#### *3.2.2.3 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. One important requirement of such models is an ability to simulate system feedbacks, either as regulatory mechanisms internal to the model (e.g., energy consumption leads to GHG emissions that contribute to climate warming, but the warming affects energy demand thus feeding back to consumption), or as external adjustments (e.g., a global protocol limiting GHG-emissions and thus reducing climate warming and its likely impacts).

The main value of this type of model is as a policy tool, to enable decision-makers to evaluate the broad scale implications of climatic change across a range of activities. However, aside from the problems of the complexity, demanding data requirements and testing of such models, a major concern remains about their ability to represent the uncertainties propagating through each level of the modelled system.

No fully integrated systems model has yet been developed, but a partially integrated approach has been pursued in a few recent studies (e.g., Department of the Environment, 1991; Rosenberg and Crosson, 1991; CRU/ERL, 1992). All of these involved the linking of individual models. A potentially powerful method of assessing the direct and indirect effects and benefits and costs of potential climate change employs a general equilibrium modelling approach to environmental and economic interactions. Research to develop such models should be a priority.

### *3.2.3 Empirical analogue 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 analogue of possible future conditions. Data collection may be guided by anomalous climatic events in the past record (e.g., drought or hot spells) or by the impacts themselves (e.g., periods of severe soil erosion by wind). The assessment follows a 'longitudinal' method (Riebsame, 1988), whereby indicators are compared before, during and after the event. Examples of this approach are found in Glantz (1988). However, the success of this method depends on the analyst's ability to separate climatic and non-climatic explanations for given effects.

*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. To justify these premises, the regions generally have to exhibit similarities in other environmental factors (e.g., soils and topography), in their level of development and in their respective economic systems. If these conditions are fulfilled, then it may be possible to conduct assessments that follow the 'case-control' method (Riebsame, 1988). Here, a target case is compared with a control case, the target area experiencing abnormal weather but the other 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. In this case, the analogue region cannot be expected to exhibit complete similarity to the present study region, because many features may themselves change as a result of climatic change (e.g., soils, land use, vegetation). These characteristics would provide indicators of how the landscape and human activities might change in the study region in the future. Of course, for a full assessment of this, it would be necessary to consider the ability of a system or population to adapt to change. This principle has proved valuable in extending the range of applicability of some impact models. For example, a model of grass growth in Iceland has been tested for species currently found in northern Britain, which is an analogue region for Iceland under a climate some 4 °C warmer than present (Bergthorsson *et al.*, 1988).

Other aspects of the analogue region, however, would need to be assumed to be similar to the study region (e.g., day length, topography, level of development and economic system). Where these conditions cannot be met (e.g., day length for grass growth in Iceland differs from that in northern Britain), the implications need to be considered on a case by case basis. For a hydrological example, see Arnell *et al.* (1990). One method of circumventing these problems is to consider altitudinal differences in the same region. This method is currently being used to investigate tree establishment and growth under the varying climatic conditions at different altitudes in Fenno-Scandinavia (Koski, personal communication, 1991).

### *3.2.4 Expert judgement*

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 judgement and opinions of experts in the field. This method is widely adopted by government departments for producing position papers on issues requiring policy responses. Because there may be insufficient time to undertake a full research study, literature is reviewed, comparable studies identified, and experience and judgement are used in applying all available information to the current problem.

The use of expert judgement 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. This method was employed in the National Defense University's study of 'Climate Change to the Year 2000', which solicited probability judgements from experts about climatic change and its possible impacts (NDU, 1978, 1980).

The pitfalls of this type of analysis are examined in detail in the context of the NDU study by Stewart and Glantz (1985). They include problems of questionnaire design and delivery, selection of representative samples of experts, and the analysis of experts' responses.

## 3.3 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.

### *3.3.1 Feasibility studies*

One way of testing some or all of the methods, is to conduct a feasibility or pilot study. This usually focuses on a subset of the study region or sector to be assessed. Case studies such as these can provide information on the effectiveness of alternative approaches, of models, of data acquisition and monitoring, and of research collaboration. Feasibility studies are most commonly adopted as a preliminary stage of large multidisciplinary and multisectoral research projects. Here, effective planning and scheduling of research relies on the assurance that different research tasks can be undertaken promptly and efficiently.

### *3.3.2 Data acquisition and compilation*

An essential element in all climate impact assessment studies is the acquisition and compilation of data. Quantitative data are required both to describe the temporal and spatial patterns of climatic events and their impacts and to develop, calibrate and test predictive models. Four main types of data collection can be identified: empirical compilation, objective survey, targetted measurement and monitoring.

*Empirical compilation* of evidence (both quantitative and qualitative) from disparate sources is the mainstay of most historical analysis of past climate-society interactions. The data are pieced together to produce a chronology of events, which can then be used to test hypotheses about the effects of past climate (e.g., see Parry, 1978), or simply as a qualitative description of past events (e.g., see Lamb, 1977; Pfister, 1984; Grove, 1988).

*Objective survey* utilises established procedures to collect data from contemporary sources (the information itself may relate to the present or the past). Such survey material may represent either a subset of a population (e.g., a sample of plant species at randomly selected locations within given ecological zones, to be related to climate at the same localities) or the complete population (e.g., a regional register of all reported illnesses during a given period that can be related to extreme weather conditions). The tools employed in data acquisition include use of government statistical sources, different methods of questionnaire survey and biological survey techniques. The types of studies reliant on this kind of information include most social impact assessments (Farhar-Pilgrim, 1985), studies of perception (Whyte, 1985), and studies of biophysical impacts where quantitative data are lacking (e.g., of village-level drought effects on agriculture—Akong'a *et al.*, 1988; Gadgil *et al.*, 1988).

*Targetted measurement* refers to the gathering of unique data from experiments where data and knowledge about vital processes or interactions are lacking. This type of measurement is especially important in considering the combined effects of future changes in climate and other environmental factors, combinations which have never before been observed. In many cases these data offer the only opportunity for testing predictive models (for example, observations of the effects of enhanced atmospheric $CO_2$ on plant growth).

*Monitoring* is a valuable source of information for climate impact assessment. Consistent and continuous collection of important data at selected locations is the only reliable method of detecting trends in climate itself, or in its effects. In most cases, impact studies make use of long-term data from other sources (e.g., observed climatological data, remotely-sensed data). However, in some projects monitoring may form the central theme of research. In these, it is important to consider aspects such as site selection, multiple-uses of single sites, design of measurements and their analysis. It should be noted that there are numerous national and international monitoring programmes, including one initiated by the IPCC (WG II). It is important that results from such programmes be made available to impact researchers for assessment studies.

### *3.3.3 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—and these should generally precede more formal impact assessment.

*Sensitivity analysis* evaluates the effects on model performance of altering the model's structure, parameter values, or values of its input variables. Extending these principles to climatic change requires that the climatic input variables to a model are altered systematically to represent the range of climatic conditions likely to occur in a region. In this way, information can be obtained on:

- The sensitivity of the outputs to changes in the inputs. This can be instructive, for example, in assessing the confidence limits surrounding model estimates arising from uncertainties in the parameter values.
- Model robustness, (i.e., the ability of the model to behave realistically under different input specifications, and the circumstances under which it may behave unrealistically).
- The full range of model application (including its transferability from one climatic region to another, and the range of climatic inputs that can be accommodated).

*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 final yield each need to be compared with measurements.

Climate change introduces some additional problems for validation, since there may be little local data that can be used to test the behaviour of a modelled system in conditions resembling those in the future. Simulation models ought, in theory, to be widely applicable (see Section 3.2.2.1), and anyway should be tested in a range of environments. There are fewer grounds, however, for extrapolating the relationships in empirical-statistical models outside the range of conditions for which they were developed. The use of regional analogies of future climate is one possible method of addressing certain aspects of this problem (see Section 3.2.3).

## 3.4 Selecting the Scenarios

Impacts are estimated as the differences between two states: environmental and socio-economic conditions expected to