used here to describe an analysis of the range of uncertainties encountered in an assessment study. These arise from two sources, here referred to as 'errors' and 'unknowns'.

Errors may arise from several sources, including measurement error, paucity of data and inadequate parameterization or assumptions. Unknowns include alternative scenarios, or the omission of important explanatory variables. The maximum range of uncertainty is the product of the individual uncertainties. The upper and lower bounds of these may be highly improbable, so more useful alternatives are confidence limits (e.g., 5 or 95 percentiles), which can be computed by studying the probability of uncertainties propagating (see, for example, Brklacich and Smit, 1992). These are often used as upper, lower and best estimates of an outcome.

3.5.6.2 Risk analysis

Risk analysis deals with uncertainty in terms of the risk of impact. Risk is defined as the product of the probability of an event and its effect on an exposure unit. It has been argued that future changes in average climate are likely to be accompanied by a change in the frequency of extreme or anomalous events, and it is these that cause the most significant impacts (Parry, 1990). Thus there is value in focusing on the changing risk of climatic extremes and of their impacts. This approach can then be helpful in assessing the potential risk of impact relative to predefined levels of acceptable or tolerable risk. It is important to stress, however, that while occurrence probabilities of hypothetical climatic events are relatively straightforward to compute, it is not generally possible to ascribe any degree of confidence to probabilities of future impacts.

3.6 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 3.7.

3.6.1 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.

3.6.2 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 a less demanding, short-season crop variety. Here, the adjustment is chosen by expert judgement, but evaluated using a model (for a similar example, see Box 7 on page 22).

It is important to recognise that any evaluation of potential adjustments necessarily makes assumptions about the way in which groups or individuals will respond when confronted with climate change. There is a whole area of research which examines the actual processes of adaptive response to changes in climate. This includes behavioural studies of actions taken during and after certain climatic events, as well as studies to identify thresholds of tolerance or constraints on adaptation to climate change and its effects (e.g., see Whyte, 1985; Smit, 1991).

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 (e.g., the breeding of drought resistant crop varieties). Reactive adjustments are implemented after impacts have occurred (e.g., 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.

3.7 Consideration of Policy Options

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

3.7.1 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: mitigative and adaptive.

Mitigation policies refer to actions that attempt to prevent or to reduce changes in climate by altering the emission rates of greenhouse gases. 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 3.4.5.3). For instance, a target emissions policy might be set that limited the likely rate of change in climate resulting from increased GHG concentrations to one that natural ecosystems would be able to accommodate and adapt to, through migration or acclimation.

Adaptive policies recognize that climate changes will occur and that it is necessary to accommodate these changes 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 (i.e., reduced incentive) to bring about farm-level adjustments such as a switch to alternative crops giving a higher return.

3.7.2 Policy exercises

A second possible method of evaluating policy adjustments is the policy exercise. Policy exercises combine elements of a modelling approach with expert judgement, and were originally advocated as a means of improving the interaction between scientists and policy-makers. Senior figures in gov-

BOX 7
CASE STUDY: POTENTIAL IMPACTS OF CLIMATE CHANGE ON AGRICULTURE IN SASKATCHEWAN, CANADA

Background. The province of Saskatchewan in Canada has about 40% of Canada's farmland and it accounts for about 60% of Canada's wheat production, most of which is exported. About one-eighth of internationally traded wheat originates from Saskatchewan.

Problem. To evaluate the possible impacts of future climate change on Saskatchewan agriculture, assuming the same technology and economic circumstances as in the 1980s.

Methods. Four different types of predictive model were linked hierarchically: crop growth, farm simulation, input-output and employment models. These provided estimates of regional crop yields, income and economic activity at the farm level, commodity use relationships between sectors of the provincial economy, and provincial employment. The effects of changed climate, described by climatic scenarios, were then traced through from changes in crop yield to effects on regional employment.

Testing of methods/sensitivity. Each of the models had been tested and calibrated based on climatic or economic data from recent years. In addition, the sensitivity of the crop growth model to arbitrary changes in climatic input variables was also investigated to ascertain its suitability for evaluating the effects of climate change.

Scenarios. Three types of climatic scenario were examined: one historical anomaly scenario (the drought year 1962), one historical analogue scenario (the dry period 1933–37) and one GCM-based 2 x CO_2 scenario. The climatological baseline was 1951–80. Future changes in other environmental and socio-economic factors were not considered.

Impacts. Under present climatic conditions, Saskatchewan can expect occasional extreme drought years with wheat yields reduced to as little as one-quarter of normal, with large effects on the agricultural economy and on provincial GDP and large scale losses in employment. Occasional periods of consecutive years with drought can lead to average yield reductions of one-fifth and substantial losses of farm income and employment. Under the GCM 2 x CO_2 scenario, with increased growing season temperatures combined with increased precipitation but higher potential evapotranspiration, wheat yields would also decline, by average levels similar in magnitude to an extreme period under present climate, with comparable economic impacts. The frequency of drought or severe drought is estimated to triple relative to the baseline under this scenario.

Adjustments. One potential adaptive response to climate change was tested: the switching of 10% of the cropped area from spring wheat to winter wheat. It was estimated that yield losses in drought years would be significantly lower with such an adaptation, but that the reverse would be true in normal years. Thus this adaptation would be favoured if climate shifted towards warmer and drier conditions in the future.

Source. Williams *et al.* (1988)

ernment, 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; Toth, 1988). The method has been tested in a number of recent climate impact assessments in South-East Asia (Parry *et al.*, 1992).