A

Prediction of the regional distribution of climate change and associated impact studies, including model validation studies

The work carried out under this task is discussed under the headings of:

Systematic observations to identify climate change consequences

Preliminary guidelines for assessing impacts of climate change

I Systematic observations to identify climate change consequences

Authors:
Yu A Izrael (Russia)
I Nazarov (Russia)

I Systematic observations to identify climate change consequences

1 Introduction

In accordance with the decision of the IPCC (Fifth Session, Geneva, 13–15 March 1991), IPCC Working Group II was given the task of identifying the regional/national components of systematic observation programs which could be used for climate change impact studies. An Expert Group, chaired by Professor Yu Izrael with representatives from Argentina, Canada, France, India, Japan and Norway, was established at the fourth session of WGII to carry out this task.

This report records the preliminary findings of this Expert Group. It comprises a summary of potential impacts of climate change as identified by the IPCC (providing the framework for required systematic observations) and a preliminary assessment of the required elements of systematic observation programs to support research on the environmental impacts and socioeconomic consequences of climate change.

2 Potential impacts of climate change

Working Group I of the IPCC has prepared an authoritative and strongly supported statement on climate change. The IPCC Scientific Assessment identifies those aspects of climate change issues of which the scientific community is relatively certain and also those for which uncertainties still exist. Uncertainties in the predictions of climate change, particularly those concerning timing, magnitude and regional patterns of climate change, are associated with imperfect knowledge of:

- future rates of man-made emissions;
- how these will change the atmospheric concentrations of greenhouse gases (GHG); and
- the response of climate to these changed concentrations.

It is clear from the IPCC Impacts Assessment, however, that the potential implications of climate change, under doubled CO_2 scenarios, are likely to be far-reaching. Climate change is likely to result in:

- changes in the amount of precipitation and in soil moisture;
- changes in the boundary zones of vegetation, particularly in northern, high-latitude areas (tundra and boreal forest areas may be significantly reduced);
- a significantly altered hydrological regime;
- increased annual runoff at high latitudes;
- altered agricultural potential, both for areal extent of arable land and the crop types;
- changes in the aerial extent and mass of glaciers;
- decreases in glaciers over Antarctica, Greenland and the Arctic islands;
- reduced volume of high-mountain glaciers;
- degradation of permafrost;
- sea-level rise, with implications for coastal and island ecosystems and structures; and
- hydrophysical, hydrochemical and biological process of the oceans and seas such as ice regime, intensity of bioproduction, redistribution of productive ocean zones, and changes in the formation of commercial fish stock.

The IPCC Impacts Assessment concluded that these impacts will not necessarily be steady, that surprises cannot be ruled out, and that the severity of the impacts will depend to a large degree on the rate of climate change.

The IPCC Impacts Assessment also concluded that uncertainties exist in our knowledge of the environmental impacts and socioeconomic consequences of climate change, particularly at the regional level and in areas most vulnerable to climate change. These uncertainties are to a large extent related to a lack of available supportive data and information at the regional level. To deal with these deficiencies, national, regional and international efforts directed at initiating and maintaining integrated systematic observation programs for terrestrial and marine (managed and unmanaged) ecosystems are required.

Tables 1 and 2 list physical, chemical and biological elements which should be included in systematic observation programs directed at providing an integrated set of data and information for impact assessments.

3 Existing systematic observation programs

At present, international organisations such as UNEP, WMO, IOC and UNESCO have a number of programs to monitor physical, chemical and biological elements. Some of these, such as UNEP's Global Environmental Monitoring System (GEMS) were developed in the mid 1970s, with a number of improvements having taken place since. The Climate System Monitoring (CSM) Project of the World Climate Data Programme (WCDP) was initiated in 1984 and has been designed to provide information on the state of the climate system and diagnostic insights into significant large-scale anomalies of regional and global consequence.

The Second World Climate Conference (1990) stressed the urgent need to develop a Global Climate Observing System (GCOS), which would provide comprehensive information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties and atmospheric, oceanic, hydrologic, cryospheric, and terrestrial processes. GCOS is intended to meet the needs for:

- climate system monitoring;
- climate change detection and systematic observations of the responses to climate change, especially in terrestrial ecosystems and mean sea-level;
- data for application to national economic development; and
- research towards improved understanding, modelling and prediction of the climate system.

GCOS will build, as far as possible, on existing operational and scientific observation, data management and information distribution systems, and on further enhancement of these systems. GCOS is to be based upon improved World Weather Watch systems and the Integrated Global Ocean Services System, data communication and other infrastructures necessary to support operational climate forecasting and the establishment of a Global Ocean Observing System for physical, chemical and biological measurements. In addition, it will require the maintenance and enhancement of programs systematically observing other key components of the climate system, such as the distribution of important atmospheric constituents (eg the Global Atmospheric Watch which includes BAPMoN and G0305), terrestrial ecosystems (including the International Geosphere-Bioshpere Programme), as well as clouds, the hydrological cycle, the earth's radiation budget, ice sheets and precipitation over the oceans (including the World Climate Research Programme).

The Climate Change Detection Project is a recent initiative; begun in 1991, its primary objective is to provide regularly updated estimates of climate change on a global and regional basis, and an assessment of the relative importance of these changes. In time, it is hoped that the assessments will enable the delineation of any climate change signal from the background noise of natural climate variability.

There is a number of international organisations implementing systematic observation programs that could be used to support efforts directed at identifying ecological impacts and socioeconomic consequences of climate change, including:

- an initial UNEP program for observing terrestrial ecosystems with observations extending on either side of the present boundaries of plant zones for early detection of possible shifts of these boundaries;
- the Arctic Monitoring and Assessment Programme (AMAP), now under development, which will monitor and assess background pollution of all major arctic environments, and includes systematic observations of CO_2 and other radiatively active gases; AMAP will also assess fluctuations of the ozone layer, and compare variations in regional climates with those globally.
- a Global Ocean Observing System (GOOS) which is being developed to meet the needs of global climate research, monitoring and prediction; it will be based on long-term systematic observations of physical, chemical and biological processes of the World Ocean; implementation will be phased-in over the next decade or two, and will provide for the description of, for example, the global circulation of heat and water in the ocean, and their exchange with the atmosphere.

Other international systematic observation programs include those of the Long Term Ecological Reserves and the Biospheric Reserves of the Man and the Biosphere (MAB) programme. National environmental systematic observation programs (related to wider international efforts) such as the UK Environmental Change Network (ECN), Chinese Ecological Research Network (CERN) and Scandinavian networks also exist. These programs, while not geared specifically to climate change impacts, contain some elements which are relevant to that purpose.

4 Recommendations

In spite of recent improvements, present programs for systematic observations of the atmosphere, land surfaces and oceans are, for the most part, insufficient to meet the requirements of data to support research directed at identifying environmental impacts and socioeconomic consequences of climate change. They are also insufficient to support efforts directed at achieving sustainable national economic and social development and to support research towards improved understanding, modelling and prediction of the climate system (eg WCRP and IGBP). Future enhancements of these programs should be directed at increasing their effectiveness and efficiency. These enhancements, therefore, will need to include an appropriate mix of both traditional (on-site) and remote sensing technologies. In particular, an enhanced satellite observation system will be essential to observe large and remote areas systematically, including the oceans, as well as sparsely populated arid and semi-arid areas of the world.

The existing programs identified above are but a few examples that can provide the required data for the assessment of regional climates and ecosystems. Notable deficiencies in areal coverage of these programs include tropical forests, savanna, oceans, polar, mountainous (particularly in developing countries) and arid and semi-arid regions of the globe. The terrestrial areas where gaps exist are largely unmanaged ecosystems and many of these are undergoing major upheaval and changes as a consequence of human interference and growing populations. Data information that could be used to increase understanding of the implications of climate change for these ecosystems and associated human systems is of particular importance.

There are two strategies that could be adopted for systematic observation programs directed at providing the data and information required for identifying environmental impacts and socioeconomic consequences: long-term integrated systematic observations of the state of terrestrial and marine (managed and unmanaged) ecosystems along with associated social and economic parameters; or systematic observations of individual physical, biological and ecological parameters as well as associated social and economic parameters.

In developing the appropriate strategy, use should be made of indices which clearly are indicative of changes in climatic factors, for example, changes in the spatial or temporal boundaries of vegetation, species distribution, and snow or ice cover, and changes in the level of the oceans.

The establishment and maintenance of supportive data and information systems (including the necessary archives) at the national, regional and international levels will be major undertakings. There are deficiencies in the state of systematic observational systems and related data management and analyses capabilities in many countries; these deficiencies are particularly acute within developing countries. The deficiencies can be met by upgrading networks and equipment, and the skills of technicians and scientists.

The availability of coincident and supportive social and economic data and information is essential for climate change impact assessments. Climate change can have both direct impacts and indirect impacts (eg biological or physical responses to climate change which, in turn, lead to socioeconomic impacts on affected human systems). To identify a broader understanding of these impacts, it is important that in addition to and coincident with physical and biological observations, that social and economic parameters/indices also be collected and archived. Having available data and information on the responses of social and economic systems to climatic changes and/or dependent physical and biological changes will enhance understanding and quantification of the interaction processes and will thereby provide a sounder basis for formulating meaningful national response strategies, including adaptation strategies. Table 3 is a preliminary attempt to present the relationships between the required data elements.

Future work in defining the data and information needs to support environmental impacts and socioeconomic consequences activities should be undertaken by the IPCC based on this preliminary analysis and IPCC development of guidelines for climate change impact assessments. Means and modalities of implementation through which efficiency of supportive systematic observation programs can be increased (eg sharing among relevant international and national networks) need to be examined further and, therefore, should be an essential component for subsequent work. Subsequent assessments should also include identifying general principles to guide systematic observation program development so that the resulting programs could support research on environmental impacts and socioeconomic consequences of climate change.

Table 1. Provisional listing of climatic system elements

Climate system state characteristics	*Priority*
1. Atmosphere	
1.1. Surface atmosphere	
– surface air temperature (SAT)	*****
– precipitation over land	*****
– precipitation over ocean	**
– air humidity	*
– sea-level pressure	***
1.2. Free atmosphere	
– air temperature	****
– humidity	*
– wind	***
– isobaric surface geopotential	****
1.3. Circulation and synoptic-climatic systems	
– energy	***
– heat, moisture and momentum transport	**
– atmosphere action centres (AAC)	***
– circumpolar vortex	****
– altitude frontal zone	****
– cyclones and anticyclones	****
– circulation indices	****
– blocking indices	****
– monsoons	*
– tropical cyclones	*
– intratropical convergence zone, tropical shower	*
– El-Niño/southern oscillation	***
– telecommunication indices	**
– quasibiannual cycling in the equatorial stratosphere	**
– stratospheric warming	*
– intraseasonal 30–60 day-variations	*
1.4. Extreme events	
– droughts and supermoisture periods	****
– severe winters	****
– floods	*
1.5. Atmosphere composition	
– GHG concentrations (CO_2 etc)	****
– aerosol	***
– ozone	***
1.6. Radiation and cloudiness	
– cloudiness	****
– albedo	****
– atmosphere transparency	****
– direct solar radiation	****
– scattered radiation	***
– total radiation	***
– radiation balance	***
– outgoing long-wave radiation	****
2. Atmosphere–ocean interface	
– sea surface temperature	*****
– salinity	***
– heat, moisture and momentum fluxes	**
– wind velocity	**
– wave information	*
– sea-level	*
3. Atmosphere–land interface	
– soil temperature	**
– soil moisture	***
– heat, moisture and momentum fluxes	*
– lakes (inland waterbodies)	*
4. Abyssal ocean	
– water temperature	****
– salinity	***
– current	*
5. Cryosphere	
– snow cover	****
– continental ice	***
– permafrost	*
– sea ice	****
– soil moisture	****
6 Biosphere, ecological effects	
– biomass	–
– desertification, deforestation	–
– yield	–
– phenological parameters	***
7. Geophysical and astronomic factors	
– Earth's rotation rate	***
– poles movement	–
– solar and geomagnetic activity	–
– volcanoes	–

Priorities denoted through:

*****	highest: basic component of observation program;
****	should be component of initial observing program;
***	should be included at the subsequent stages of development;
**	possible element for inclusion to improve the observation program;
*	other author's reference;
–	need for further assessment to determine priority.

Table 2. Provisional list of elements

1. Impact of increased atmospheric CO_2 and climate change on terrestrial ecosystems.

   1.1. Plant response to increased CO_2 carbon budget.
   Carbon budget
   Interaction between CO_2 and temperature and natural environment stress
   Plant–plant interaction
   Vegetation–animal interaction
   Ecosystem response to increased CO_2

   1.2. Ecosystem response to changed temperature and humidity
   Carbon budget
   Phenology and aging
   Biological diversity
   Health and productivity
   Vegetative community composition
   Models of ecosystems response to climate change
   Modelling of global response based on vegetation–climate interaction
   Palaeo-ecological evidence

2. Impact of changed terrestrial ecosystems on climate system
   Deforestation
   Afforestation and reforestation
   Eutrophication and pollution
   Reforestation/afforestation as means of reducing atmospheric CO_2 concentrations

3. Methane and nitrous oxide fluxes

4. Ecosystem change and regional hydrological cycles

5. Marine ecosystems
   Community responses
   Land–ocean interactions
   Atmosphere–ocean interactions
   Carbon system and biological pump

Table 3. Provisional list of elements to be included in systematic observation programs to support environmental impacts and socioeconomic consequences research

Environmental impacts
Socioeconomic consequences
Observational elements

I. Changes in the boundaries of natural climatic zones

1. Changes in the structure of agriculture productivity;
   Areas under various agricultural crops;
   Areas of grazing;
   Areas of desertification;
   Yield and incomes associated with different crops;
   Disease and pest occurrences;
   Rural vs Urban populations and incomes (trends);
   Emissions and sinks of GHGs due to the loss and accumulation of carbon in soils, methane emissions by livestock, decomposition of nitrogen fertilisers.

2. Changes in the structure of forestry
   Productivity and health of forests;
   Areas under various forest species;
   Fire, pest and disease occurrence;
   Demographic and income trends for forest communities;
   Emissions and sinks of GHG due to accumulation of carbon in soils and forest management practices.

3. Changes in the structure of territories and human activities as a result of permafrost degradation
   Areas with permafrost;
   Areas of water occurring within permafrost zones;
   Areas affected by permafrost degradation,
   Changes in areas used as natural habitats;
   Disruption of human settlements, infrastructure, and oil and gas pipelines;
   Costs of refurbishing or relocation of human structures;
   Emission of carbon dioxide and methane as a result of permafrost degradation.

4. Changes in the structure of natural ecosystems impact on biological diversity
   Productivity and health of natural ecosystems and their component species;
   Areas occupied by plant and animal species;
   Economic implications (eg recreation, tourism and indigenous crafts).

II. Sea-level rise

1. Changes in human settlements and related infrastructure
   Areas of island and coastal flooding;
   Disruption of human settlements;
   Disruption of transport and other infrastructure;
   Productive area of land loss;
   Number of people relocated and associated costs;
   Costs of relocating, protection and refurbishing of water, sewage and transport systems.

2. Changes in associated natural ecosystems
   Area and number of beach areas impact;
   Area and number of coastal ecosystems impacted;
   Areas lost and/or associated protection costs.

II Preliminary guidelines for assessing impacts of climate change

Expert Group for Guidelines of IPCC

Co-chairmen
S Nishioka (Japan)
M L Parry (UK)

Authors
T R Carter (UK)
M L Parry (UK)
H Harasawa (Japan)
S Nishioka (Japan)

Experts
Dr O F Canziani (Argentina)
Dr W J McG Tegart (Australia)
H Kolb (Austria)
R B Street (Canada)
M Sanwal (India)
T Morita (Japan)
A M Lopez (Peru)
L Amadore (Philippines)
A Yakovlev (Russia)
A J Al-Saati (Saudi Arabia)
M Beniston (Switzerland)
S Prasith-rathsint(Thailand)
I M Goklany (USA)
J Schefter (USA)
J D Scheraga (USA)
E Z Stakhiv (USA)
N Thi Loc (Vietnam)
W Soambroek (FAO)
Bo R Doos (IIASA)

II Preliminary guidelines for assessing impacts of climate change

1 Objectives

1.1 Purpose of this report

In August 1991, Working Group II, in its Fourth Plenary, agreed on the importance of developing guidelines for assessing the impacts of climate change. This report is a preliminary statement on approaches to climate impact assessment, with particular emphasis on assessing the possible impacts of future change in climate due to the enhanced greenhouse effect. There is little experience with evaluating the social and economic impacts of climate change, so the report deals with these only cursorily. It is desirable that future versions address these topics in more detail. The report does not aim to prescribe a single preferred method, but provides an analytical outline that comprises a number of steps. A range of methods is identified at each step. Where possible, the merits and drawbacks of different methods are briefly discussed, with some suggestions on their selection and use.

1.2 Purpose of climate impact assessment

There are many reasons for conducting climate impact assessments, but the ultimate objective of such assessments is to provide the public and policy makers with estimates of the extent to which climate change may affect the environment and human activities and result in changes in social and economic welfare. The role of assessments is to assist in the development and evaluation of alternative strategies for managing human activities under changeable climatic conditions.

1.3 Methods of assessment

A general framework for conducting a climate impact assessment is shown in Figure 1. It consists of the following steps:

- definition of the problem;
- selection of the method;
- testing the method;
- selection of scenarios;
- assessment of impacts;
- evaluation of adjustments; and
- consideration of policy options.

The first five steps can be regarded as common to most assessments. The last two steps may be included in some studies. The steps are consecutive (single arrows), but the framework also allows for the redefinition and repetition of some steps (double arrows). At each step, a range of study methods is available. These are described and evaluated in the following sections. For reasons of brevity, however, only the essence of each method is introduced, along with references to sources of further information.

2 Definition of the problem

A necessary first step in undertaking a climate impact assessment is to define precisely the nature and scope of the problem to be investigated. This usually involves identifying the goals of the assessment, the sector(s) of interest, the spatial and temporal scope of the study, the data needs, and the wider context of the work.

O?'?
O?'?1 DEFINE PROBLEM
I?'‹O?'
O?'>?
2 SELECT METHOD
I?'<O?'
O?'>?
3 TEST METHOD/SENSITIVITY
I?'<O?'
O?'>I?
,I?4 SELECT SCENARIOS
I?'< <O?'
O?'O?'
O?'>?
ASSESS BIOPHYSICAL IMPACTS
5 --
ASSESS SOCIOECONOMIC IMPACTS
I?'<O?'
O?'>?
I?'?6 EVALUATE ADJUSTMENTS
I?'<O?'
O?'>?
I?'?7 POLICY OPTIONS
I?'O?'

Figure 1: Seven steps of climate impact assessment

2.1 Goals of the assessment

Some general reasons for conducting an assessment were outlined in Section 1.2. Once the general goals are clearly defined, it is important to be precise about the specific objectives of a study, as these will affect the conduct of the investigation. For example, an assessment of the hydrological impacts of future climatic change in a river catchment would have quite different requirements for data and expertise if the goal is to estimate the capacity for power generation, from those required to predict changes in agricultural income as a result of changes in the availability of water for irrigation.

2.2 *Sector to be studied*

The sector(s) to be assessed determine, to a large degree, the type of researchers who will conduct the assessment, the methods to be employed and the data required. Studies can focus on a single sector or activity (eg agriculture, forestry, energy production or water resources), several sectors in parallel but separately, or several sectors interactively.

2.3 *Study area*

The selection of a study area is guided by the goals of the study and by the constraints on available data. Some options are reasonably well defined, including governmental units, geographical units, ecological zones, and climatic zones. Other options requiring more subjective selection criteria include sensitive regions and representative units. Sensitive regions (eg tree line, coastal zones, ecological niche, marginal community) are selected because of their inherent sensitivity to external forcing such as climate change, and are where changes in climate are likely to be felt first and with the greatest effect. Representative units may be chosen according to any of the above criteria, but in addition are selected to be representative of that regional type and thus amenable to generalisation. For instance, a single river catchment may serve as a useful integrating unit for considering impacts of climate on water resources, agriculture, forestry, recreation, natural vegetation, soil erosion and hydro-electric power generation. Information from this type of study may then be applicable to other similar catchments in a region.

2.4 *Time frame*

The selection of a time horizon for study is also influenced by the goals of the assessment. For example, in studies of industrial impacts the planning horizons may be 5–10 years, investigations of tree growth may require a 100-year perspective, while considerations of nuclear waste disposal may accommodate time spans of well over 1000 years. However, as the time horizon widens, the ability to project future trends accurately declines rapidly. Most climate projections rely on general circulation models (GCMs), and are subject to great uncertainties over all projection periods. The only prediction horizon of proven reliability is that provided by weather forecast models extending for days or, at most, weeks into the future. In general, few credible projections of socioeconomic factors such as population, economic development and technological change can be made for periods exceeding 15–20 years.

2.5 *Data needs*

The availability of data is probably the major limitation in most impact studies. The collection of new data is an important element of some studies, but most rely on existing sources. Thus, before embarking on a detailed assessment, it is important to identify the main features of the data requirements, namely the variables for which data are needed, the time period, spatial coverage and resolution of the required data, the sources and format of the data and their quantity and quality, and the data availability, cost and delivery time.

2.6 *Wider context of the work*

Although the goals of the research may be quite specific, it is still important to place the study in context with respect to, first, similar or parallel studies that have been completed or are in progress; second, the political, economic and social system of the study region; and third, other social, economical and environmental changes occurring in the study region. Consideration of these aspects may assist policy makers in evaluating the wider significance of individual studies.

3 Selection of the method

A variety of analytical methods can be adopted in climate impact assessment, ranging from qualitative descriptive studies, through more diagnostic and semi-quantitative assessments, to quantitative and prognostic analyses. Any single impact assessment may contain elements of one or more of these types. Four general methods can be identified: experimentation, impact projections, empirical analog studies and expert judgment.

3.1 Experimentation

In the physical sciences, a standard method of testing hypotheses or of evaluating processes of cause and effect is through direct experimentation. An example is the behaviour of plant species under controlled conditions of climate and atmospheric composition. In the context of climate impact assessment, however, experimentation has only a limited application. Clearly it is not possible physically to simulate large-scale systems such as the global climate, nor is it feasible to conduct controlled experiments to observe interactions involving climate and human-related activities. Only where the scale of impact is manageable, the exposure unit (ie anything exposed to a given climate event) measurable, and the environment controllable, can experiments be usefully conducted.

The information obtained from experiments, while useful in its own right, is also invaluable for calibrating models which are to be used in projecting impacts of climatic change (see below).

3.2 Impact projections

One of the major goals of climate impact assessment, especially concerning aspects of future climatic change, is the prediction of future impacts. A growing number of model projections has become available on how global climate may change in the future as a result of increases in greenhouse gas (GHG) concentrations (eg see IPCC 1990a). A main focus of much recent work has been on impact projections, using an array of mathematical models to extrapolate into the future. In order to distinguish them from 'climate models', which are used to project future climate, the term 'impact model' has now received wide currency. First-order effects of climate are usually assessed using biophysical models, second- and higher-order effects using a range of biophysical, economic and qualitative models. Finally, attempts have also been made at comprehensive assessments using integrated systems models.

3.2.1 Biophysical models

Biophysical models may be used to evaluate the physical interactions between climate and an exposure unit. There are two main types: empirical-statistical models and simulation models. Empirical-statistical models are based on the statistical relationships between climate and the exposure unit. Simulation models make use of established physical laws and theories to express the dynamics of the interactions between climate and an exposure unit. The use of these in evaluating future impacts is probably best documented for the agricultural sector (eg see WMO 1985) and the hydrological aspects of water resources (eg WMO 1988) but the principles can easily be extended to other sectors.

3.2.2 Economic models

Economic models of several types can be employed to evaluate the implications of first-order impacts for local and regional economies. Although their application in climate impact assessment has been advocated for many years, few have actually been used. The main classes of models are microsimulation models, market models and economy-wide models.

3.2.3 Integrated systems models

Integrated systems models represent an attempt to combine elements of the modelling approaches described above into a comprehensive model of a given regionally or sectorally bounded system. No fully integrated systems model has yet been developed, but a partially integrated approach has been achieved in a few recent studies (eg Rosenberg and Crosson 1991). All of these involved the linking of individual models. A general equilibrium modelling approach to environmental and economic interactions is necessary for assessments of the direct and indirect effects and benefits and costs of potential climate. Research to develop such models has become a priority in some regions.

3.3 Empirical analog studies

Observations of the interactions of climate and society in a region can be of value in anticipating future impacts. The most common method employed involves the transfer of information from a different time or place to an area of interest to serve as an analogy.

Three types of analogy can be identified: historical analogies, regional analogies of present climate and regional analogies of future climate. Historical analogies use information from the past as an analog of possible future conditions. Regional analogies of present climate refer to regions having a similar present-day climate to the study region, where the impacts of climate on society are judged also likely to be similar. If these conditions are fulfilled, then it may be possible to conduct assessments whereby a target case is compared with a control case, the target area experiencing abnormal weather but the control normal conditions.

Regional analogies of future climate work on the same principle as analogies for present-day climate, except that here the analyst attempts to identify regions having a climate today which is similar to that projected for the study region in the future. The analog region may thus provide indicators of how the landscape and human activities might change in the study region in the future.

3.4 *Expert judgment*

A useful method of obtaining a rapid assessment of the state of knowledge concerning the effects of climate on given exposure units is to solicit the judgment and opinions of experts in the field. Literature is reviewed, comparable studies identified, and experience and judgment used in applying all available information to the current problem. The use of expert judgment can also be formalised into a quantitative assessment method by classifying and then aggregating the responses of different experts to a range of questions requiring evaluation. Probability judgments from experts have been used to assess climatic change and its possible impacts (NDU 1978, 1980), but there have been problems of questionnaire design and delivery, selection of representative samples of experts, and the analysis of experts' responses (Stewart and Glantz 1985).

4 Testing the method

Following the selection of the assessment methods, it is important that these are thoroughly tested in preparation for the main evaluation tasks. There are many examples of studies where inadequate preparation has resulted in long delays in obtaining results. Three types of analysis may be useful in evaluating the methods: feasibility studies, data acquisition and compilation, and model testing.

4.1 *Feasibility studies*

Feasibility studies usually focus on a subset of the study region or sector to be assessed. Such case studies can provide information on the effectiveness of alternative approaches, of models, of data acquisition and monitoring, and of research collaboration.

4.2 *Data acquisition and compilation*

Data must be acquired both to describe the temporal and spatial patterns of climate change and their impacts and to develop, test and calibrate predictive models. Data collection may rely on existing information obtained and compiled from different sources, or require the acquisition of primary data, through survey methods, direct measurement or monitoring.

4.3 *Model testing*

The testing of predictive models is, arguably, the most critical stage of an impact assessment. Most studies rely almost exclusively on the use of models to estimate future impacts. Thus, it is crucial for the credibility of the research that model performance is tested rigorously. Standard procedures should be used to evaluate models, but these may need to be modified to accommodate climate change. Two main procedures are recommended: sensitivity analysis and validation. Sensitivity analysis evaluates the effects on model performance of altering its structure, parameter values, or values of its input variables. Extending these principles to climatic change requires that the climatic input variables to a model be altered systematically to represent the range of climatic conditions likely to occur in a region. Validation involves the comparison of model predictions with real world observations to test model performance. The validation procedures adopted depend to some extent on the type of model being tested. For example, the validity of a simple regression model of the relationship between temperature and grass yield would ideally be tested on data from additional years not used in the regression. Here, the success of the model is judged by its outputs, namely the ability to predict grass yield. Conversely, a simulation model might estimate grass yield based on basic growth processes, which are affected by climate, including temperature. Here, the different internal components of the model (such as plant development and water use) as well as predicted final yield each need to be compared with measurements.

An additional problem in considering climate change concerns the requirement in many models to extrapolate model relationships outside their normal range of application. Model validation and sensitivity analysis should serve to define the level of confidence that can be attached to such extrapolations.

5 Selection of the scenarios

Impacts are estimated as the differences between two states: environmental and socioeconomic conditions expected to exist over the period of analysis in the absence of climate change and those expected to exist with climate change. It is important to recognise that the environment, society and economy are not static. Environmental, societal and economic change will continue, even in the absence of climate change. In order to estimate accurately the environmental and socioeconomic effects of climate change, it is necessary to separate them from unrelated, independent, environmental and socioeconomic changes occurring in the study area. Thus, it is necessary first to develop baselines that describe current climatological, environmental and socioeconomic conditions. Then it is necessary to project environmental and socioeconomic conditions over the study period in the absence of climate change. These baseline conditions are then compared, after impact projections, with environmental and socioeconomic conditions under climate change. Thus, development of baselines accurately representing current and projected conditions in the absence of climate change is a key and fundamental step in assessment.

5.1 Establishing the present situation

In order to provide reference points with which to compare future projections, three types of 'baseline' conditions need to be specified: the climatological, environmental and socioeconomic baselines.

5.1.1 Climatological baseline

The climatological baseline is usually selected according to the following criteria:

- the representativeness of the present-day or recent average climate in the study region.
- the duration to be long enough to encompass a range of climatic variations, including a number of significant weather anomalies (eg a severe drought or an extremely cool season). Such events are of particular use as inputs to impact models, providing a means to evaluate the impacts of the extreme range of climatic variability experienced at the present day.
- the period covered to have adequate local climatological data available, in terms both of the number of different variables represented and of the geographical coverage of source stations.
- the date employed to be of sufficient quality for use in evaluating impacts.

A popular climatological baseline is a 30-year 'normal' period as defined by the World Meteorological Organization (WMO). The current standard WMO normal period is 1961–90. While it would be desirable to provide some consistency between impact studies by recommending this as an appropriate baseline period to select in future assessments, there are also difficulties in doing so. Several points illustrate this.

First, this period coincides conveniently with the start of the projection period commonly employed in estimating future global climate (for example, the IPCC projections begin at 1990 (IPCC 1990a)). On the other hand, most GCMs providing regional estimates of climate are initialised using observed climatologies taken from earlier periods. Second, the availability of observed climatological data, particularly computer-coded daily data, varies considerably from country to country, thus influencing the practical selection of a baseline period. Third, it is often desirable to compare future impacts with the current rather than some past condition. However, while it can be justifiably assumed in some studies that present-day human or natural systems subject to possible future climate change are reasonably well adapted to the current climate, in other assessments this will not be the case. Finally, there is the problem that the more recent periods (particularly during the 1980s) may already include a significant global warming 'signal', although this signal is likely to vary considerably between regions and be absent from some.

Climatological data from the baseline period are used to describe the present climate of the study region and provide inputs for impact models. In the latter case, several methods are used. Some models produce estimates for periods of a year or less (eg crop growth models). These can generally use the original climatological station data for years within the baseline period.

Other models run over long periods of decades or centuries (eg soil erosion models). One option here is to select a long baseline period, but lack of data usually precludes this. An alternative is to use the baseline data on a repeating basis. For example, year 1 in a 30-year baseline could be used as years 1, 31, 61 and 91 of a 100-year simulation. One problem with this method is that chance trends or cycles in the baseline climate are then repeated in a manner that may be unrealistic over the long term.

To overcome some of the problems of data sparsity and of long-term cycles, some modelling studies now employ weather generators. These simulate daily weather at a site randomly, based on the statistical features of the observed climate. Once developed, they can produce time series of climatological data having the same statistical description as the baseline climate, but extending for as long a period as is required (see Hutchinson 1987).

5.1.2 Environmental baseline

The environmental baseline refers to the present state of other, non-climatic environmental factors, that affect the exposure unit. It can be defined in terms of fixed or variable quantities. A fixed baseline is often used to describe the average state of an environmental attribute at a particular point in time. Examples include: mean atmospheric concentration of carbon dioxide in a given year, mean soil pH at a site, or location of natural wetlands. A notable case is the mean sea-level, which is expected to rise as a result of future climate change. Furthermore, a fixed baseline is also required for specifying the 'control' in field experiments (eg of CO_2 effects on plant growth). A representation of variability in the baseline may be required for considering the spatial and temporal fluctuations of environmental factors and their interactions with climate. For example, in studies of the effects of ozone and climate on plant growth, it is important to have information both on the mean and on peak concentrations of ozone under present conditions.

5.1.3 *Socioeconomic baseline*

The socioeconomic baseline describes the present state of all the non-environmental factors that influence the exposure unit. The factors may be geographical (eg land use, communications), technological (eg pollution control, crop cultivation), managerial (eg forest rotation, fertiliser use), legislative (eg water use quotas, air quality standards), economic (eg commodity prices, labour costs), social (eg population, diet), or political (eg land set aside, land tenure). All of these are liable to change in the future, so it is important that baseline conditions of the most relevant factors are noted.

5.2 *Time frame of projections*

A critical consideration for conducting impact experiments is the time horizon over which estimates are to be made. Three elements influence the time horizon selected: the limits of predictability, the compatibility of projections and whether the assessment is continuous or considers discrete points in time.

5.2.1 *Limits of predictability*

The time horizon selected depends primarily on the goals of the assessment. However, there are obvious limits to the ability to project into the future. Climate projections, since they are a key element of climate impact studies, define the outer limit on impact projections. GCM estimates seldom extend beyond about 100 years, owing to the large uncertainties attached to such long-term projections and to constraints on computational resources. This fixes an outer horizon at about 2100. Many climate projections are for a radiative forcing of the atmosphere equivalent to a doubling of CO_2 relative to pre-industrial levels. This could occur as early as 2020 (IPCC 1990a), which could be used as a mid-term projection horizon.

Of course, long time-scale projection periods may be wholly unrealistic for considering some impacts (eg in many economic assessments). On the other hand, if the projection period is too short, then the estimated changes in climate and their impacts may not be easily detectable, making it difficult to evaluate policy responses.

5.2.2 *Compatibility of projections*

It is important to ensure that future climate, environment and socioeconomic projections are mutually consistent over space and time. A common area of confusion concerns the relative timing of CO_2 increase and climate change. Thus, it should be noted that an equivalent $2xCO_2$ atmosphere does not coincide in time with a $2xCO_2$ atmosphere, and there are time lags in the climate response to both of these.

5.2.3 *Point in time or continuous assessment*

A distinction can be drawn between considering impacts at discrete points in time in the future and examining continuous or time-dependent impacts. The former are characteristic of many climate impact assessments based on $2xCO_2$ scenarios. These consider impacts occurring at the time specified by the scenario climate (a time that is often not easy to define and which usually varies from place to place). They ignore any effects occurring during the interim period that might influence the final impacts. They also make it very difficult to assess rates of change and thus to evaluate adaptation strategies.

In contrast, transient climatic scenarios allow time-dependent phenomena and dynamic feedback mechanisms to be examined and socioeconomic adjustments to be considered. Nevertheless, in order to present results of impact studies based on transient scenarios, it is customary to select 'time slices' at key points in time during the projection period.

5.3 *Projecting environmental trends in the absence of climate change*

The development of a baseline describing conditions without climate change is crucial, for it is this baseline against which all projected impacts are measured. It is highly probable that future changes in other environmental factors will occur even in the absence of climate change, which may be of importance for an exposure unit. Examples include deforestation, change in grazing pressure, changes in groundwater level and changes in air, water and soil pollution. Official projections may exist to describe trends in some of these (eg groundwater level), but for others it may be necessary to use expert judgment or simply to extrapolate past trends. Most factors are related to, and projections should be consistent with, trends in socioeconomic factors (see Section 5.4, below). GHG concentrations may also change, but these would usually be linked to climate (which is assumed unchanged here).

5.4 Projecting socioeconomic trends in the absence of climate change

Global climate change is projected to occur over time periods that are relatively long in socioeconomic terms. Over that period it is certain that the economy and society will change, even in the absence of climate change. One of the most difficult aspects of establishing trends in socioeconomic conditions without climate change over the period of analysis is the forecasting of future demands on resources of interest. Simple extrapolation of historical trends without regard for changes in prices, technology or population, will often provide an inaccurate base against which to measure impacts.

Official projections exist for some of these changes, as they are required for planning purposes. These vary in their time horizon from several years (eg economic growth, unemployment), through decades (eg urbanisation, industrial development, agricultural production), to a century or longer (eg population). Reputable sources of such projections include the United Nations (eg United Nations 1991), Organization of Economic Cooperation and Development (eg OECD 1990), World Bank (eg World Bank 1990), International Monetary Fund and national governments.

5.5 Projecting future climate

In order to conduct experiments to assess the impacts of climate change, it is first necessary to obtain a quantitative representation of the changes in climate themselves. No method yet exists of providing confident predictions of future climate. Instead, it is customary to specify a number of plausible future climates. These are referred to as 'climatic scenarios' and they are selected to provide climatic data that are spatially compatible, mutually consistent, freely available or easily derived from, and suitable as inputs to impact models.

There are four basic types of scenario of future climate: historical instrumentally based scenarios, palaeoclimatic analog scenarios, arbitrary adjustments and scenarios from GCMs.

5.5.1 Historical instrumentally based scenarios

An obvious source of climatological data for scenario development is past instrumental records. These are known to be spatially compatible and mutually consistent because they have actually been observed, and are available for the recent past over a reasonably dense network of land-based stations worldwide. Such scenarios can be based upon:

- *Historical-anomalies*, focusing on weather anomalies that can have significant short-term impacts (such as droughts, floods and cold spells). A change in future climate could mean a change in the frequency of such events. They are selected from the instrumental record as individual years or periods of years during which anomalous weather was observed (eg Parry and Carter 1988).
- *Historical-analogs*, which focus on past periods of global-scale warmth as potential analogs of a GHG-induced warmer world. They are usually developed on the basis of global-scale temperatures during past warm and cold periods, and consist of regional composites of the differences in climate between the two periods (eg Lough et al. 1983).
- *Historical-correlations*, which represent a variation of the analog approach, involving the estimation of linear relationships between the historical record of global surface air temperatures and records over the same period of local climatic variables. For a given variation in global temperature, it is then possible to estimate from these relationships expected variations in local climate (eg Vinnikov and Groisman 1979).
- *Circulation-patterns*, which are designed for cases where input data for impact models cannot be provided by conventional scenarios (eg wind fields for air pollution studies). The approach also uses linear relationships, this time between past global mean temperatures and regional atmospheric circulation patterns. Individual seasons are then identified in the historical record having circulation types resembling those found to be correlated with global warmth (eg Pitovranov 1988).

There is a number of difficulties associated with the use of instrumental scenarios:

- They are based on temperature changes during the past century that are much smaller than those possible in the future. Thus, they may not be applicable to conditions outside the range of past variations.
- The causes of past variations in global temperature may have been different from those responsible for a future GHG-induced change in temperature.
- The strength of the relationships between past changes in temperature and changes in other climatic variables is usually rather weak.
- The nature of the relationships between variables may be different in the future than those occurring in the past. It is also known that relationships established for the past can themselves vary, depending on the time period selected.

5.5.2 Palaeoclimatic analog scenarios

Palaeoclimatic scenarios are based on reconstructions of past climate from fossil evidence. Features of the past temperature and moisture regime in a region (usually at a seasonal time resolution) can often be inferred by assembling the different types of evidence. If absolute dating methods are available, and the spatial coverage of evidence is sufficient, maps can be constructed for particular time periods in the past.

In the context of future climatic warming, palaeoclimatic scenarios for warm periods in the past have been adopted in several climate impact assessment studies as analogs of possible future climate. They have been used extensively in Russia, where three periods have been selected to represent progressively warmer conditions in the northern hemisphere (Budyko 1989; IPCC 1990a): the Mid-Holocene (5–6000 years Before Present), when northern hemisphere temperatures are estimated to have been about 1°C warmer than today, the Last (Eemian) Interglacial (125 000 BP) with temperatures about 2°C warmer than today, and the Pliocene (3–4 million BP) when temperatures were about 3–4°C warmer than today.

If the evidence upon which they are based is of good quality, palaeoclimatic scenarios can provide a reasonable representation of past climate, which is consistent in space and time. Moreover, they have an advantage over instrumental scenarios in that the level of global warmth is much greater than that experienced in the past century, and more closely analogous to the magnitude of warming expected during the next century.

There are some serious reservations, however, in using these reconstructions as scenarios of future climate:

- Boundary conditions of the climate system (eg sea level, ice volume, land cover) were not the same in the past as they are today. Thus, even if the radiative forcing were the same, the climate response might differ in the future from that in the past.
- It is probable that some periods of past warmth resulted from different forcing factors than the future GHG forcing (eg orbital variations).
- There are large uncertainties about the quality of the palaeoclimatic reconstructions. None is geographically comprehensive, some may be biased in favour of climatic conditions that preserved the evidence upon which they are based, and the dating of material (especially in the more distant past) may not be precise.
- They represent the average conditions prevailing in the past. It is rare for them to yield concrete information on the variability of climate or frequency of extreme events.

5.5.3 Arbitrary adjustments

A simple method of specifying a future climate is to adjust the baseline climate in a systematic, though essentially arbitrary manner. Adjustments might include, for example, changes in mean annual temperature of ± 1°, 2°, 3°C... etc, or changes in annual precipitation of ± 5%, 10%, 15% ... etc relative to the baseline climate. Adjustments can be made independently or in combination.

These types of adjustments are of use for testing the robustness of impact models, and for studying sensitivity to climatic variations (see Section 4.3). This is also the preferred method of altering climate and/or atmospheric composition when conducting climatic change experiments in the field or laboratory. Furthermore, the approach can be useful for expressing expert estimates of future climate, in the absence of more detailed projections.

Perhaps the most valuable function of arbitrary adjustments, however, is as a diagnostic tool to be used before conducting scenario studies. In this way information can be obtained on:

- *Thresholds or discontinuities of response* that might occur under a given magnitude or rate of change. These may represent levels of change above which the nature of the response alters (eg warming may promote plant growth, but very high temperatures cause heat stress), or responses which have a critical impact on the system (eg wind speeds above which structural damage may occur to buildings).
- *Tolerable climate change*, which refers to the magnitude or rate of climate change that a modelled system can tolerate without major disruptive effects (sometimes termed the 'critical load'). This type of measure is potentially of value for policy, as it can assist in

defining specific goals or targets for limiting future climate change.

One of the main drawbacks of the approach is that adjustments to combinations of variables are unlikely to be physically plausible or internally consistent. Thus, this approach should normally only be used for sensitivity analysis.

5.5.4 Scenarios from GCMs

GCMs are the most sophisticated tools currently available for estimating the likely future effects of increasing GHG concentrations on climate. They simulate the major mechanisms affecting the global climate system according to the laws of physics, producing estimates of climatic variables for a regular network of grid points across the globe. Results from about ten GCMs have been reported to date (eg see IPCC 1990a).

GCMs are not yet sufficiently realistic to provide reliable predictions of climatic change at the regional level, and even at the global level model estimates are subject to considerable uncertainties. Thus, GCM outputs represent, at best, broad-scale sets of possible future climatic conditions and should *not* be regarded as predictions.

GCMs have been used to conduct two types of experiment for estimating future climate: *equilibrium-response* and *transient-forcing experiments*.

The majority of experiments have been conducted to evaluate the *equilibrium response* of the global climate to an abrupt increase (commonly, a doubling) of atmospheric concentrations of CO_2. Clearly, such a step change in atmospheric composition is unrealistic, as increases in GHG concentrations (including CO_2) are occurring continually and are unlikely to stabilise in the foreseeable future. Moreover, since different parts of the global climate system have different thermal inertias, they will approach equilibrium at different rates and may never approximate the composite equilibrium condition modelled in these simulations. This also results in difficulties in estimating the simultaneous effects of increasing CO_2 and climate change.

Recent work has focused on fashioning more realistic experiments with GCMs, specifically, simulations of the response of climate to a *transient forcing*. These simulations offer several advantages over equilibrium-response experiments. First, the specifications of the atmospheric perturbation are more realistic, involving a continuous (transient) change over time in GHG concentrations. Second, the representation of the oceans is more realistic, the most recent simulations coupling atmospheric models to dynamic ocean models. Finally, transient simulations provide information on the *rate* as well as the magnitude of climate change, which is of considerable value for impact studies.

Information from GCMs is usually made available to impact analysts as surface or near-surface climatic variables for model grid boxes characteristically spaced at intervals of several hundred kilometres around the globe, and most commonly at a monthly time resolution. GCM projections of changes in climate under GHG-forcing relative to the control simulation are usually applied as adjustments (expressed as differences or ratios) to the observed baseline climate. Several techniques have been used to apply transient response outputs to the baseline climate (eg Croley 1990) and to provide data at a different time resolution from those obtained from GCMs (eg Bultot et al. 1988). One of the major problems faced in applying GCM projections to regional impact assessments is the coarse spatial scale of the estimates. Several methods have been adopted for developing regional GCM-based scenarios at sub-grid-scale, including assignment of the nearest grid box estimate (eg Croley 1990), objective interpolation (eg Parry and Carter 1988; Cohen 1991), statistical analysis of local climatic fields (eg Wilks 1988) and merging of several scenarios based on expert judgment (eg Pearman 1988) or averaging (eg Department of the Environment 1991).

There have been objections to the concept of using GCMs for developing climate change scenarios for regional impact studies, owing to uncertainties that prevent accurate regional-scale simulations. However, these scenarios are often beyond the design criteria of various facilities or resource systems, and it seems prudent to begin to test the sensitivities of these systems under various scenarios directly or indirectly based on GCM outputs to provide an indication of uncertainly in regional terms.

Many GCM simulations have been conducted in recent years, and it is not easy to choose suitable examples for use in impact assessments. In general, the more recent simulations are likely to be more reliable as they are based on recent knowledge, and they tend to be of a higher spatial resolution than earlier model runs. It is strongly recommended that recent reviews of GCMs be consulted before selection. The National Center of Atmospheric Research, Boulder, Colorado, USA, has been acting as a clearing house for GCM data from different modelling groups.

Finally, it has become common to use simple climate models rather than GCMs to estimate the effects on future global temperatures of alternative GHG emission scenarios (IPCC 1990a). Their attractiveness as policy tools makes it desirable to use these scenarios in impact studies. However, since only global estimates are provided they cannot be used directly in regional assessments. A method of overcoming this problem makes use of GCM information in conjunction with the global estimates, whereby the GCM estimates of regional changes are scaled according to the ratio between the GCM estimate of global temperature change and that provided in the simple scenario (for example, for a doubling of CO_2).

5.6 Projecting environmental trends with climate change

Projections must be made for each of the environmental variables or characteristics of interest in the study and included in the description of environmental trends in the absence of climate change. These projections are made using the climate projections and the biophysical models selected for the study (as described in Section 3.2.1). Because all changes in environmental conditions not due to climatic factors should already have been incorporated in the development of the environmental trends in the absence of climate change, the only changes in these trends to be incorporated here are those due solely to climate change. The two factors most commonly required in assessments are GHG concentrations and sea-level rise. Future changes in these are still under discussion, but the estimates reported by the IPCC may serve as a useful basis for constructing scenarios (IPCC 1990a). Other factors that are directly affected by climate (such as river flows, runoff, erosion) would probably require full impact assessments of their own, although some might be incorporated as 'automatic adjustments' in projections.

5.7 Projecting socioeconomic trends with climate change

The changes in environmental conditions that are attributable solely to climate change serve as inputs to the economic modelling that projects the changes in socioeconomic conditions due to climate change over the study period. All other changes in socioeconomic conditions over the period of analysis are attributable to non-climatic factors and should have been included in the estimation of socioeconomic changes in the absence of climate change.

It is not known how climate change might affect some important socioeconomic factors (eg population growth) and trends estimated in the absence of climate change would probably suffice. Other factors can be estimated, however (eg winter electricity demand in relation to future warming). Moreover, some human responses to climate change are predictable enough to be factored-in to future projections. These are often accounted for in model simulations as feedbacks or 'automatic adjustments' to climate change (eg altering crop sowing dates to account for a shift in the timing of rainfall).

6 Assessment of impacts

Impacts are estimated as the differences over the study period between the environmental and socioeconomic conditions projected to exist without climate change and those that are projected with climate change. The impacts provide the basis for the assessment of impacts. Assessments may include:

- *Geographical analysis* of the impacts. Impacts vary over space, and this pattern of variation is of concern to policy makers operating at regional, national or international scales, because these spatial differences may have consequent policy and planning implications. The geographical depiction of climate change, presented as maps, is one method of describing impacts. Geographical information systems (GIS) may be used to depict patterns of climate change, evaluate the regional potential for different activities using simple indices, map changes in the pattern of potential induced by a given climate change, identify regions of particular sensitivity to climate change, and display the impact of climate on different activities within a given geographical region.
- *Compliance to standards*, which may provide a reference or an objective against which to measure the impacts of climate change. For example, the effect on water quality could be gauged by reference to current water quality standards.
- *Qualitative description*, which may be used to evaluate the impacts of climate change. The success of this method rests on the experience and interpretive skills of the analyst, especially the analyst's ability to consider all factors of importance and their interrelationships.
- *Costs and benefits*, which should be estimated quantitatively to the extent possible and discounted to net present value. This approach makes explicit the expectation that a change in resources and resource allocation due to climate change is likely to yield benefits as well as costs, and can also examine the 'waiting' costs or benefits of doing nothing to mitigate potential climate change. The choice of discount rate used to discount benefits and costs will vary from nation to nation, depending upon the economic and social circumstances of each. Some costs and benefits are difficult to assess in monetary terms, and will have to be considered in descriptive terms.

Finally, the assessment should also take into account the uncertainties resulting from choices of assumptions and modelling techniques, as well as incomplete knowledge of biophysical, social and economic processes and the long time horizons over which projections are to be made.

7 Evaluation of adjustments

Impact experiments are usually conducted to evaluate the effects of climate change on an exposure unit in the absence of any adjustments which might prevent, mitigate or exploit them, and are not already automatic or built in to future projections. It is these adjustments which form the basis of measures to cope with climate change. Two types are described here: feedbacks to climate and tested adjustments at the enterprise level. A third type, policy responses, is considered in Section 8.

7.1 Feedbacks to climate

The global climate system is influenced, in part, by interactions with the surface biosphere. To date, projections of future climate have assumed that the biosphere remains unchanged, but this is clearly unrealistic. As climate changes, so the pattern of vegetation and of other important organisms such as oceanic plankton, which feedback to climate, are likely to shift geographically. Impact models can identify these possible shifts, but they have not yet been linked effectively to climate models for simulating feedbacks to climate.

7.2 Tested adjustments at the enterprise level

Tested adjustments are experiments that can be conducted with impact models to evaluate alternative options for adjusting to climate change at the level of individual enterprises. To illustrate, a climatic scenario may indicate that the water requirements of a crop are no longer satisfied under a changed rainfall regime. In this case an adjustment that could be tested using a crop growth model might be the substitution of less demanding, short-season crop variety. Here, the adjustment is chosen by expert judgment, but evaluated using the model.

When analysing potential adjustments, it is useful to distinguish between two types: anticipatory and reactive. *Anticipatory adjustments* are put into place in prospect of impacts occurring (eg the breeding of drought resistant crop varieties). *Reactive adjustments* are implemented after impacts have occurred (eg the adoption of drought resistant varieties). In many cases, adjustment experiments can assist in evaluating different options so that anticipatory, rather than reactive adjustments can be put in place.

Of course, not all adjustments can be tested. For some, an accurate evaluation may not be possible, and for others the required technology may not yet be available.

8 Consideration of policy options

Another method of responding to climatic change is through policy decisions. Apart from purely qualitative assessments, two methods of policy evaluation can be identified: policy simulation and policy exercises.

8.1 Policy simulation

In some assessments it is possible to simulate the effectiveness of alternative policy adjustments using impact models. Two types of policy response to climatic change are commonly simulated: mitigation and adaptive.

Mitigation policies refer to actions that attempt to prevent or to reduce changes in climate by altering the emission rates of GHGs. These effects can be estimated and the costs evaluated using a range of models. Impact assessments can assist in identifying targets for mitigation policy with respect to minimising the effects of climate change (see Section 5.5.3).

Adaptive policies recognise that climate changes will occur and that it is necessary to accommodate them in policy. For instance, the lifting of government subsidies on some food crops might be one policy method of offsetting overproduction due to a more favourable climate. Such a policy would rely on economic factors (ie reduced incentive) to bring about farm-level adjustments such as a switch to alternative crops giving a higher return.

8.2 Policy exercises

A second possible method of evaluating policy adjustments is policy exercises. These combine elements of a modelling approach with expert judgment, and were originally advocated as a means of improving the interaction between scientists and policy makers. Senior figures in government, industry and finance are encouraged to participate with senior scientists in 'exercises' (often based on the principles of gaming), whereby they are asked to judge appropriate policy responses to a number of given climatic scenarios. Their decisions are then evaluated using impact models (Brewer 1986; Parry et al. 1992).

References

Brewer, G. D. 1986. 'Methods for synthesis: policy exercises', Ch.17 in W.C.Clark and R.E.Munn (eds), *Sustainable Development of the Biosphere*, pp. 455–473, Cambridge University Press.

Budyko, M.I. 1989. 'Empirical estimates of imminent climatic changes', *Soviet Meteorology and Hydrology*, No.10, 1–8.

Bultot, F., A. Coppens, G.L.Dupriez, D.Gellens and F.Meulenberghs 1988. 'Repercussions of a CO_2 doubling on the water cycle and on the water balance - a case study for Belgium', *Journal of Hydrology*, 99, 319–347.

Cohen, S.J. 1991. 'Possible impacts of climatic warming scenarios on water resources in the Saskatchewan River sub-basin, Canada', *Climatic Change*, 19, 291–317.

Croley, T.E., II 1990. 'Laurentian Great Lakes double-CO_2 climate change hydrological impacts', *Climatic Change*, 17, 27–47.

Department of the Environment 1991. *The Potential Effects of Climate Change in the United Kingdom*, United Kingdom Climate Change Impacts Review Group, HMSO, London, 124 pp.

Hutchinson, M.F. 1987. 'Methods of generating weather sequences', in A.H.Bunting (Ed.) *Agricultural Environments: Characterization, Classification and Mapping*, CAB International, Wallingford, UK, pp.149–157.

IPCC 1990a. *Climate Change: The IPCC Scientific Assessment*. Report of Working Group I of the Intergovernmental Panel on Climate Change, Cambridge University Press, 364 pp.

Lough, J.M., Wigley, T.M.L. and Palutikof, J.P. 1983. 'Climate and climate impact scenarios for Europe in a warmer world', *J.Clim.Appl.Meteorol.*, 22, 1673–1684.

National Defence University (NDU) 1978. *Climate Change in the Year 2000*, Washington, D.C., Fort Lesley J. McNair.

National Defence University (NDU) 1980. *Crop Yields and Climate Change to the Year 2000*. Vol.1, Washington, D.C., Fort Lesley J. McNair.

OECD 1990. *Main Economic Indicators—Historical Statistics*, 1969–1988, 766 pp.

Parry, M.L. and Carter, T.R. 1988. 'The assessment of effects of climatic variations on agriculture: aims, methods and summary of results', in M.L.Parry, T.R.Carter and N.T.Konijn (eds), *The Impact of Climatic Variations on Agriculture*. Volume 1. Assessments in Cool Temperate and Cold Regions, Kluwer, Dordrecht, The Netherlands, 11–95.

Parry, M.L., Blantran de Rozari, M., Chong, A.L. and Panich, S. (eds) 1992. *The Potential Socio-Economic Effects of Climate Change in South-East Asia*, United Nations Environment Programme, Nairobi, 126 pp.

Pearman (ed.) 1988. *Greenhouse: Planning for Climate Change*, CSIRO, Melbourne.

Pitovranov, S.E. 1988. 'The assessment of impacts of possible climate changes on the results of the IIASA RAINS sulfur deposition model in Europe', *Water, Air, and Soil Pollution*, 40, 95–119.

Rosenberg, N.J. and Crosson, P.J. 1991. *Processes for Identifying Regional Influences and Responses to Increasing Atmospheric CO_2 and Climate Change—The Mink Project.An Overview*. United States Department of Energy, DOE/RL/01830T-H5, Washington, D.C., 35 pp.

Stewart, T.R. and Glantz, M.H. 1985. 'Expert judgement and climate forecasting: A methodological critique of "Climate Change to the Year 2000"', *Climatic Change*, 7, 159–183.

United Nations 1991. *World Population Prospects*, 1991.

Vinnikov, K. Ya. and Groisman, P.Ya. 1979. 'An empirical model of present-day climatic changes', *Meteorol.Gidrolog.*, 1979, No.3, 25–36 (in Russian).

Wilks, D.S. 1988. 'Estimating the consequences of CO_2-induced climatic change on North American grain agriculture using general circulation model information', *Climatic Change*, 13, pp.19–42.

WMO 1985. *Report of the WMO/UNEP/ICSU-SCOPE Expert Meeting on the Reliability of Crop-Climate Models for Assessing the Impacts of Climatic Change and Variability*, WCP-90, World Meteorological Organization, Geneva, 31 pp.

WMO 1988. *Water Resources and Climatic Change: Sensitivity of Water Resource Systems to Climate Change and Variability*, WCAP-4, Geneva.

World Bank 1990. *World Tables 1989–90 Edition*, Johns Hopkins University Press, Baltimore and London.

General references

EPA 1988. *The Potential Effect of Climate Change on the United States. Volume 1: Regional Studies.* Draft Report to Congress, United States Environmental Protection Agency, 91 pp.

IPCC 1990b. *Climate Change: The IPCC Impacts Assessment*, Report prepared for IPCC by Working Group II, Australian Government Publishing Service.

OECD Environmental Committee 1991. *Climate Change: Evaluating the Socio-Economic Impacts*, 109 pp.

Riebsame, W.E. 1988. *Assessing the Social Implications of Climate Fluctuations: A Guide to Climate Impact Studies.* United Nations Environment Programme, Nairobi, 82 pp.