AN ANTIPODEAN CLIMATE OF UNCERTAINTY?

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Abstract. Climatic impact assessment is generally conducted by reference to numerical models, from which most estimates of climatic change are derived, and to the policy developers, by whom the impact assessments are demanded. The propagation of estimates derived from numerical climate model predictions of greenhouse-induced climate change through impact models into policy advice is a precariously uncertain process which compounds the considerable uncertainties already inherent in policy development. Clear statements of scientific confidence in the greenhouse phenomenon in the mid-1980s prompted demands for policy, and hence for policy advice. In Australia, as in many other countries, public and political awareness of the possibility of greenhouse-induced climatic change increased. These developments led to the formation of the Intergovernmental Panel on Climate Change (IPCC); to the Framework Convention on Climate Change, signed at the United Nations Conference on Environment and Development (UNCED) in June 1992; and to the review of the World Climate Programme in April 1993. This special issue of *Climatic Change* illustrates some aspects of the difficulties surrounding projections of climatic impacts at a national scale where policy development almost always occurs under conditions of uncertainty. It may be valuable to identify uncertainty issues which could benefit from additional research and also sensitive points in the policy development process at which uncertainty can be used and abused. In this paper, the role of uncertainty in the greenhouse debate is reviewed from the perspective of a natural scientist working in a developed country. The aim is to offer a framework for the rest of this special issue of *Climatic Change*. Uncertainty is by no means the only factor which influences views on climate change but increased understanding and more informed debate of all aspects of the uncertainties relating greenhouse-induced climatic change to policy development and implementation would be beneficial.

1. Global Warming Warnings

International Concern about Climatic Change

Although the scientific basis for believing that increases in the atmospheric concentrations of greenhouse gases could cause global warming has been recognized for about a century, the warnings emanating from the scientific community did not significantly stimulate public awareness until the Villach Conference in 1985 (e.g. Bolin *et al.*, 1986). Even following the Villach declaration, national awareness often followed a nationally recognized climatic event (e.g. the 1988 drought in the U.S.A.). From the mid-1980s to date, there has been an escalation in scientific review and in discussion of governmental and international responses. This process

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was particularly carried out by the Intergovernmental Panel on Climate Change (IPCC) which was formed in 1988 and required to report to the United Nations in 1990 (Figure 1).

Since the first reports of IPCC (Houghton *et al.*, 1990; Tegart *et al.*, 1990; IPCC, 1990), the process of response to predicted global warming has become more politicized, particularly so during the meetings of the international negotiating committee charged with drafting the Framework Convention on Climate Change which was signed by 154 countries at the United Nations Conference on Environment and Development (UNCED) in June 1992. The present situation is that the convention enters into force on the ninetieth day after fifty signatory nations have ratified the Framework Convention: a process that is expected to take about two years. Even though the convention has been reported as being 'devoid of targets and timetables' for the reduction of greenhouse gas emissions, it does include an 'aim' of stabilizing emissions at 1990 levels by the year 2000; so there remains considerable pressure on both national governments and on international negotiating teams to develop appropriate response strategies (e.g. Haas *et al.*, 1992).

Of the three IPCC reports, published late in 1990 and discussed at the Second World Climate Conference in October of that year, the first report on Science is without doubt the strongest and most authoritative document. The Impacts Report (Tegart *et al.*, 1990) suffered to some extent from being generated at the same time as IPCC 1. Thus the best estimates of climate change finally delivered by Houghton *et al.* (1990) were not available to those developing impacts assessments for IPCC

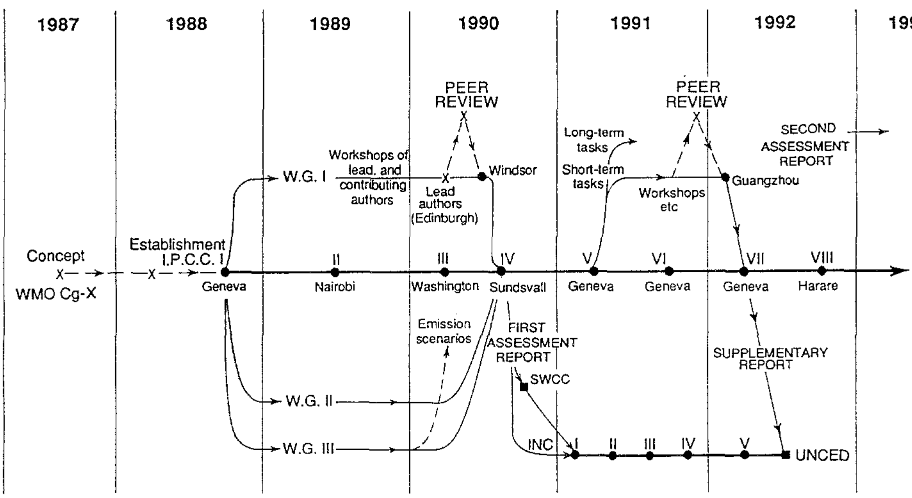

Fig. 1. The recent development of the international process of climate change-related policy formulation initially through the Intergovernmental Panel on Climate Change (IPCC), itself prompted by the strong scientific statements made at the Villach conference in 1985 (adapted by R. Taplin from sketch by J. Zillman, p.c.).

2. The third IPCC report, on response strategies, is widely considered to be the least successful of the three. Steve Schneider says in a review of the three reports: "Not surprisingly, the reports get decreasingly quantitative and increasingly non specific as they move from the physical and biological sciences to impact assessment and ultimately policy. This trend partly reflects the states of the arts for these areas, but it also reflects the increasing divergence of opinions as one moves from natural science towards impact assessment and policy response" (Schneider, 1991, p. 28).

If the science report of IPCC is seen as achieving the widest agreement and most quantitative assessment, it is equally clear that this quantitative assessment of future climate change is firmly based in careful interpretation of observations as setting the range of likely climatic change (Folland *et al.*, 1990) and in numerical climate modelling. IPCC 1 describes these general circulation climate models (GCMs) as "the most highly developed tool which we have to predict future climate" (Houghton *et al.*, 1990, p. xxv). Despite considerable pressure from a minority of scientists, IPCC 1 finally opted to put almost all the emphasis on the results of numerical climate models. The Policy Makers Summary says:

"A completely different, and potentially useful, way of predicting patterns of future climate is to search for periods in the past when the global mean temperatures were similar to those we expect in future, and then use the past spatial patterns as analogues of those which will arise in the future. For a good analogue, it is also necessary for the forcing factors (for example, greenhouse gases, orbital variations) and other conditions (for example, ice cover, topography, etc.) to be similar; direct comparisons with climate situations for which these conditions do not apply cannot be easily interpreted. Analogues of future greenhouse-gas-changed climate have not been found.

We cannot therefore advocate the use of palæo-climates as predictions of regional climate change due to future increases in greenhouse gases. However, palæo-climatological information can provide useful insights into climate processes, and can assist in the validation of climate models." (Houghton *et al.*, 1990, p. xxv).

IPCC 2 followed a similar path, although its introductory chapter on scenarios used in the report comments that these scenarios are derived both from GCMs and from palæo-analogue techniques. The criticism of these techniques is more muted in IPCC 2, partly because it is clear that many impacts models must draw their data from periods when the climate differed from the present day's. Indeed, more fundamentally, simple impact models depend upon the observation that climate differences are often correlated with other environmental and social changes (e.g. Holdridge, 1947; Parry, 1978).

Stemming from the Villach statement in 1985 (e.g. Bolin *et al.*, 1986) and the consensus reported in IPCC 1 the need for action in response to the increasing greenhouse effect is now firmly on national and international political agendas (e.g. Schneider, 1989a). Although most scientists now recognize that debate and policy development will be pursued by a wide variety of groups, it probably remains true that the issue of uncertainty will continue to receive emphasis in the future.

The recognition that improved understanding of the uncertainty associated with greenhouse-related climate (and impact) projections may be critical to future policy development has prompted national and international responses. One example is the formation in 1991 of the Model Evaluation Consortium for Climate Assessment (MECCA). This consortium draws funds from a number of national electric power research agencies and also enjoys the support of the U.S.A.'s University Corporation for Atmospheric Research (UCAR). In the statement of its overall objective, MECCA recognizes that it is "urgent that the uncertainties of these model projections be quantified in the most systematic and useful manner possible" (MECCA Experiment and Analysis Plan, 1991, p. 5).

A Climate of Uncertainty

It has been claimed that the uncertainty present in individual climate models' predictions of the climate of a greenhouse-warmed world 'explodes' as reference is made to other climate models; as impact models are used to predict impacts especially when more than one impact model is used and finally as these predicted impacts are fed into the policy formulation process (Figure 2). This increase or, less emotively, 'cascade' of uncertainty occurs even if, individually, greater confidence is felt in the outcomes of impacts models than in the climate models. As long as uncertainty exists at each stage in the assessment process, the overall range of projections will grow. However, the degree of this growth is *not known*. Two reviewers of an earlier version of this paper placed contrary views: "the uncertainty of impacts is probably smaller than the uncertainty over climate change" as compared to "uncertainties (of models) together with the even greater uncertainties of application models". However, the reality of low-probability but high-impact effects (towards the right or left hand sides of the last panel in Figure 2) is the basis of the continued existence and expansion of the insurance industry worldwide.

The magnitude of the uncertainty explosion, cascade or slump (Figure 2) may not matter since other issues, such as economics in developed nations or hunger in poor nations, may overwhelm the debate about the confidence in model projections (e.g. Swart *et al.*, 1991; Swart and Hootsmans, 1991; Swart, 1992). In this context, Green (1992 crediting Hogan p.c.) notes a possible economic analogue to Heisenberg's uncertainty principle in relation to actions to reduce the impact of greenhouse induced climatic changes. The argument is that if (costly) action was to be taken on the basis of a truly uncertain (i.e. lacking a known probability distribution) and never-before-experienced event such as greenhouse gas induced climatic change, then the outcomes will be modified by the action. This is claimed to be 'disadvantageous' because not only will it be uncertain whether any action was required (cf. Schlesinger and Jiang, 1991) but the result of the action will not be determinable (at least in economic terms). On the other hand, 'no action' can also be viewed as 'disadvantageous' if 'bad luck' results in a low probability but highly damaging (cf. last panel in Figure 2) impact outcome (cf. Schneider, 1993).

This 'collapse of confidence', real or perceived, in climate predictions is one of the reasons for uncertainty in policy development and implementation. On the

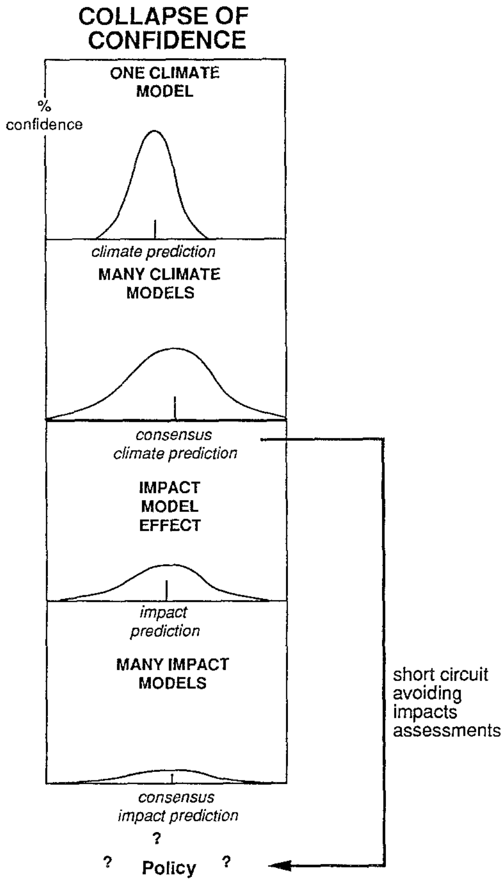

Fig. 2. A schematic representation of what has been termed the cascade of uncertainty or the collapse of confidence in which uncertainty increases from climate model outcomes through impact models.

other hand, it must be recognized that the desire for policy development, perhaps prompted by other factors, can short-circuit the assessment of likely impacts, as has been the case, at least to some extent, for greenhouse-related climatic change, although impacts assessments are continuing (as is clear from this Special Issue of *Climatic Change*).

Clearly, uncertainty in model results and impacts assessments is not the only, and perhaps not the most important, factor influencing the climate change debate. The risks of climate change, the costs of the impacts of change and the costs of response measures are also strongly influential (Nordhaus, 1991 but cf. Schneider, 1993; Peck and Teisberg, 1992; Lovins and Lovins, 1992). Nonetheless, the uncertainty in predicted climate change has been used as the basis for a call for a 10-year delay in the implementation of emission reduction programmes, while scientists undertake a crash programme aimed at greatly improved understanding of the scientific uncertainties (Schlesinger and Jiang, 1991). Other authors, notably Risby *et al.* (1991a, b), Oeschger *et al.* (1992), Bolin (1992) and Harvey (1992), take issue with various aspects of Schlesinger and Jiang's argument and modelling approach, emphasizing particularly that the transition from today's world to one in which CO_2 and other greenhouse gas emissions remain constant will be a long, slow and difficult process.

Another slant on the decadal delay perspective on greenhouse has been given by Schneider (1993). Using the (simple) economic model of Nordhaus (1991), he shows that the predicted temperature rise by 2100 could be halved if society were prepared to accept a delay of 'only' 10 years on the predicted time scale of achieving 470% economic growth.

Although the initial proposal of Schlesinger and Jiang (1991) had a (sound) scientific basis, it is interesting that subsequent responses have shifted the emphasis from a discussion of scientific uncertainties to policy-, economic- and community-related comments. The political, social and economic inertia to be overcome in all nations is so great that Bert Bolin, the Chairman of IPCC, urges "the sooner we begin [to cut emissions], the more likely it is that certain targets will be reached" (Bolin, 1992, p. 325).

In addition to this seesaw of emphasis between science and policy, there is a vocal, media accessible, minority of scientists and commentators who have taken issue with the underlying science of greenhouse warming (e.g. Marshall Report, 1992). The latter issues have, to an extent, been answered in the update of IPCC 1 (Houghton *et al.*, 1992). The overall conclusion of this update was that the findings of IPCC 1, and the worldwide consensus underpinning them, held firm.

On the other hand, IPCC 1 summarizes the consensus (in 1990) view on scientific uncertainty as follows:

"Although we can say that some climate change is unavoidable, much uncertainty exists in the prediction of global climate properties such as the temperature and rainfall. Even greater uncertainty exists in predictions of regional climate change, and the subsequent consequences for sea level and ecosystems. The key areas of scientific uncertainty are:

- **clouds:** primarily cloud formation, dissipation, and radiative properties, which influence the response of the atmosphere to greenhouse forcing;
- **oceans:** the exchange of energy between the ocean and the atmosphere, between the upper layers of the ocean and the deep ocean, and transport within the ocean, all of which control the rate of global climate change and the patterns of regional change;
- **greenhouse gases:** quantification of the uptake and release of the greenhouse gases,their chemical reactions in the atmosphere, and how these may be influenced by climate change;
- **polar ice sheets:** which affect predictions of sea level rise.

Studies of land surface hydrology, and of impact on ecosystems, are also important." (Houghton *et al.*, 1990, p. xxxi).

Overall, uncertainty can be recognized as of importance in the arena of public policy. The perceived progression from science, through impact assessment to policy, may be short-circuited if scientific consequences are stated strongly. Nonetheless, uncertainties abound at each stage of policy development. They are, unfortunately, exceedingly difficult to evaluate and understand. In this paper the issue of uncertainty and its quantification is explored in order to offer a philosophical framework for the rest of this Special Issue of *Climatic Change* which focusses on climatic impacts in Australia.

Australian Responses to the Climatic Change Issue

The Villach Conference and the statements of its findings was recognized in Australia as not simply the latest expression of the greenhouse theory but rather as a crucial pointer towards the need to assess potential impacts of future climatic change (Zillman, 1986; Pearman, 1988).

Dr Graeme Pearman of Australia's Commonwealth Scientific and Industrial Research Organization believed that it was time to encourage within Australia an evaluation of the likely impacts of climatic change. To this end, an association was forged with the Australian government's Commission for the Futgure and a joint project entitled 'The Greenhouse Project: Planning for Climate Change' was launched. An important component of this project was the 'Greenhouse 87' conference. Each contributor to this conference was supplied with a scenario of the climate of Australia projected into the future by 30–50 years. They were asked to prepare a paper describing the impacts that this scenario would have on their sectoral interest. The conference papers were published in the landmark book, *Greenhouse: Planning for Climate Change* (Pearman, 1988).

In October 1990, the Commonwealth Government announced that it would adopt an interim planning target to stabilize emissions of greenhouse gases (including CO_2, methane and nitrous oxide) not controlled by the Montreal Protocol on Ozone Depleting Substances, based on 1988 levels, by the year 2000, and to reduce these emissions by 20% by the year 2005. The Commonwealth's decision to adopt this target was endorsed by all State and Territory governments at the Special Premiers' Conference in October 1990. This target will be reviewed periodically in the light of additional scientific information about the extent of global warming likely to result from increased emissions of greenhouse gases and measurements of the likely impacts of warmer climates. It is also now being reviewed in the light of the recent international agreements on climatic change. In its decision, the Commonwealth government, while recognizing the need to restrict greenhouse gas emissions and to aim for a 20% reduction, agreed that Australia will not proceed with the adoption of response measures which have net adverse economic impacts nationally (but cf. Schneider, 1993) or on Australia's trade competitiveness, in the absence of similar measures by major greenhouse gas producing countries.

This requirement for the economic evaluation of measures to respond to greenhouse gas increases has spawned a variety of economic impact assessments including a Federal Government Industry Commission report in 1991 (see also the paper by Jones in this volume and Nordhaus, 1991 cf. Schneider, 1993). In addition, the Federal department with responsibility for the environment (the Department of the Environment, Sport and Territories (DEST)) sponsored a series of workshops designed to assess the potential impacts of climatic change in Australia with a particular goal of contributing to a compendium of costs and benefits of climatic change and climate policies in Australia. The papers in this Special Issue of *Climatic Change* are drawn from two of the workshops in this Series.

2. Uncertainty in Model Predictions

Validation of Climate Models

The policy makers summary of IPCC 1 describes the means of making a climate forecast: the model is run for a few simulated decades and the statistics of the model's climate are compared with the climate of the real world; these simulations are then repeated with increasing concentrations of greenhouse gases in the model atmosphere, thereby offering an estimate of probable future climate change. All climate modelling groups undertake validation comparisons between the simulations generated by their climate models and available observations. Until recently, however, these validation exercises have not been particularly thorough. This is partly because of the inadequacy of observational data and also because the relatively short model simulations available in the 1970s and '80s made calculation of anything other than the mean climate untenable.

Gates (1992) discusses the range of climate predictions which can, and should, be made and the climatic parameters which should be compared with observational data. It is generally agreed that knowledge of the value and the uncertainty (error in measurement) of observational fields is somewhat better than for model predictions, but that in both cases very much more information is available about mean conditions and 'common' variables than about variance, frequency distribution, and other statistics. It should also be noted that, because of the relatively coarse resolution of most GCMs, phenomena of considerable importance for impact assessment, and hence policy development, such as monsoons and droughts have generally not been included in validation exercises.

IPCC 1 contains a chapter entitled 'Validation of climate models' (Gates *et al.*, 1990). This chapter stresses the urgent need to acquire further data for climate model validation on both global and regional scales. Despite the considerable skill achieved by GCMs in the portrayal of the largescale climate, Gates *et al.* (1990) note that on regional scales there are significant errors. For example, they report that in a validation exercise conducted for five regions (the U.S. Great Plains, southern Asia, the Sahel, southern Europe and Australia) mean surface air temperatures exhibited errors of 2–3 °Celsius, compared with an average seasonal variation of 15 °C. Similar model flaws were seen in precipitation estimates, where errors ranged from 20%–50% of the average rainfall for the region.

Somewhat greater skill is achieved in simulating the radiative fluxes at the top of the Earth's atmosphere. Errors, in this case averaged around latitude circles, were mostly less than 20 W m^{-2} with an average error magnitude as low as 5 W m^{-2}, or about 2% of the unperturbed value. On the other hand, Gates *et al.* (1990) note that there were substantial discrepancies in the simulation of planetary albedo by models from which results were used in IPCC, particularly in middle and high latitudes.

Since the completion of the first IPCC reports, at least two new intercomparison programmes have been established: FANGIO, the Feedback Analysis of GCMs for Intercomparison with Observations (e.g. Cess *et al.*, 1990, 1991) and the Atmospheric Model Intercomparison Project (AMIP). Initiated by the World Climate Research Programme's Working Group on Numerical Experimentation (WGNE), AMIP has, as one of its prime goals, to provide an unprecedented opportunity for realistic and detailed validation of the ability of current GCMs to simulate the mean climate and a wide variety of associated variabilities and statistics. AMIP's design is for all participating GCMs to undertake a simulation of the 10-year period 1979–1988 using initial conditions as realistic as possible for 1 January 1979 and observed sea surface temperatures and sea-ice distributions as boundary conditions. It is anticipated that, when complete, AMIP will provide a bench-mark against which new or alternative models, or model versions, can be evaluated.

Despite about 30 years' evolution, climate models are agreed to be rather incompletely evaluated primarily because of (earlier) lack of computer power and (throughout) lack of adequate observational data. On the other hand, climate models are generally agreed to be much more completely validated than, for instance, economic models. In addition, the two problems, lack of computational power and good observations, are steadily being resolved. Nonetheless, it seems that while global-mean model projections may converge, it is less likely that high levels of confidence in regional climate model projections are achievable within the next decade.

Towards a Consensus amongst Climate Change Projections

The IPCC 1 Science Report is a remarkable document in the sense that it represents the consensus view of the overwhelming majority of atmospheric scientists throughout the world. The reported equilibrium climate changes for doubling of CO_2 include temperature increases ranging between 1.5 °C and 4.5 °C with a 'best guess' of 2.5 °C and global precipitation increases associated with the intensification of the hydrologic cycle ranging between +3% and +15%. Despite considerable scientific progress since the completion of IPCC 1, the supplementary document published in 1992 (Houghton *et al.*, 1992) underscores continued agreement to these 'most likely' scenarios of global climate change. The executive summary reports "findings of scientific research since 1990 do not affect our fundamental understanding of the science of the greenhouse effect and either confirm or do not justify alteration of the major conclusions of the first IPCC Scientific Assessment" (Houghton *et al.*, 1992, p. 5). On the other hand, no attempt was made to establish the basis for these 'best estimates' as Schneider's (1991, p. 29) comments on

"...IPCC's use of the dubious phrase 'best estimate', which is somewhat misleading because the basis for such choice is intuitive at best and IPCC did not make a communitywide survey to assess all of the 'best' guesses. The ranges that IPCC gives certainly encompass most of the credible guesses, and that is enough."

Despite this considerable consensus amongst scientific findings, it cannot be denied that even at a global scale the range amongst climate models from which results were used in IPCC is considerable (Figure 3(a)). Although the reasons for many of the differences are understood, there are also considerable discrepancies in processes and feedbacks which were thought to be understood and similarly implemented (e.g. Cess *et al.*, 1990, 1991). The model sensitivities depicted in Figure 3(a) are for equilibrium, $2 \times CO_2$ experiments and are, by and large, achieved using models incorporating only rather simplified representations of oceanic processes. IPCC 1 contains a full review of the responses of a large number of such equilibrium, doubled CO_2 experiments and uses these as the basis for a list of likely climate changes under a greenhouse-warmed world. These changes are reproduced in Table I using Mitchell *et al.*'s (1990) certainty rating in which five * indicates virtual certainty and one * indicates low confidence.

Transient (i.e. gradual rather than instantaneous greenhouse gas increase) climate model responses are described in Bretherton *et al.* (1990) and, based on a larger number (but still very few) of coupled ocean-atmosphere transient experiments, in Houghton *et al.* (1992). Generally, the temperature response of a coupled ocean-atmosphere general circulation climate model at $2 \times CO_2$ in a transient experiment is about 60% of the same model's equilibrium value after doubling CO_2 but incorporating only a simple mixed layer ocean model. The more complete ocean-atmosphere model simulations show a nearly linear upward trend in temperatures of approximately 0.3 °C per decade as a global mean response although there are major regional heterogeneities.

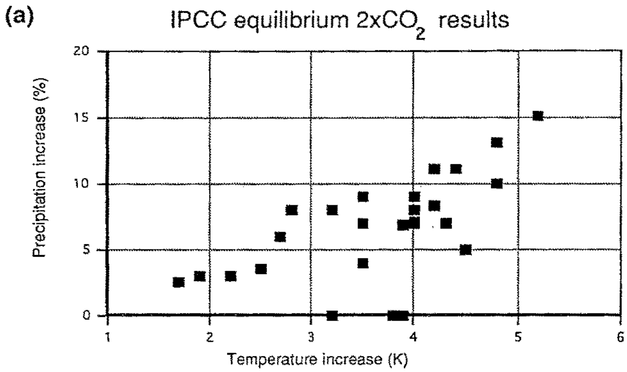

Fig. 3(a). Relative change in globally-averaged surface temperature (K) and percentage precipitation from the equilibrium, doubled-CO_2 experiments reported in IPCC 1 and its update (data from Houghton *et al.*, 1990 and 1992). Points showing zero precipitation change occur because precipitation values were not reported.

TABLE I: Confidence rating of climate system responses following a series of equilibrium, doubled-CO_2 experiments (after Mitchell *et al.*, 1990). Five *s indicates virtual certainty, one * indicates low confidence

Temperature	
Rating	*Responses*
*****	the lower atmosphere and Earth's surface warm
*****	the stratosphere cools
***	near the Earth's surface, the global average warming lies between +1.5 °C and +4.5 °C, with a 'best guess' of 2.5 °C
***	the surface warming at high latitudes is greater than the global average in winter but smaller than in summer. (In time dependent simulations with a deep ocean, there is little warming over the high latitude southern ocean)
***	the surface warming and its seasonal variation are least in the tropics
Precipitation	
****	the global average increases (as does that of evaporation), the larger the warming, the larger the increase
***	increases at high latitudes throughout, especially wintertime
***	increases globally by 3% to 15% (as does evaporation)
**	increases at mid-latitudes in midwinter
**	the zonal mean value increases in the tropics although there are areas of decrease. Shifts in the main tropical rain bands differ from model to model, so there is little consistency between models in simulated regional changes.
**	changes little in subtropical arid areas
Soil moisture	
***	increases in high latitudes in winter
**	decreases over northern mid-latitude continents in summer
Snow and sea-ice	
****	the area of sea-ice and seasonal snow-cover diminish

Overall, the 1992 update to IPCC 1 serves to increase the level of confidence in the science of climate model predictions of the response to the increasing greenhouse effect. Some apparently contentious issues, such as the water vapour feedback, have been reviewed with the generally accepted view prevailing. Otherwise the model-related uncertainties have not increased in the two years, nor, it must be added, do they seem to have been substantially decreased over the last two decades.

3. Uncertainty in Impact Assessments

Impact Modelling

The second working group of IPCC was required to assess the environmental and socio-economic consequences of predicted climate change. The first report of this working group was issued in 1990 (Tegart *et al.*, 1990) and an update is imminent.

The impact models reviewed by IPCC 2 are generally simpler than the numerical climate models upon whose output they draw. The strength of many impact models is that they are derived from empirical studies of environmental, ecological and human responses to climate change. An 'opposing' strength often claimed for numerical climate models is that they are based upon physical, or other, 'laws'. Most impact models typically depend only upon a small number of parameters and are often applicable only to a limited geographical area, climatic regime, or environmental or community situation. Assessment of uncertainty of impact models, usually based on sensitivity analysis, is probably more fully developed than for GCMs.

There has been relatively little attempt so far to compare the results from different impact models. The IPCC 2 report tends, rather, to describe regionally specific responses which depend upon only one or two models which are typically in agreement. Recently, Rind *et al.* (1992) have undertaken a very simple assessment of some fundamental aspects of surface hydrology as captured in a small number of impact models. They compare results from the Goddard Institute for Space Studies (GISS) GCM, the CERES maize and wheat prediction models, a forest dynamics model entitled FORENA and, finally, an index of water availability known as the Palmer drought severity index (PDSI). Figure 3(b) illustrates the range of variation which Rind *et al.* (1992) found for the change in evaporation calculated by each of these four models when they were disturbed by a climate change comprising only a 4.5 °C warming. Note that these evaporation changes are calculated for between 8 and 15 sites in the continental U.S.A. so that they are not comparable with the global average changes in precipitation shown on the ordinate in Figure 3(a). Nonetheless, it is interesting to see that the U.S.A.-specific range in annually-averaged evaporative changes (−1% to +18%) is greater than the precipitation change range occurring for a temperature increase of 4.5 K (+5% to +12%) predicted by the GCM (precipitation and evaporation changes are usually equivalent in the global case).

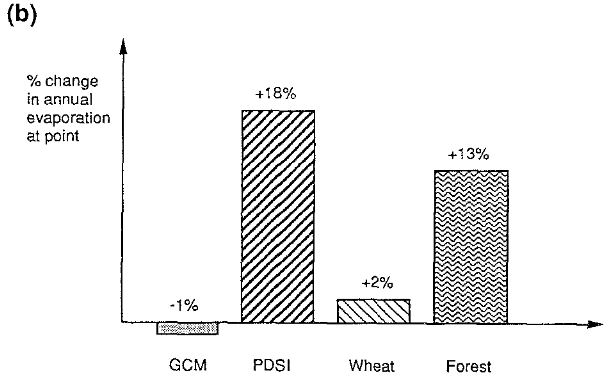

Fig. 3(b). The range of percentage change in evaporation at a specific locations in the U.S. Mid-West as projected by four different impact models when forced by a climate disturbance equivalent to an annual mean warming of 4.5 °C. PDSI is the Palmer drought severity index. (Data from Rind *et al.*, 1992).

Even fairly simple impact models can generate very different predictions of the impacts of climate change. The range of predictions is often greater than from the numerical climate models alone (Figure 2 cf. Figure 3). There is really no 'impacts community'. Instead a number of meta-communities or grouping can be identified. This means that impact assessments seem to be less well-organized and researchers less mutually aware than the climate modelling community. This is perhaps the inevitable result of the interdisciplinary nature of impacts assessment encompassing backgrounds as diverse as hydrology, social equity and economics. Thus achieving a consensus for impact models of the type exhibited in IPCC 1 is most unlikely in the near future. This special issue of *Climate Change* illustrates these truths. It comprises a set of papers which individually address potentially important aspects of climatic impact assessment for Australia but which collectively fail to offer a coherent, or even consistent, picture.

Integrated Impact Assessments

It is clear that the impacts of climate change cannot be assessed solely, or even primarily, by the use of simple, first-order, single-attribute impact models. Whilst first-order effects on natural and human communities might be significant, it is by no means certain that the second and third order effects and their synergistic interactions will be smaller. Thus impact assessment demands an integrative framework (Figure 4). Integration is likely to be demanded at least over spatial scales and sectoral issues and may also have to be attempted over different time scales.

There have been a few attempts to produce national/continental scale overviews

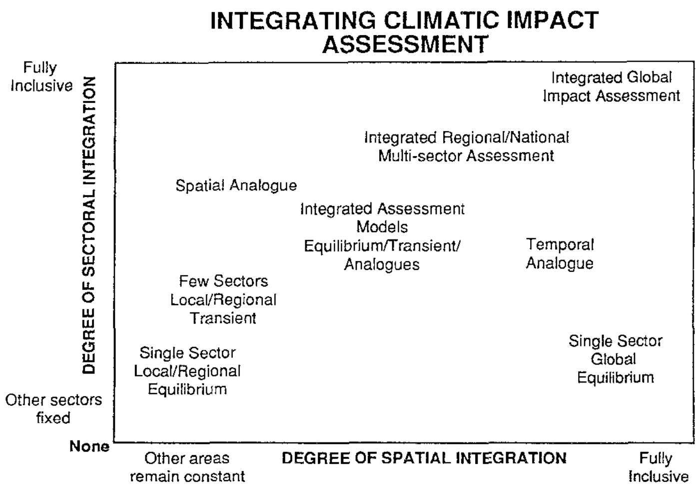

Fig. 4. The relationship between climate impact assessment frameworks measured on scales showing the degree of spatial integration and the degree of sectoral integration.

of the possible impacts of climatic change. Two good examples are assessments produced for Australia (Pearman, 1988) and for the United States (Smith and Tirpak, 1989). To date, there has been relatively little work undertaken on sectoral integration of climatic impact assessment: two recent exceptions are the MINK study (Rosenberg *et al.*, 1991) and the Mackenzie Basin study (e.g. Cohen, 1992). These studies fall towards the centre of Figure 4 since they address multi-sector impacts, the latter two being concerned also with their interactions, and comprise assessments for national to sub-national regions. Such studies are too limited (in terms of climatic inputs, models employed and the completeness of the overall assessment) to be truly representative of an integrated impact assessment. Moreover, they seem to suffer from the effects of aggregating several levels of models e.g. leaf and plant evaporation, crop districts, state agricultural prices and international futures trading.

Almost all the impact assessments reported in IPCC 2 (Tegart *et al.*, 1990) and its forthcoming update lie towards the bottom left of Figure 4 being predominantly single sector, local to regional and equilibrium assessments only. There have also been attempts to assess the possible effects on single sectors at the global scale e.g. forests: (Shugart *et al.*, 1986); terrestrial ecology: Henderson-Sellers (1990); sea-level rise: Church *et al.* (1991) and agriculture: Parry (1990).

At the national level, governments can initiate integrated assessments of potential climatic impacts. This special issue of *Climatic Change* is derived from papers presented at two workshops sponsored by Australia's Federal Department of Arts, Sport, the Environment, Tourism and Territories (DASETT, arts and tourism have since been removed from the portfolio). Stated goals of these workshops included: (i) to provide input to DASETT's compendium of costs and benefits of climate change and climate policies in Australia and (ii) to identify research groups in Australia actively engaged in attempts to measure the costs and benefits of both mitigation and adaptation strategies.

Although there are clear advantages in undertaking more integrated assessments of climatic impacts than those reported in IPCC 2, there are also disadvantages. These include the unwitting introduction of non-linearities together with the inevitable addition of uncertainty as results are fed progressively through impact models (cf. Figure 2). Any integrated assessment model has the potential to be at least as non-linear as the numerical climate model from which the inputs are derived. Care must therefore be taken (cf. IPCC 1) to validate contemporary and historial predictions before confidence is vested in future projections. It seems likely that integrated assessments have the capability of removing some of the simplistic assumptions underpinning current impact models (e.g. the neglect of demographics or economics in assessments of human health). In addition, they could be used to try to pinpoint escalation in uncertainty. On the other hand, their increased complexity cf. impact models means that the overall uncertainty is likely to increase until they, like the climate models, can be fully validated.

4. Uncertainty in Policy Development and Implementation

A Natural Scientist's View of the Policy Process

The science, impacts, policy relationship is not straightforward nor are the links balanced or equally strong (Figure 5). Although policy development is often described as if progress were linear (and rational) (cf. Figure 2), responses to greenhouse-induced climatic change at both national, and especially international, levels was initiated before the implications of the likely impact were enunciated. Greenhouse actions of this type prior to a clear understanding of likely impacts shares characteristics with the development of some medical treatments, and responses to toxics and radiation. This has led to scientific results being translated directly into the policy arena without a fully developed awareness of the possible economic and social impacts. In addition, missing this process has meant that impact models remain generally less well developed and apparently less well validated than numerical climate models although there are clear exceptions.

Policy formulation depends to an extent upn the evaluation by government and intergovernmental agencies of the importance of uncertainty in climate predictions and in its likely consequences for natural and human systems (e.g. Swart, 1992) although the importance of uncertainty is weighed against the cost of mitigation and the fact that current actions could commit future generations to a different environment. The initiation of a demand for policy change or new policy development is generally the result of confident statements about changes, impacts and their consequences or confidence in such statements by leaders and voters or, sometimes confidence about possibilities. This was certainly the case for climate

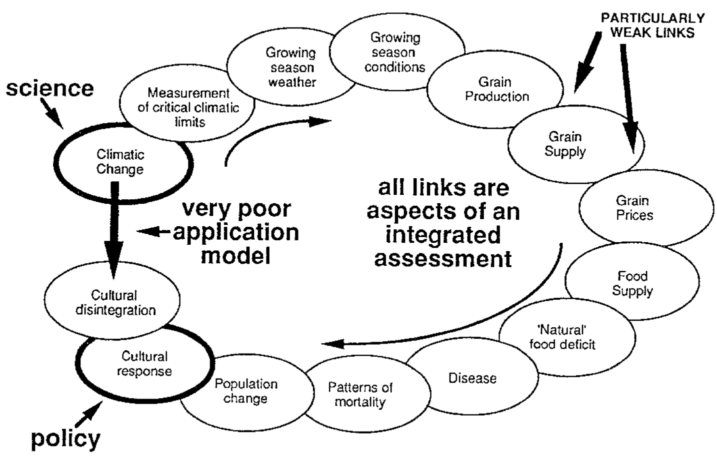

Fig. 5. An illustration of the catenary relationships linking climatic change, food resources and societal wellbeing. Poor impact models assume direct and simplistic links but a fully integrated assessment must also make many assumptions.

change which did not enter the political agenda until the scientific certainties were clearly enunciated in the mid-1980s (cf. Figure 1).

Once the demand for policy development is recognized, the national and international processes can be schematized as following roughly complementary paths (Figure 6). A rationalization of the process might be as follows: information is gathered and analysis undertaken; views are formulated by consultation and as a result of analysis; policy advisers will communicate their developing views prior to preparing a policy analysis brief. At the national level, this policy analysis brief is then the primary means by which decisions on policy formulation are made, although other factors such as the political stance of the government (and indeed sometimes the individual ministers), topic or geographical favouritism by indi-

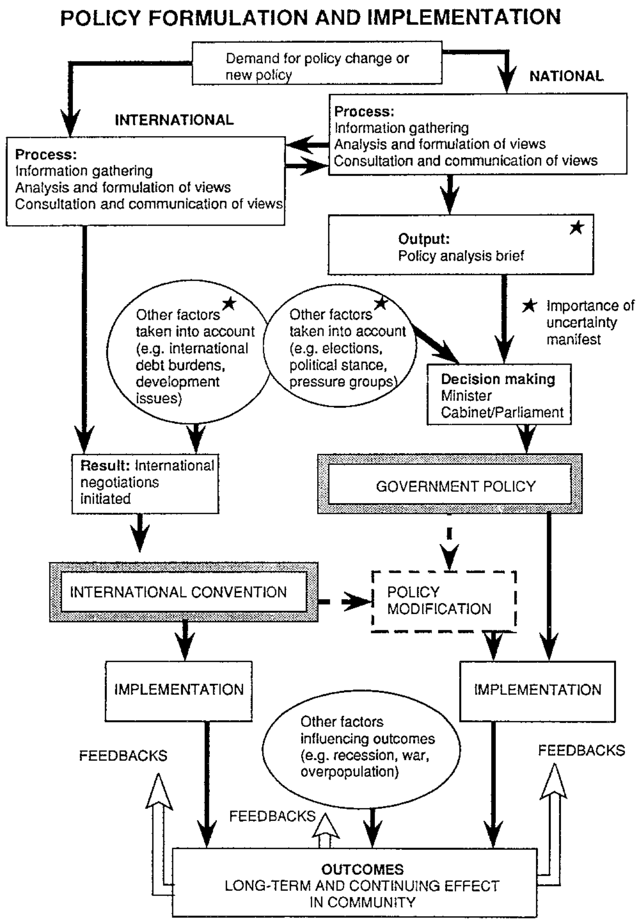

Fig. 6. A highly schematic representation of a simplified policy formulation and implementation process within national and international spheres. The starred points identify stages at which issues of climate or impact projection uncertainties may be important.

viduals (the pork barrel), the nearness of the next election and so on can also be important. In addition, it is very likely that pressure groups ranging from multinational industries to local environmental groups will bring pressure to bear during the decision-making process. Non-governmental organizations (NGOs) are becoming increasingly important in national and international policy development (e.g. Livernash, 1992). It must be recognized that Figure 6 represents an idealized process which might occur in some democracies but could probably not occur in e.g. the U.S.A. where 'pork barrelling' can dominate other aspects of bargaining within the legislature. It could be argued that this schematization presumes a level of rationality for which there is little evidence.

Although the policy analysis brief will contain an assessment of the uncertainties, it is almost inevitable that the other factors feeding into the policy formulation will lay much greater emphasis on, and probably take a more subjective view of, perceived uncertainty. Government policy, once developed or while still being developed, is one of the many factors which feeds into international negotiations. These are also prey to factors beyond the scope of climatic impacts and response *per se*. In the case of the Framework Convention on Climatic Change, these factors included the international debt burden and development issues. Similarly, the increasing uncertainty reflected in the third IPCC Report cf. IPCC 1 (Schneider, 1991) is a consequence of the increasing influence of national politics.

Once an international convention is developed, it is possible that national policies may be modified, at least in order that the international convention can be ratified. It is also the case that government policy is developed during international negotiations or even after an international agreement has been reached. Following the implementation of national policies and international conventions, and after some suitable time lapse, the outcomes as they affect the community can be assessed. Once again, these outcomes will be modified to a greater or lesser extent by other non-climate-related changes such as economic recession, war and population shifts.

It is clear that the uncertainties associated with climate projections themselves and with the resulting impact assessments are of importance in policy development. Figure 6 suggests that uncertainties are more likely in representations made by lobby groups with particular aims than in the (hopefully) objective assessments made by policy advisers. On the other hand, during the lead-up to UNCED the reverse situation occurred in both Australia and the U.S.A. in which some Federal Departments and White House staff respectively emphasized the uncertainties while the environmental lobby described the scientific certainties and argued the case for action. Finally, it is virtually impossible to detect, at least in the medium term, the effect of implementation of rather weak mitigation or response strategies because of the disturbing effects of other factors on national and global communities.

Boosting Confidence

Confidence in the predictions of climatic change and its impacts may follow the collapse depicted in Figure 2. If this 'explosion' or 'cascade' of uncertainty is a valid representation of our current and future understanding of the impacts of climatic change, it is fair to say that policy development and implementation is likely to be limited to measures, sometimes termed 'tie-in' strategies (e.g. Schneider, 1989b), which have other over-riding advantages (e.g. the reduction of air pollution in cities, the reduction in the cost of severe weather hazards, the exploitation of cheap, alternative energy sources in rural areas or the transfer of clean technologies as part of development aid). Even these policy developments are likely to be challenged if they are presented primarily as responses to the increasing greenhouse effect (cf. Lovins and Lovins, 1992). There is, therefore, considerable interest in attempts to understand, and if at all possible reduce, the current levels of uncertainty. For example, it might be considered desirable to quantify the reduction in uncertainty necessary in order to ensure stronger greenhouse gas emission reductions. If the cost of response is high then the uncertainty must be relatively lower (e.g. Green, 1992).

Figure 7 depicts some ways in which the slump in confidence could be reduced. These include:

- increasing confidence in individual models by improved model validation (primarily for present-day climate but also with reference to other, well-described climates including the recent historic past and selected palæoclimates);
- confidence in the consensus view from a large number of climate models could be increased by increased agreement amongst the models, although this is most preferably accomplished whilst still retaining different formulations and adequate validation;
- uncertainty in consensus model prediction can also be reduced (though not by as much) by improved understanding of the differences between different model projections of future climates;
- confidence in impact predictions can, similarly, be increased by improvement in the impact model and improved validation of the model;
- under certain circumstances, confidence in the impact predictions could be further increased by recognition/demonstration that uncertainty is very small or zero for certain climate outcomes (for example, beyond certain temperature thresholds most natural and many human systems cannot persist);
- confidence in consensus impact model predictions can be increased by agreement amongst different impact models and also by a concerted effort to reduce the range in uncertainty by different impact models focussing on the upper and lower bounds of predictions;
- confidence in the appropriateness of response and mitigation policies can be increased by the recognition that other factors external to climate policy can

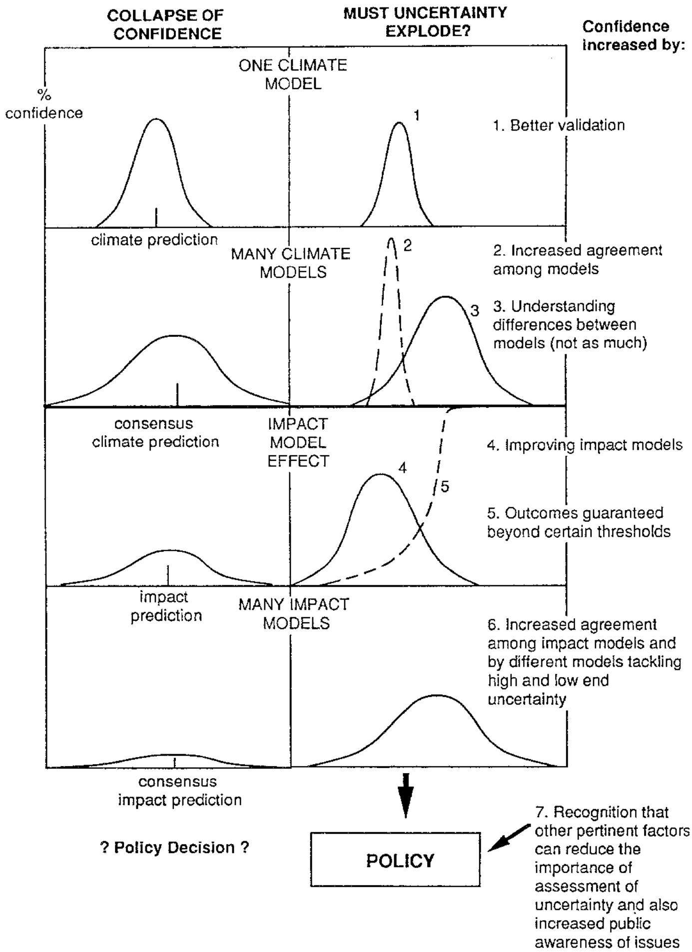

Fig. 7. Comparison of the collapse in confidence (cf. Figure 2) and a scenario in which uncertainty is greatly reduced by research efforts focussed at particularly sensitive points.

greatly reduce the importance of certain aspects of uncertainty in some circumstances. In addition, confidence in policy appropriateness is also a function of public familiarity with an issue. Thus good communication of the terms of debate can help increase public acceptance of a policy, even when large uncertainty remains. (The most familiar examples are health and economics policies which rest on great uncertainty but are also very familiar (Schneider, 1989a)).

In this special issue of *Climatic Change* the papers represent a wide variety of climatic impact issues of importance to Australia. These include: severe weather hazards (especially hailstorms, bushfires, flash floods and tropical cyclones), human health hazards and urban air quality. Many of the discussions could contribute to the means of reducing uncertainty identified in Figure 7 although the reported results are typically not yet general enough for this to occur. Although the authors describe their topics and relate them to current and future, projected, climate excellently well, the overall effect is of a collection of incomplete impact model descriptions and applications. The whole seems to become less than the sum of the parts; it falls well short of an integrated assessment.

Integrated assessment (cf. Figure 4) is clearly of great value for policy development. However, it must be recognized that any catenary (or more complex) relationship is only as strong as its weakest link (Figure 5). The science/policy debate will short-cut full and integrated assessments from time-to-time (Figure 2). Thus great care must be taken that such short cuts are not very poor impact models and that uncertainties are acknowledged but not exaggerated. The papers in this volume underline the fact that any attempt at integrated assessment of the potential impacts of greenhouse-induced climatic change is premature. The impact models are not adequately developed, are not yet evaluated for the present-day, and, most importantly, cannot yet satisfy the policy demands of government.

In summary, it seems that while scientific confidence in the basis for greenhouse warming, which originally prompted policy development, remains high, there is the potential for the 'uncertainty issue' to be captured by both those advocating strong response strategies and those challenging the usefulness of *any* policies. Despite this, remarkable progress has been made in alerting policy makers and the general public to the greenhouse issue and steps are beginning to be made towards reducing greenhouse gas emissions. It seems likely that in particular areas the degree of uncertainty may be susceptible to increased and focussed research efforts. In particular, it would be beneficial to strengthen links between impacts and science and policy. It is clear that increased understanding of the issue, and propagation, of uncertainty is highly desirable. I believe that this Special Issue of *Climatic Change* is an important contribution towards this goal.

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