2 and A1FI) and for the A2 scenario alone, expressed as rates of change per century. Recent A2 projections, reported in WG I, are also shown for the same regions for comparison.

Almost all model-simulated temperature changes, but fewer precipitation changes were statistically significant relative to 95% confidence intervals calculated from 1000-year unforced coupled AOGCM simulations (Ruosteenoja *et al.* 2003 − Figure 2.7). Modelled surface air temperature increases in all regions and seasons, with most land areas warming more rapidly than the global average (Giorgi *et al.* 2001; Ruosteenoja *et al.* 2003). Warming is especially pronounced in high northern latitude regions in the boreal winter and in southern Europe and parts of central and northern Asia in the boreal summer. Warming is less than the global average in southern parts of Asia and South America, southern ocean areas (containing many small islands) and the North Atlantic (Figure 2.7a).

For precipitation, changes with both sign occur, but an increase of regional precipitation is more common than a decrease. All models simulate higher precipitation at high latitudes in both seasons, in northern mid-latitude regions in boreal winter, and enhanced monsoon precipitation for Southern and Eastern Asia in boreal summer. Models also agree that precipitation declines in Central America, Southern Africa and southern Europe in certain seasons (Giorgi *et al.* 2001; Ruosteenoja *et al.* 2003 Figure 2.7b).

Comparing TAR projections to recent projections

Chapters 10 and 11 of WG I provide an extensive inter-comparison of recent regional projections from AOGCMs, focusing on those assuming the SRES A1B emissions scenario, for which the greatest number of simulations (21) were available. In summary:

- the basic pattern of projected warming is little changed from previous assessments.
- all models project temperature increases in a narrow range of 0.64–0.69°C, averaged over 2011–2030 relative to 1980–1999, regardless of emission scenario.
- the inter-model range of warming for the A2 scenario is smaller than the pre-TAR range at 2100, despite the larger number of models (compare the red and blue bars in Figure 2.7a).
- the global mean near-surface temperature changes (between the 20-year periods 1980–1999 and 2080–2099) averaged across the GCMs analysed are in the ratio 0.69:1:1.17 for the B1:A1B:A2 emissions scenarios, respectively, with local temperature responses in most regions following the same ratio.
- the ensemble mean local precipitation responses also roughly scale with the global mean temperature response, although not as precisely as for local temperature.
- the evolution of the local temperature response in the mean model A1B projection is typically very linear in time.

While AOGCMs are the most common source of regional climate scenarios, other methods and tools are also applied in specific CCIAV studies. Numerous regionalisation methods have been employed to obtain high resolution SRES-based climate scenarios, nearly always using low resolution GCM outputs as a starting point. The added value of these methods is context-specific, as described in section 2.2.2.6 and chapter 11, WG I.

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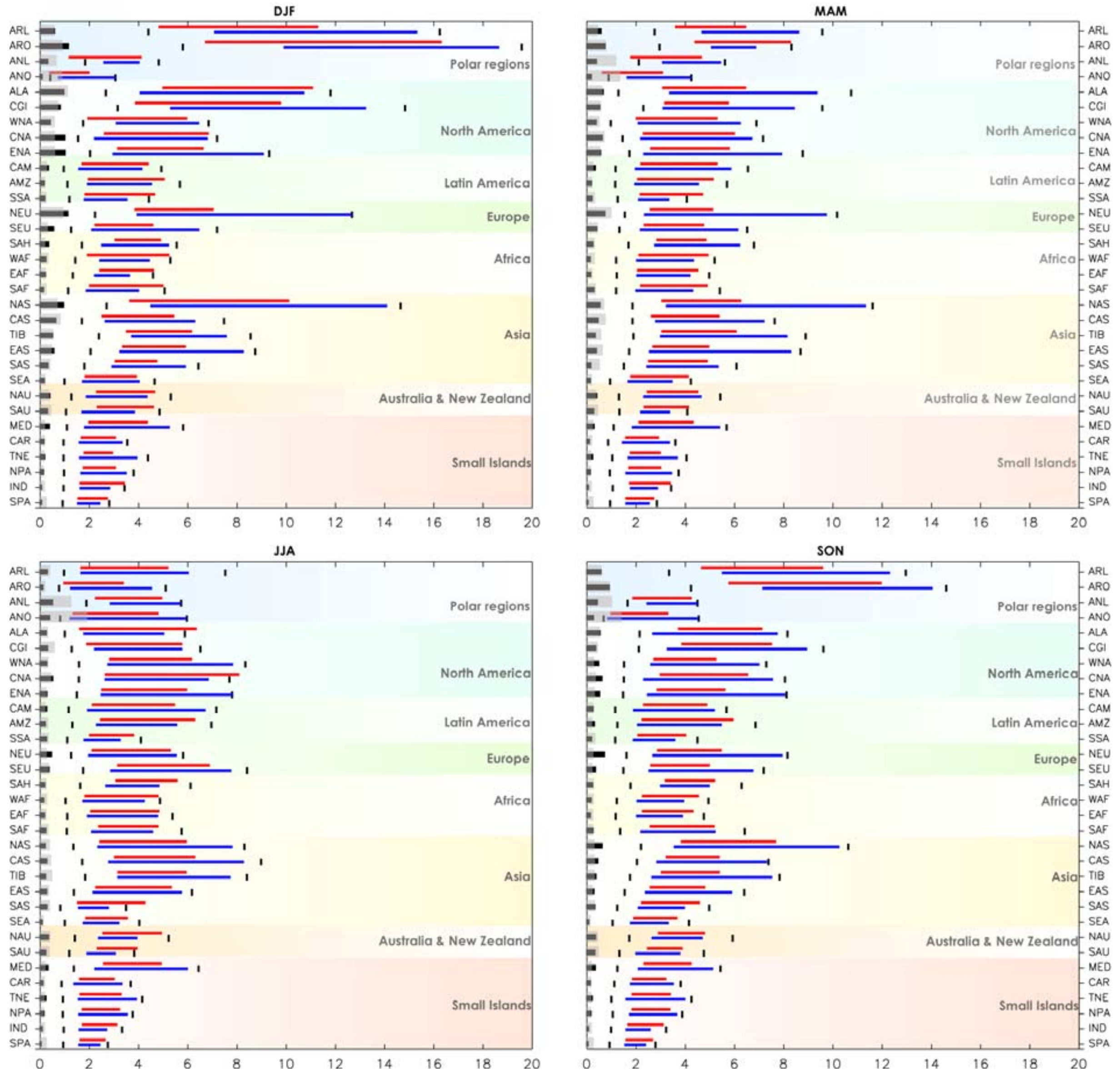
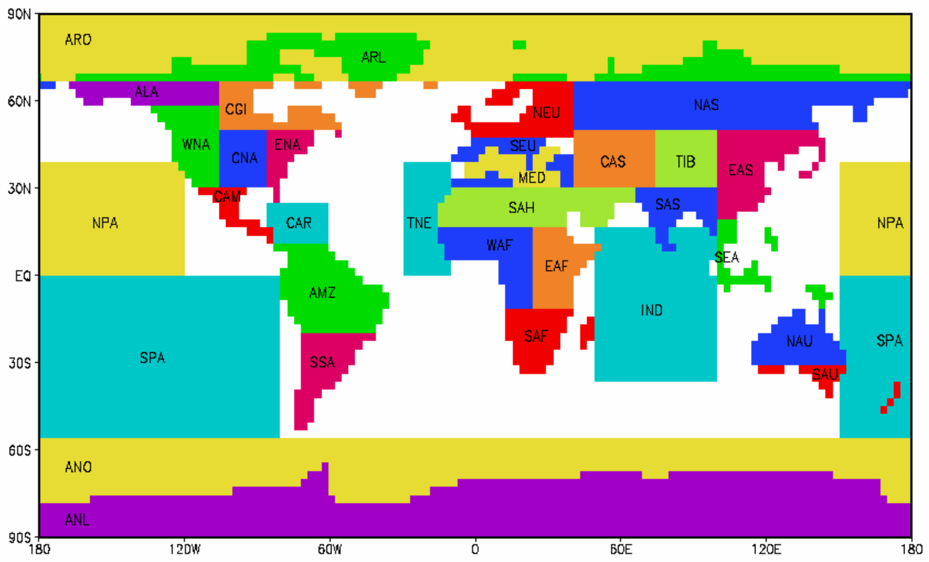
[9] Scatter diagrams are downloadable at: http://ipcc-ddc.cru.uea.ac.uk/asres/scatter plots/scatterplots_region.html

(a) Temperature change (°C per century)





(b) Precipitation change (percent per century)

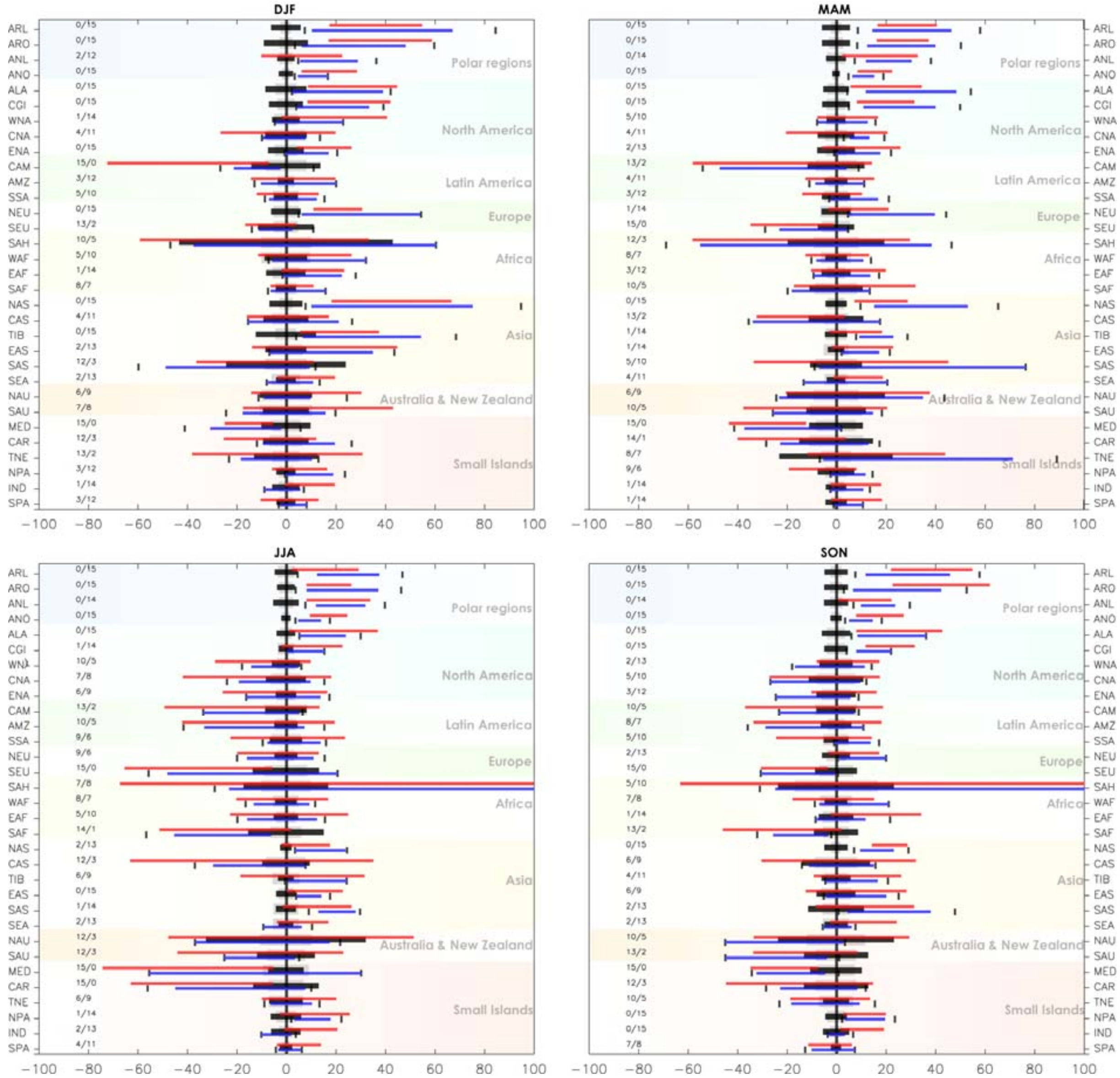


Figure 2.7: AOGCM projections of seasonal changes in (a) mean temperature and (b) precipitation up to the end of the 21st century for 32 world regions. For each region three ranges between minimum and maximum are shown. Red bar: range from 15 recent AOGCM simulations for the A2 emissions scenario (data analysed for chapter 11, WG 1). Blue bar: range from seven pre-TAR AOGCMs for the A2 emissions scenario (Ruosteenoja et al. 2003). Whiskers: range from seven pre-TAR AOGCMs (some pattern-scaled), assuming the four SRES emissions scenarios – B1, B2, A2 and A1FI (Ruosteenoja et al. 2003). Seasons: DJF (December–February); MAM (March–May); JJA (June–August); SON (September–November). Regional definitions, plotted on the ECHAM4 model grid (resolution 2.8 × 2.8º), are shown on the inset map (Ruosteenoja et al. 2003). Pre-TAR changes were originally computed for 1961-90 to 2070-99 and recent changes for 1979-1998 to 2079-2098, and are converted here to rates per century for comparison. 95% confidence limits on modelled 30-year natural variability (grey bars) are based on millennial AOGCM control simulations with HadCM3 (dark grey) and CGCM2 (light grey) for constant forcing (Ruosteenoja et al. 2003). Numbers on precipitation plots show the number of recent A2 runs giving negative/positive precipitation change. Percentage changes for the SAH region (Sahara) exceed 100% in JJA and SON due to low present-day precipitation.

Table 2.5: *Trends, attribution and projections of extreme weather and climate events for which there is evidence of an observed late 20th century trend. Colour coding groups phenomena with similar levels of likelihood of attribution of trend to human influence. Italics indicate cases where no formal detection and attribution study has been completed. Source: Working Group I, Technical Summary.*

Phenomenon	***Likelihood that trend occurred in late 20th century (typically post 1960)***	***Likelihood that observed trend is due to human influence***	***Confidence[a] in trend predicted for 21st century***
Cool days / cool nights / frosts: decrease over mid- and high-latitude land areas	Very likely	Likely	High
Warm days / warm nights: increase over mid- and high-latitude land areas	Very likely	Likely (warm nights)	High
Warm spells / heat waves: increase	Likely	*More likely than not*	High
Proportion of heavy precipitation events: increase over many areas	Likely	*More likely than not*	High (but a few areas with projected decreases in absolute number of heavy events)
Droughts: increase over low-latitudes (and mid-latitudes in summer)	Likely	More likely than not	Moderate – mid-latitude continental interiors in summer (but sensitive to model land-surface formulation)
Tropical cyclones: increase in intensity	More likely than not since 1970	*More likely than not (but with low confidence)*	Moderate (few high-resolution models)
Mid- and high-latitude cyclones: increase in most intense storms; storm tracks move polewards	More likely than not	*Not assessed*	Moderate (intensity not explicitly analysed for all models)
High sea level events: increase (excludes tsunamis)	More likely than not	*Not assessed*	Moderate (most mid-latitude oceans)

Notes:

(a) Confidence terms for projected trends are as follows: "high" means consistency across model projections and/or consistent with theory and/or changes in mean; "moderate" indicates some inconsistencies across model projections or only a few relevant model projections available or analysed.

Projections of climate variability and extremes

Possible changes in variability and the frequency/severity of extreme events are critical to undertaking realistic CCIAV assessments. Past trends and projected changes in extreme weather and climate events were summarised globally in the TAR (Cubasch *et al.* 2001), and an updated version from the Technical Summary of WG I is reproduced in Table 2.5. Some key conclusions reported by WG I include:

- Heat waves become more frequent and longer lasting in a future warmer climate. Decreases in frost days are projected almost everywhere in the mid and high latitudes, with an increase in growing season length. Many mid-continental areas become drier during summer, indicating a greater risk of droughts.

- Extremes of precipitation or storms show large ranges in amplitude and geographical locations.
- Extremes in daily precipitation will very likely increase in northern Europe, South Asia, East Asia, Southeast Asia, Australia and New Zealand.
- The response of some major modes of climate variability such as ENSO still differs from model to model, due to differences in spatial and temporal representation.
- The robustness of model responses of tropical cyclones and mid-latitude storms is still limited by a too-coarse resolution.
- In some regions the study of key aspects of regional climate change has been very limited, particularly with regard to extreme events.

2.3.1.3 SRES-based sea level scenarios

At the global level, simple models that account for the expansion of sea water and melting/sliding of land-based ice sheets and glaciers were used in the TAR to obtain estimates of global mean sea-level rise across the SRES scenarios, yielding a range of 9–88 cm by 2100 relative to 1990 (IPCC 2001). This range has been updated in this assessment to 14–44 cm relative to 2000 (chapter 10, WG I). The range is narrower than in the TAR because: (i) the new projections are only presented for the A1B emissions scenario, (ii) projections of ice melt are smaller than in the TAR, and (iii) additional terms (i.e. the ongoing response of the ice sheets to palaeoclimate change, runoff from permafrost and sedimentation in the oceans), which were in the TAR projections, are not yet included (chapter 10, WG I).

A number of studies have made use of the TAR sea level scenarios. In a global study of coastal flooding and wetland loss, Nicholls (2004) used global mean sea-level rise estimates for the four SRES storylines by 2025, 2055 and 2085. These were consistent with climate scenarios used in parallel studies (see section 2.2.2.8). Two subsidence rates were also applied to obtain relative sea level rise in countries already experiencing coastal subsidence. The United Kingdom Climate Impacts Programme adopted the TAR global mean sea-level rise estimates in national scenarios out to the 2080s. Scenarios of high water levels were also developed, by combining mean sea level changes with estimates of future storminess, using a storm surge model (Hulme *et al.* 2002). SRES-based sea level scenarios accounting for global mean sea level, local land uplift and estimates of the water balance of the Baltic Sea were estimated for the Finnish coast up to 2100 by Johansson (2004), along with calculations of uncertainties and extreme high water levels.

2.3.1.4 SRES-based projections of CO_2 and other atmospheric components

Projections of atmospheric composition account for the concurrent effects of air pollution and climate changes. Apart from CO_2 concentration (discussed below), spatially and temporally detailed scenarios of atmospheric composition are needed to account for large variations in the concentration and impacts of different atmospheric species. However, the SRES scenarios have only provided global-scale summaries (e.g. for surface ozone concentrations in the TAR – Prather *et al.* 2001, and see updates for the A2 scenario in chapter 10, WG I). Examples of regional scenarios based on SRES include Mayerhofer *et al.* (2002) for Europe, and two related studies for Finland (Laurila *et al.* 2004; Syri *et al.* 2004 − see section 2.2.2.13).

Carbon dioxide concentration is required as a direct input to plant growth models, since it can affect both the growth and water use of many plants (see chapters 4 and 5), with possible feedbacks on regional hydrology (Gedney *et al.* 2006). CO_2 is well mixed in the atmosphere, so concentrations at a single observing site will usually suffice to represent global conditions. In the TAR, global CO_2 concentration was projected to increase from 367 ppm in 1999 to between 490 and 1,260 ppm by

2100 under the SRES emissions scenarios (Prentice *et al.* 2001).

2.3.1.5 SRES-based socio-economic characterisations

SRES provides socio-economic information in the form of storylines and quantitative assumptions on population, GDP, and rates of technological progress, for four large world regions. Since the TAR, several of the quantitative assumptions about the SRES driving forces have been re-examined (see also the discussion in chapter 3, WG III). For example, the range of global population size projections made by major demographic institutions has shifted downward by about 1−2 billion since the SRES were developed (van Vuuren and O'Neill submitted). Nevertheless, on balance the population assumptions used in SRES remain credible, with the exception of some regions of the A2 scenario which now lie above the current range of projections (van Vuuren and O'Neill submitted). Researchers are now producing alternative interpretations of SRES population assumptions (Hilderink 2004; Grübler *et al.* submitted national; O'Neill 2004; Fisher *et al.* in press).

SRES GDP growth assumptions for the ALM region (Africa, Latin America and Middle East) are generally higher than those of more recent projections, particularly for the A1 and B1 scenarios (van Vuuren and O'Neill submitted). The SRES GDP assumptions are generally consistent with recent projections for other regions and, given the small share of the ALM region in global GDP, for the world as a whole.

For international comparison, economic data must be converted into a common unit, which is generally done in terms of US$ based on market exchange rates (MER). Purchasing-Power-Parity estimates (PPP), in which a correction is made for differences in price levels among countries, are considered to be a better alternative for comparison of income levels across regions and countries. Most models and economic projections, however, use MER-based estimates, partly due to a lack of consistent PPP-based data sets. The use of MER-based economic projections in SRES has been questioned (Castles and Henderson 2003), suggesting that this results in inflated economic growth projections. In an ongoing debate, some researchers argue that PPP is indeed a better measure and that its use will, in the context of scenarios of economic convergence, lead to lower economic growth and emissions paths for developing countries. Others argue that consistent use of either PPP- or MER-based numbers will lead to, at most, only small changes in emissions. This debate is summarised in chapter 3 of WG III, which concludes that the impact on emissions of the use of alternative GDP metrics is likely to be small, but indicating alternative positions as well (van Vuuren and Alfsen in press). The use of alternative measures of income is likely to affect CCIAV assessments, since both are related to income level (Tol in press), especially where vulnerability and adaptive capacity are related to access to locally traded goods and services.

2.3.1.6 SRES-based land use and land cover characterisations

Future land use was estimated by most of the IAMs used to characterize the SRES storylines, but estimates for any one storyline are model-dependent, so vary widely. For example, under the B2 storyline the change in the global area of grassland between 1990 and 2050 varies between -49 and +628 million ha (Mha), with the marker scenario giving a change of +167 Mha (Nakićenović *et al.* 2000). The IAM used to characterize the A2 marker scenario did not include land cover change, so changes under the A1 scenario were assumed to apply also to A2. Given the differences in socio-economic drivers between A1 and A2 that can affect land use change, this assumption is not appropriate. Nor do the SRES land cover scenarios include the effect of climate change on future land cover. This lack of internal consistency will especially affect the representation of agricultural land use where changes in crop productivity play an important role (Audsley *et al.* 2006; Ewert *et al.* 2005). A proportional approach to downscaling the SRES land cover scenarios has been applied to global ecosystem modelling (Arnell *et al.* 2004) by assuming uniform rates of change everywhere within an SRES macro region. In practice, however, land cover change is likely to be greatest where population and population growth rates are greatest. A mismatch was also found in some of the SRES storylines and for some regions between recent trends and projected trends for cropland and forestry (Arnell *et al.* 2004).

More sophisticated downscaling exercises of the SRES scenarios have been undertaken at the regional scale within Europe (Abildtrup *et al.* 2006; Audsley *et al.* 2006; Ewert *et al.* 2005; Kankaanpää and Carter 2004; Rounsevell *et al.* 2005; Rounsevell *et al.* 2006; van Meijl *et al.* 2006). These analyses highlighted the potential role of non-climate change drivers in future land use change. Indeed, climate change was shown in many examples to have a negligible effect on land use compared with socio-economic change (Schröter *et al.* 2005). Technology, especially as it affects crop yield development, is an important determinant of future agricultural land use (and much more important than climate change), contributing to declines in agricultural areas of both cropland and grassland by as much as 50% by 2080 under the A1FI and A2 scenarios (Rounsevell *et al.* 2006). Such declines in land use did not occur within scenarios that assumed more extensive agricultural management, such as "organic" production systems, or the widespread substitution of agricultural food and fibre production by bioenergy crops. This highlights the role of policy decisions in moderating future land use change. However, broad-scale changes often belie large potential differences in the spatial distribution of land use change that can occur at the sub-regional scale (Schröter *et al.* 2005 – see Figure 2.8), and these spatial patterns may have greater effects on CCIAV than the overall changes in land use quantities (Metzger *et al.* 2006; Reidsma *et al.* 2006).

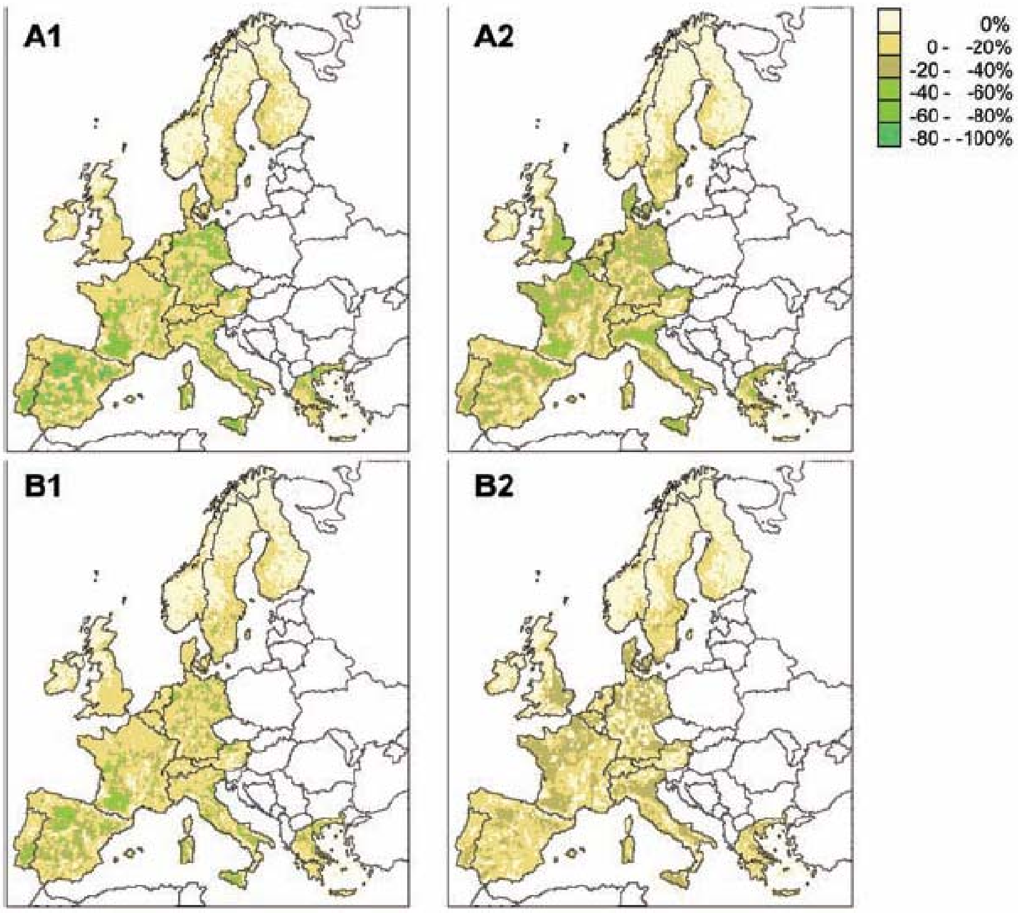


Figure 2.8: *Percentage change in cropland area (for food production) by 2080 compared with the baseline in 2000 for the 4 SRES storylines (A1FI, A2, B1, B2) with climate calculated by the HadCM3 AOGCM (after Schröter et al. 2005)*

2.3.1.7 Comparison of SRES with other scenarios and storylines

Other assessments have also used the scenario approach as a way to explore uncertainties and risks related to climatic and other global environmental changes. Many of these are based on similar assumptions to those used in the SRES scenarios, in some cases employing the same models for quantifying the main drivers and indicators.

Table 2.6 compares the SRES scenarios with some major global scenario exercises, based on reviews by Raskin (2005) and Westhoeck (2006a). A common feature of all these exercises is their adoption of the Storyline-and-Simulation (SAS) approach (introduced in section 2.2.2.5, above − Alcamo 2001). Furthermore, since they also share similar archetypical visions of the future, they can be conveniently grouped into "scenario families" (Raskin, 2005, Global scenarios in historical; Westhoeck, 2006, A brief comparison of, and see Table 2.4}.

Table 2.6: *Comparison of SRES with other selected global scenarios using the GSG scenario structure as a framework. Adapted from Raskin et al. (2005)*

SRES 2100	WBCSD* 2050	WWV 2025	GSG 2050	GEO-3 2032	MA 2100
			Conventional Worlds		
A1	*FROG!*	*BaU*	*Market Forces*	*Markets First*	*Global Orchestration*
B1	*GeoPolity*	*Technology & economics*	*Policy Reform*	*Policy First*	*Techno Garden*
			Barbarization		
A2			*Breakdown*		
			Fortress World	*Security First*	*Order from Strength*
			Great transitions		
B2			*Eco-communalism*		*Adapting Mosaic*
	Jazz	*Lifestyle & values*	*New sustainability paradigm*	*Sustainability First*	

*WBSCD: World Business Council of Sustainable Development; WWV: World Water Vision; GSG: Global Scenarios Group; GEO-3: UNEP Global Environmental Outlook; MA: Millennium Ecosystem Assessment

Important defining features of most exercises are also described by the SRES scenarios: how fast and in what way will global integration take place (and can it be reversed) and how readily will environmental considerations be mainstreamed into economic decision-making? All exercises include scenarios that describe "conventional worlds", depicting extensions of currently strong trends, such as increased globalization. A reversed trend that, combined with low economic and high population growth and a disregard for the environment, could result in a "Fortress world", with "Barbarization" or societal breakdown being another common vision various exercises share. The quest to reach the "Great Transition" to an environmentally sustainable and equitable society is also an important future pathway described by a number of the studies, though methods of realising this goal differ widely.

All the global scenarios exercises described contain important features that can be useful for CCIAV studies. A number of the exercises (e.g. MA, WWV, GEO-3) also go one step further than the original SRES scenarios. They not only describe possible emissions under differing socio-economic pathways but also include imaginable outcomes for climate variables and their impact on ecological and social systems. This helps to illustrate risks and possible response strategies to deal with possible impacts.

2.3.2 Mitigation/stabilisation scenarios

Mitigation scenarios (also known as climate intervention or climate policy scenarios) are defined, as in TAR WG III (Morita *et al.* 2001), as scenarios that "(1) include explicit policies and/or measures, the primary goal of which is to reduce GHG emissions (e.g. carbon tax) and/or (2) mention no climate policies and/or measures, but assume temporal changes in GHG emission sources or drivers required to achieve particular climate targets (e.g. GHG emission levels, GHG concentration levels, temperature increase or sea level rise limits)." A wide variety of mitigation scenarios have been developed (see chapter 3 WG III) that differ in three principal ways: their degree of comprehensiveness, whether they take a forward or inverse approach to scenario development, and whether they are deterministic or probabilistic (see section 2.2.2.1).

2.3.2.1 Types of mitigation/stabilisation scenarios

Stabilisation scenarios are an important sub-set of inverse mitigation scenarios, describing futures in which emissions reductions are undertaken so that greenhouse gas concentrations or global average temperature change do not exceed a prescribed limit. The majority of mitigation scenarios focus on economic and technological aspects of emissions reductions (e.g. van Vuuren *et al.* 2006; Morita *et al.* 2001). The use of mitigation scenarios in regional impact assessments, discussed in section 2.2.3.8, has been less common, in large part due to a paucity of regional socio-economic, land use and other detail commensurate with a mitigated future (see discussion in Arnell *et al.* 2002).

2.3.2.2 Climate change information for mitigation scenarios

While simple climate models have been used to explore the implications for global mean temperature of stabilising CO_2 concentration at different levels (e.g. Cubasch *et al.* 2001), relatively few AOGCM runs have been undertaken using stabilisation scenarios (see chapter 10, WG I for recent examples), with few direct applications in regional impact assessments (e.g. Parry *et al.* 2001). However, although they are non-intervention scenarios, some of the SRES scenarios closely resemble mitigation scenarios because they assume policies that promote emissions reduction for reasons other than climate change. These similarities have been analysed by Swart (2002) who suggested the use of selected projections based on SRES emissions scenarios as surrogates (Table 2.7). There is no surrogate in the SRES scenarios for stabilisation at 450 ppm, one of the stabilisation levels often considered in policy analyses (Swart *et al.* 2002).

Table 2.7: *The six SRES illustrative scenarios and the stabilisation scenarios (parts per million CO_2) they most resemble (based on Swart et al. 2002).*

SRES illustrative scenario	Description of emissions	Surrogate stabilisation scenario
A1FI	High end of SRES range	Does not stabilise
A1B	Intermediate case	750 ppm
A1T	Intermediate/low case	650 ppm
A2	High case	Does not stabilise
B1	Low end of SRES range	550 ppm
B2	Intermediate/low case	650 ppm

2.4 Key conclusions and future directions

Climate change impact, adaptation and vulnerability (CCIAV) assessment has now moved far beyond its early status as a speculative, narrowly defined academic curiosity. Climate change is already underway, and the natural environment and human societies are adapting to its consequences, many of which are summarised in this volume. Since the TAR, knowledge and uncertainty in many areas of CCIAV assessment have changed:

- *Uncertainty has been reduced*. Inter-model differences in projected climate have narrowed (in most regions for temperature and in some regions for precipitation); confidence in projections of some climate extremes has increased. Current impacts and their attribution are becoming better quantified.

- *Uncertainty has increased*. The quantified range of climate sensitivity has increased from previous IPCC assessments. The integration of multiple drivers into integrated models increases quantified uncertainties (see below).

- *Known uncertainties have become better quantified*. The interaction of climate with other changes (e.g. population, the economy, technology, land-use change), their integrated impacts and feedbacks of these impacts to the climate system have been better quantified. Many of these changes lead to an increase in quantified uncertainty.

- *Uncertainties are being better managed in CCIAV assessments*. The development of risk assessment, and improved adaptation and vulnerability assessments, all involving stakeholders, are processes designed to manage uncertainty.

Policy makers need to know how best to respond to a changing climate, and this potentially places demands on the CCIAV community to provide:

- good quality information on what impacts are occurring now, their location and the groups or systems most affected;
- reliable estimates of impacts to be expected due to natural climate variability and projected climate change;
- early warning of potentially alarming or irreversible impacts;
- quantification of different risks and opportunities associated with a changing climate;
- effective approaches for identifying and evaluating both existing and prospective adaptation measures and strategies;
- credible methods of costing different outcomes and response measures;
- an adequate basis to compare and prioritise alternative response measures, including both adaptation and mitigation.

To meet these demands, future research efforts need to address a set of fundamental scientific, technical, and information gaps. These include:

- *Developing methods and tools appropriate for regional and local application.* An increasing focus on adaptation to climate change at local scales requires new methods, scenarios, and models to address emerging issues. New approaches are also reconciling scale issues in scenario development, such as the nesting of scenarios at different scales.

- *Cross-sectoral assessment*s. Limited by data and technical complexity, most CCIAV assessments have so far focused on single sectors. However, impacts of climate change on one sector will have implications, directly and/or indirectly, for others, some adverse and some beneficial. To be more policy relevant, future analyses need to account for the interactions between different sectors, particularly at national level.

- *Use of local knowledge.* The knowledge of local communities, especially traditional knowledge from indigenous populations (as contrasted with modern, formal methods of learning and imparting knowledge), represents an important, yet currently largely under-used resource for CCIAV assessment.

- *Collection of empirical knowledge from past experience*. Experience gained in dealing with climate-related natural disasters, documented using both modern methods and traditional knowledge, can be particularly helpful in understanding the coping strategies and adaptive capacity of vulnerable communities. This applies to climate events such as droughts and floods as well as longer-term trends in mean climatic conditions

- *Effective communication of the risks and opportunities of climate change to policy makers and the public.* Awareness-building and dissemination of research results is essential for many aspects of CCIAV assessments, in particular for engaging key stakeholders and for gaining trust and credibility among the public as a whole.

- *Use of storylines in scenario development.* Improved methods of interpreting and quantifying storylines that limit subjectivity and promote reproducibility are needed, especially at regional and local scales.

- *Consistent approaches in relation to scenarios in other assessments.* Climate change is only one issue of many that concern policy makers. The integration of climate-related scenarios into those widely accepted and used by other international bodies is needed (e.g. as part of mainstreaming). The interchange of ideas and information between different research and policy communities will strongly improve scenario quality, usage and acceptance.

- *Improved scenarios for poorly specified indicators*. CCIAV outcomes are highly sensitive to assumptions about factors such as future technology and adaptive capacity that at present are poorly understood. For instance, the theories and processes of technological innovation and its relationship to other indicators such as education, wealth and governance, requires closer attention, as do studies of the processes and costs of adaptation.

- *Internally-consistent scenarios.* The increasing diversity of scenarios being applied in CCIAV studies has highlighted shortcomings in how interactions between key drivers of change are represented. For example, SRES did not account for the effects of climate change on land cover, pointing to a clear need for more integrated treatment of interactions and feedbacks involving ecosystems, hydrology, climate and land cover. Similarly, socio-economic and technological scenarios need to account for the costs and other ancillary effects of both mitigation and adaptation actions, which at present are rarely considered.

- *Provision of improved climate predictions for near-term planning horizons.* Many of the most severe impacts of climate change are manifest through extreme weather events. Resource planners increasingly need reliable information, years to decades ahead, on the risks of adverse weather events at the scales of river catchments and communities.

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