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Comments on Climate Change Scenario Development

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Abstract—A short review is presented of progress in climate change scenario development. Sources of uncertainty are discussed. Critical assessment of climate models for their veracity in describing the present climate is considered essential. Methods of deriving sub-continental scale patterns of climate change, per degree of global warming, include the use of finer resolution global models, nested modelling, and spatial interpolation. Transient effects and the importance of extreme events are also discussed.

Keywords—Climate change, Scenarios, Global climate models, Greenhouse effect.

1. INTRODUCTION

There has been a marked increase in the concentrations of infrared-absorbing gases in the atmosphere since the beginning of the industrial revolution. Their expected warming effect on the surface climate has led to a widespread demand for "predictions" of possible future climate change for use in impact and policy studies.

However, various sources of uncertainty prohibit the issuing of confident predictions. Rather, "scenarios" of possible climate change are being developed for use in sensitivity studies, and as an aid to decision making regarding policies to limit greenhouse gas emissions, the adoption of adaptive strategies, and forward planning. In so far as the uncertainties regarding future climate are related to uncertain future rates of anthropogenic emissions of greenhouse gases, these uncertainties demonstrate that human decision-making may influence future climate change.

2. SOURCES OF UNCERTAINTY

Major sources of uncertainty about future climates arise from:

(i) uncertainties about future greenhouse gas emissions and concentrations;
(ii) limitations on the physical representations of processes in global climate models (GCMs), which lead to uncertainty regarding the global temperature sensitivity to increasing greenhouse gas concentrations;
(iii) differences between models as to the spatial patterns of local climate change for a given global warming; and
(iv) other less quantifiable uncertainties, such as the effect of changes in the ocean circulations (including El Niño), natural climate variability, and changes due to other pollutants such as sulfate particles.

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Emissions of carbon dioxide, the most important anthropogenic greenhouse gas, are uncertain at 2100 AD by a factor of about seven, according to the Intergovernmental Panel on Climate Change, known as IPCC [1]. The global climate sensitivity is usually expressed as the global average surface warming, at equilibrium, due to an effective doubling of CO_2 concentration, and lies in the range 1.5 to 4.5°C. IPCC, in its 1992 supplementary report [1], repeats the view that at present GCMs do not give good agreement on the regional details of climate change, even for the same global average warmings.

3. PROGRESS TOWARDS CREDIBLE SCENARIOS

The first two sources of uncertainty above are now readily quantifiable using IPCC emission scenarios and ranges of global climate sensitivity, together with highly parameterised transient (time transgressive) models of the global ocean-atmosphere system. Regarding differences between GCMs at the regional scale, considerable progress has now been made by focusing on results from the more recent and improved GCM simulations.

We have taken the view that results from different GCMs should only be considered for climate change scenarios if they can be shown to perform acceptably well in simulating the present climate. While "acceptance" is somewhat subjective, objective statistical tests can be applied to various simulated fields in comparing them with observed fields. In 1991, we did this for seven different GCM simulations of the present Australian climate, and were forced to reject five as completely unsatisfactory, accepting only two, with reservations, for scenario development [2]. However, in 1993, a similar test of five newer GCM simulations found that the worst of the newer five was better than the best of the earlier seven [3].

More recently, we have carried out statistical tests on the measure of agreement between these five more "acceptable" GCMs, in their predictions of the direction of change in precipitation between the present climate ($1 \times CO_2$) and an enhanced greenhouse climate (the $2 \times CO_2$ simulations). All five GCMs, like others, agree on a global average increase in precipitation, and on increases preferentially at high latitudes (polewards of 60 N or S).

In our statistical tests, we have eliminated both these factors, and reduced the degrees of freedom to take account of spatial correlations in the climate changes at neighbouring gridpoints. We derived a frequency distribution of numbers of gridpoints, between 60 S and 60 N, to determine how many models would be expected to agree on an increase (or on a decrease) if there were no skill in the models at the regional scale. We then compared this with the frequency distribution of levels of agreement from the five simulations.

We found that there were many more gridpoints at which all five GCMs agreed on the direction of precipitation change than would be expected by chance. According to our tests, the differences between actual numbers of agreements and those expected by chance were generally significant at better than the 99% probability level, showing that the patterns of regional increases and decreases in precipitation simulated by the GCMs are not random.

This result gives us some confidence that there is meaning in the regional climate change patterns, at least at the coarse spatial scale of the existing GCMs, which have gridpoints several hundred kilometers apart (although agreement between models does not guarantee that the models are correct). Consequently, we have felt justified in using the range of results at particular gridpoints, between the five different GCMs, to estimate a range of possible regional climate changes per degree of global warming. These estimates can be converted to regional climate change scenarios for any time in the future using transient global warming projections.

4. NEEDS FOR FURTHER PROGRESS

A useful range of climate change scenarios for various times in the future can now be generated at the subcontinental scale. However, the range of uncertainty represented by the range of scenarios is still rather large, and the spatial scale is still too coarse for many impact studies.

Moreover, other uncertainties should be quantified and reduced, such as the effect of possible changes in ocean circulations (e.g., on El Niño), effects of other pollutants, natural variability, and transient variations due to the time-transgressive nature of the real-world problem.

The spatial scaling problem is being attacked in several ways. First, the spatial resolution of GCMs is being improved, although this is computationally expensive. Second, finer resolution models of limited areas are being driven by the output of GCMs at their boundaries (termed "nested modelling") [4,5]. Third, various schemes are being explored for spatial interpolation to subgridscales.

Dynamic ocean models are also being coupled to atmospheric general circulation models to create atmosphere-ocean GCMs. These presently suffer from problems of mismatches at the ocean boundary, where slight imbalances in the energy fluxes across the ocean-atmosphere interface lead to long-term drifts in the climate. This is presently dealt with by an artificial "flux correction" method, and great efforts are going into reducing this correction term.

Transient effects are best examined with coupled atmosphere-ocean GCMs. The first few such simulations have been done with fairly coarse resolution ocean models. These seem largely to agree that, relative to "equilibrium" $2 \times CO_2$ simulations, regional differences appear in those regions of the oceans where deep convection takes place, namely at high latitudes in the North Atlantic, and around the Antarctic Convergence at about 60 S [1]. Differences between transient and equilibrium results do not seem to be important at lower latitudes, although at finer spatial resolution, some differences may appear in future simulations associated with coastal currents.

One of the main features of recent GCM simulations is the strong agreement, over most of the globe, on increases in rainfall intensity under enhanced greenhouse conditions [6]. This may turn out to have important practical impacts such as increased frequency of flood events, and increased soil erosion. This highlights the importance for climate impact studies of changes in the magnitude and frequency of extreme events [7–9]. Other examples include threshold temperatures; and the frequency, intensity and location of severe storms including tropical cyclones. Coastal impacts may in the shorter term (next 50 years) be dominated not by mean sea level rise, but by changes in the frequency and intensity of extreme coastal events such as storm surges [10]. It may be that the impact of many of these changes in the behaviour of extreme events will be felt more on the built infrastructure than on agriculture, since the latter is in many respects highly adaptable.

5. CONCLUSION

Climate scenario development is reaching a new level of sophistication, with the use of multiple GCM simulations, and increasing efforts to quantify ranges of uncertainty. In addition, moves to finer spatial resolution, and to studies of changes in the frequency and magnitude of extreme or threshold events are leading to scenarios more useful in climate impact studies. In the process, we are learning more and more about present climate variability and its impacts, and about how to bridge the interdisciplinary gaps between climate modellers and those concerned about potential impacts in the real world.

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