Risks Associated with Stabilisation Scenarios and Uncertainty in Regional and Global Climate Change Impacts.

David Stainforth, Myles Allen, David Frame, Claudio Piani
Department of Physics, University of Oxford, Parks Road, Oxford. OX1 3PU UK

Abstract

*Any stabilisation level for greenhouse gas concentrations implies an acceptance of a certain degree of climate change. The choice of a stabilisation level as a political or societal goal can therefore only be made in the context of the predicted effects of different choices. However, the science of how the earth's climate responds to changing concentrations of greenhouse gases, and particularly the probabilistic analysis of such responses, is still in its infancy. The climate*prediction*.net project has found that the response to even a relatively low stabilisation level could be substantial (greater than 11℃ for a doubling of CO_2). This is consistent with previous work using simpler models but by using complex models we are able to extract ranges of response for multiple variables, on both a global and regional level. Such results are of profound significance in terms of the risks associated with political decisions and the methodology of impact assessments.*

1. Introduction

Planning for climate change mitigation and adaptation needs to consider a range of possible futures. Even if anthropogenic greenhouse gas (GHG) emissions exactly follow some emission scenario there are significant uncertainties in how the climate might respond. Intrinsic uncertainties result from the chaotic nature of the climate system and further uncertainties result from our lack of scientific understanding. Over recent years there have been a number of attempts to quantify these uncertainties and thus produce probabilistic statements regarding the effects of climate change. Most of these have been at a global level.

Using a complex climate model we have undertaken a grand ensemble of climate simulations; made possible using the e-science, distributed computing methodology of climate*prediction*.net. In this way we have found model versions which are as realistic as other state of the art climate models but with climate sensitivities (the equilibrium global mean temperature change with doubling levels of carbon dioxide) ranging from less than 2℃ to more than 11℃. This has significant implications for any choice of stabilisation level as such a choice implies acceptance of a risk of extreme climate change.

We present here the method and analysis which leads to this result as well as the associated ranges for precipitation in Northern and Southern Europe; such regional information is critical for mitigation and adaptation planning. We also discuss procedures for extracting ranges / distributions for climate variables at a regional level. The development of analysis methods to assess the **probability** of such responses is extremely problematic and can not be simply inferred from ensemble distributions ([1]). Research is ongoing in this subject in a number of academic disciplines. In any case it is possible to carry out risk analyses for a variety of societal vulnerabilities from these types of results. The existence of the climate*prediction*.net dataset and the regional information it contains suggests a possibility for new procedures for impact analyses. Rather than such assessments being based on generalised, average information from the modellers, it may be more appropriate for impact assessments to search the whole dataset for behaviour distributions. For instance, in assessing the flood risks or agricultural impact it would be possible to search the dataset for the range of combined precipitation and temperature behaviour.

2. Background

The IPCC Third Assessment Report ([2]) provided uncertainty estimates based on the range of behaviour found in general circulation models (GCMs) and concluded that the climate sensitivity was likely to be in the range of 1.5 to 4.5℃. There are fundamental problems with interpreting this range as a probabilistic statement. First only O(10) GCMs were available so it is statistically inappropriate to identify any behaviour which only has, say, a 5% probability of occurring. And yet such possibilities could be crucial in the decision making process. Second, the climate modelling community worldwide is not large so it is not surprising that modellers share methodological approaches. Consequently the models are not independent.

Furthermore, each model is “tuned” to improve their simulations so there is inevitably a pressure for models to behave in similar ways.

There have been several more recent studies using observations of past climate to constrain the future climate response ([3,4,5]). These studies allow for the possibility of high sensitivities (>6℃) although the probability assigned to them varies.

3. Grand Ensembles

The science of climate change is still a young discipline. An enormous amount has been achieved in a very short period of time and it is clear, as concluded by the IPCC ([2]), that the earth is warming and that “most of the warming observed [since 1950] is attributable to human activities” ([2]). Consequently the scientific basis for societal action on a global level is clear. Nevertheless, it is important not to overstate what science can tell us in this field. In particular, there has been relatively little attention paid to uncertainty analyses so it is not surprising that the IPCC identified as a high priority for action the need to “improve methods to quantify uncertainties of climate projections and scenarios, including long-term ensemble simulations using complex models”.

There are three sources of uncertainty in climate change predictions. They are:

i. Response Uncertainty

This reflects our incomplete understanding of the climate system. It is not possible to carry out repeated experiments on the real atmosphere so we use climate models but there are large uncertainties in how such models are constructed. To evaluate such uncertainties we have used a perturbed-physics ensemble (PPE). Such ensembles consist of large numbers of simulations which are identical except for the values given to certain parameters; the different parameter combinations produce different “model versions”. The parameters are perturbed from their standard values within a range considered plausible by experts in the relevant parameterisation schemes. There are hundreds of uncertain parameters in a GCM and parameter perturbations combine non-linearly ([1,3]) (i.e. it is not possible to predict the effect of changing multiple parameters simultaneously, by changing one at a time) so it is necessary to carry out a Monte Carl sampling of parameter space, requiring tens of thousands of simulations. Since this is beyond the capacity of conventional super computing facilities we have used a distributed computing approach in which more than 90,000 people from over 140 countries have volunteered the unused computing capacity of their personal computers ([6]).

In the future it will be necessary to take this concept of model perturbations further by changing entire parameterisation schemes and repeating such experiments using different GCMs.

ii. Natural Variability

This is a consequence of the chaotic nature of the climate system such that very small changes at one point in time can lead to completely different states at some future time. It is addressed in models using initial condition (IC) ensembles in which small changes are made to the starting conditions of the simulation.

iii. Forcing Uncertainty

This represents the familiar uncertainty in future factors which influence climate, including anthropogenic GHG emissions, natural GHG emissions (e.g. volcanic activity) and external natural forcing (e.g. changes in solar radiation). In climate models they are represented using scenarios of different future forcings. Typically an ensemble of simulations is carried out, each representing a different scenario of possible future forcings.

Since these three sources of uncertainty interact non-linearly it is necessary to investigate them using one “grand ensemble” (i.e. ensemble of ensembles) as illustrated in figure 1. The first climate*prediction*.net experiment comprises a grand ensemble exploring model response and natural variability uncertainty using the Hadley Centre GCM HadSM3 at standard climate resolution. Within each ensemble member (simulation) the response to changing forcing is explored using a double CO_2 scenario. Using a distributed computing methodology enables us to carry out such a grand ensemble but also somewhat restricts the type of experiments undertaken e.g. the length of each phase is limited by the need to keep participant interest.

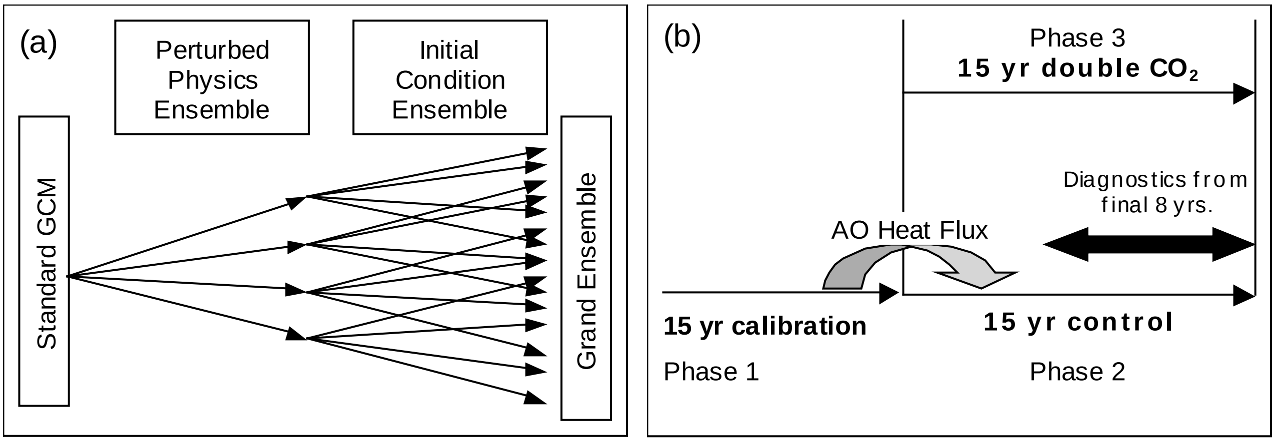

Figure 1: Schematic of the experimental design. A grand ensemble is an ensemble of ensembles designed to explore uncertainty resulting from model construction, initial conditions and forcing. (a) the standard GCM has parameters perturbed to create a large PPE and for each member of this ensemble an IC ensemble is created, producing a grand ensemble of simulations. (b) For each member of the grand ensemble 45 years of simulation are undertaken, including 15 exploring the response to doubling the concentrations of CO_2 in the atmospheric component of the model.

4. Uncertainty in Global Temperature Change

Almost 50,000 simulations have been completed to date (December 2004) and an analysis of the uncertainty in climate sensitivity from an initial subset of simulations (2578) is contained in reference [1]. Details of this analysis will be presented at the conference but can not be included here due to embargos on not yet published material. Model versions have been found with climate sensitivities ranging from less than 2℃ to more than 11℃. The problems associated with interpreting the distribution as a probability distribution will be discussed and comparisons will be made with other state-of-the-art climate models (the models from the second Coupled Model InterComparison Project {CMIP II}) demonstrating that it is not possible to rule out high sensitivities on the basis of the ability of model versions to simulate observations.

The existence of such model versions enables the hitherto impossible study of a wide range of sensitivities, with GCMs. We hope that such studies will reveal constraints on the possible range of future behaviour but such constraints have not yet been identified.

5. Uncertainty in Regional Changes

i. Results from the Grand Ensemble

A significant benefit from a grand ensemble of GCM simulations is that regional information can be extracted. Figure 2 shows the distribution of mean precipitation change eight to fifteen years after CO_2 concentrations are doubled, for Northern European and Mediterranean winter, summer and annual mean. These results are based on the same dataset and quality control procedures used in reference [1]. All model versions show an increase in Northern European annual mean precipitation (0-30%) and a decrease in the Mediterranean basin annual mean precipitation (0-40%). However, this annual mean behaviour masks more extreme behaviour on a seasonal basis. Virtually all model versions show an increase in Northern European winter precipitation of more than 10%, and up to 50%. In the Mediterranean basin the summer decrease is between 10 and 70%. By contrast there is no clear indication of even the sign of the change in Mediterranean basin winter and Northern European summer precipitation. Such information is available for other regions and variables and should provide valuable inputs to mitigation and adaptation planning. Furthermore it will be possible to extract distributions based on the combined behaviour of a number of variables e.g. temperature, cloud cover, surface pressure etc which should enable improved uncertainty analyses in impact studies.

As highlighted in reference [1] it is important not to interpret these distributions as probability density functions because they are highly dependent on the choice of perturbations explored in the perturbed physics ensemble. Furthermore, these regional distributions are not the equilibrium response. Low sensitivity model versions have reached equilibrium after eight years but high sensitivity model versions are still adjusting after fifteen. These ranges are therefore likely to represent a lower bound on the range of potential climatic response in these variables. For global mean temperature it is possible to use fitting techniques to extract the equilibrium response ([1]). A combination of re-running simulations in-house and scaling pattern analyses may help provide ranges for equilibrium regional responses.

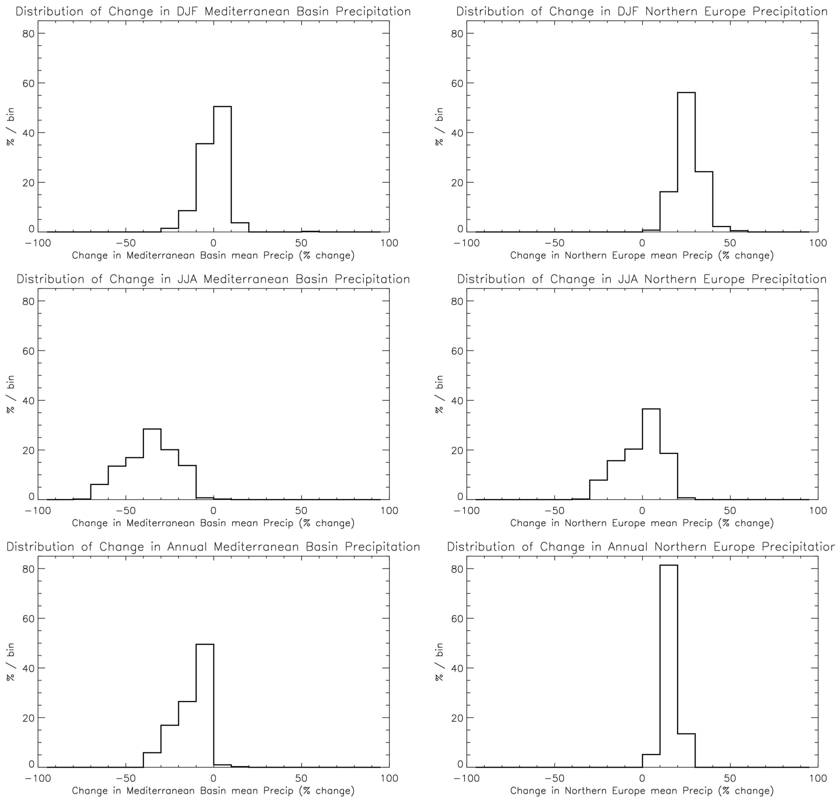

Figure 2: The distribution of changes in precipitation in response to doubling levels of CO_2 for northern hemisphere winter (DJF = December/ January/ February) and northern hemisphere summer (JJA=June/ July/August) for the Mediterranean basin ([-10:40 longitude, 30:50 latitude]) and Northern Europe (-10:40 longitude, 40:75 latitude). The changes are calculated as the difference between the control and double CO2 phases, of the mean precipitation in the region averaged over years eight to fifteen after the start of the phases (see figure 1b).

ii. Alternative Methods

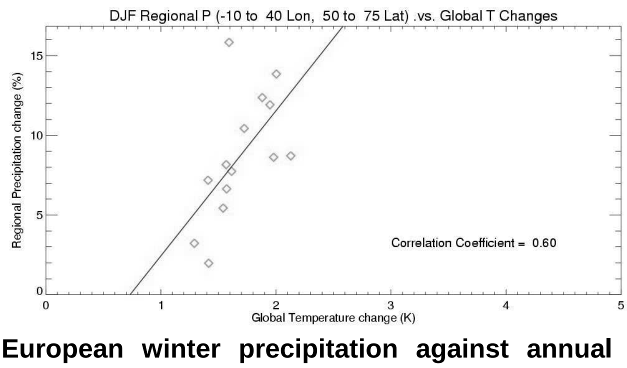

Figure 3: Northern European winter precipitation against annual mean global mean temperature change in the CMIP II transient simulations.

Beyond looking simply at the regional/seasonal distributions from the grand ensemble it is possible to extract such distributions using other methods. For instance examination of the data can reveal correlations between predicted variables of interest and better constrained or observable quantities. For instance, figure 3 shows Northern European winter precipitation against global annual mean temperature from the transient simulations of the CMIP II ensemble. The correlation appears to be good suggesting that in this case we can convert a distribution in global temperature to one in Northern European seasonal precipitation. Examination of the grand ensemble supports this result and provides the opportunity to look for such constraints in a statistically valid way. Analysis of the grand ensemble is also revealing **patterns** of observations which constrain predicted quantities; not surprisingly such patterns vary according to the predicted quantity of interest.

6. Conclusions

i. Implications for Stabilisation Levels

The disturbing conclusion of this work is that currently we can provide neither an upper bound on climate sensitivity nor an objective probability distribution for this quantity ([1]) This has profound implications for any choice of stabilisation level. In our experiment a stabilisation scenario of twice pre-industrial CO_2 levels has been studied;~ 550ppm. The results suggest that in such a scenario the response in global mean temperature could range from less than 2℃ to more than 11℃. The associated increase in Northern European winter precipitation could be at least 10 to 50% and the decrease in Mediterranean basin summer precipitation could be at least 10 to 70%. While the lower ends of these ranges could provide tolerable targets it would be unwise to dismiss the possibility that the response could be extreme.

ii. Risk Analyses

Until recently climate science has been restricted in its ability to even attempt objective probabilistic statements of potential climate response; as reflected in the conclusion of the IPCC Third Assessment Report ([2]). It is not surprising therefore that the first probabilistic analyses are broadening the range of responses which should be considered. We can not yet provide objective probabilities on climate change forecasts but requiring model behaviour to be consistent with our knowledge of past climate provides a range of possible responses. This allows for the development of risk analyses which will be hugely beneficial in mitigation and adaptation planning; particularly as further regional and seasonal information becomes available. In many circumstances it is not important to have a probability distribution but rather to be able to rule out possible futures. For instance in planning a specific flood protection scheme the design and costs may vary little for certain levels of climate change but change dramatically after a certain point e.g. 100% (or 10%) seasonal precipitation increase. In that case, if studies of the type presented herein, suggest that that point will not be met (or is very likely to be met) then it provides information of significant value for the organisation concerned.

iii. Impact Assessments

Impact assessments involve a further range of assumptions and therefore uncertainties in the analysis process and are typically based on mean predictions from the climate science community. The availability of grand ensemble data provide the possibility for impact assessments to integrate climate uncertainty into their analysis procedures. They should be able to interrogate the dataset and extract information on the combined distributions of the variables relevant for their particular impact or vulnerability studies.

Furthermore, the methodology of climate*prediction*.net provides the opportunity for a range of additional experiments and for actively involving the general public in attempts to understand the possible consequences of climate change.

7. References

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