# Casino-21: Climate Simulation of the 21st Century

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**Abstract**

The Casino-21 project aims to involve business corporations, educational institutions and the general public in a large-scale Monte Carlo simulation of the climate of the 20th and 21st centuries. Because of the chaotic nature of the climate system and the uncertainties inherent in climate modeling, the only way to assess the range of future climates consistent with current knowledge is Monte Carlo simulation. This involves running a huge number of model versions, each with a set of physical parameterisations consistent with current knowledge but different from all the rest; the larger the ensemble, the more reliable the resulting uncertainty estimate. The Casino-21 project will make possible a large ensemble by harnessing idle CPU cycles in home and office PCs. In the spirit of the SETI@home project we are adapting a state-of-the-art coupled climate model to run on a PC; current benchmark tests indicate that a 50-year integration would take 6-12 months on an up-to-date PC. Although still in the development stage, the project has generated a huge amount of interest in the media, educational circles and the general public: we will discuss the basic experimental design, initial test results and the scope for wider involvement of the academic community. For more information see: http://www.climate-dynamics.rl.ac.uk.

**Keywords**: Climate change, Distributed computing, Education, Ensemble, Uncertainty

## 1. Introduction

The Climate Simulation of the 21st Century (Casino-21) project is a collaboration between the Rutherford Appleton Laboratory, the UK Meteorological Office and the UGAMP consortium of UK universities that aims to quantify uncertainty in forecasts of human-induced climate change. One of the most rigorous approaches to uncertainty-analysis in climate change prediction is to run a very large number of full-scale climate models, each slightly different from the rest and to analyse the distribution of results. To accommodate the considerable computational cost of such an approach, we hope to capture the imagination and interest of the general public and harness the idle CPU available on personal and business computers. The project's two main themes are (*i*) the execution of a large, perhaps multi-million-member, ensemble forecast of the climate of the 21st century, and (*ii*) the raising of public awareness of the difficulties and possibilities associated with climate prediction.

The modeling of the climate system is an uncertain business. The need for a large number of model runs arises from the fact that climate models involve the parameterisation of many atmospheric and oceanic processes. Unfortunately the details of many of these parameters are only known within certain relatively large ranges. The goal is therefore to perturb selected parameterisations within their range of uncertainty and perform many simulations of the period 1950-2000. Each simulation will use a different combination of the chosen parameters. The parameter combinations that are inconsistent with observed climate change over the 1950-2000 period, i.e. up to the present day, will be discarded. The surviving simulations will be run from the period 2000-2050, providing an estimate of uncertainty in decadal-timescale forecasts of climate change under a range of future scenarios.

This Monte Carlo, or ensemble, approach to climate forecasting involves comparing the predictions of many slightly different versions of a climate model. However, an ensemble of this size requires so much computing capacity that it would not be feasible using the facilities available to the research community. Therefore, following the lead of the SETI@home project, the plan is to utilize the spare CPU available on PCs in homes and businesses. To do this the project must engage the interest of many PC owners and their interest must be maintained for at least the length of the model run, which could be a year or more. Consequently the public awareness issues will be intrinsic to the project's success.

A discussion of the uncertainties inherent to modeling the climate system is given in section 2 along with a description of the current methods used to account for this uncertainty. The experimental design of the Casino-21 project is given in section 3, and ideas on how the Casino-21 project can be used to advance the public understanding of science are presented in section 4. Section 5 describes the current state of the project, and our proposed future trajectory, while a brief statement of conclusions is given in section 6.

## 2. Uncertainty in climate change modeling

Climate researchers have a good theoretical understanding of the principles and processes that impact the climate system, but it is computationally impossible to fully implement those principles and processes given the operational constraints imposed by a numerical climate model. For example, the way in which clouds are handled is of critical importance in climate modeling, yet it is impossible to resolve individual clouds; each model grid-box is, at best, 100km on a side.

Researchers are aware of this problem and attempt to account for uncertainty in a number of ways. Perhaps the simplest approach is to assume that climate models are capable of reproducing the spatial pattern and overall time-evolution of the response to external forcing, with the only uncertainty being the magnitude of this response (although crude, there is some theoretical and model-based support for this assumption at least for forecasts over the next few decades (Allen *et al.* (2000))). It is then possible to scale the model-produced pattern of change so that it is consistent with the pattern of change seen in the observational record and assign an uncertainty range to the estimated scaling parameter. A forecast uncertainty range is produced by assuming the ratio of the magnitude of the observed pattern of change to the magnitude of the uncertainty in that pattern remains constant as one moves into the future. Thus, the uncertainty range increases as the signal strengthens. While a reasonable starting point, this approach clearly involves many, essentially untestable, assumptions concerning the linearity of the climate system's response to external forcing.

An alternative approach is to carry out an uncertainty analysis using a simplified climate model that has been tuned to mimic the output of a particular complex climate model. This approach has recently been employed by Forest *et al.* (2000) using the MIT 2D statistical-dynamical climate model of Sokolov & Stone (1998). Their approach was to systematically vary two model parameters (climate sensitivity to doubling of $CO_2$ and the rate of heat mixing into the deep ocean) and assess whether the resulting model is capable of accurately reproducing observations of the climate system. They found that observations can be accurately reproduced for a wide range of combinations of the two parameters, suggesting that the observational record does a poor job constraining the uncertainty in these two parameters, and hence a wide range of forecasts are possible (significantly wider than the range spanned by current coupled climate model simulations).

A method similar in concept to that which will be employed by the Casino-21 project the multi-model ensemble approach used by the Coupled Model Intercomparison Project, CMIP. The purpose of CMIP is to examine climate variability and predictability as simulated by a range of coupled climate models from different climate modeling centres, and to compare the model output with observations where available. In one of their experiments, they requested that a number of climate modeling centers run their climate models under a specified forcing scenario and compared the results. They found that despite the different approaches taken in the various models, the large-scale model responses were strikingly similar under the influence of a 1% per year increase in green house gas concentrations (Barnett *et al.* (2000)). The spread of predictions of global mean temperature under this forcing scenario was much lower than the estimates of uncertainty produced by the simple pattern-scaling approach of Allen *et al.* (2000) previously discussed. There are a number ways to interpret this similarity, one is that there is only one way in which the climate can respond to this type of forcing, and each of the models is capable of capturing this response. A second is that each of the models has been heavily tuned to give “realistic” simulations over the 20th century. The implication of this tuning is that each of the models is predisposed to produce a middle-of-the-road forecast; none are likely to populate the tails of the climate system’s true future uncertainty distribution.

The Casino-21 project aims to explore the uncertainty associated with a single climate model structure using a method analogous to the CMIP multi-model ensemble, but in the Casino-21 approach the model is perturbed explicitly to span the range of behaviour consistent with recent observations. Instead of analysing the response of a large number of models from different climate modeling centres, we will consider the responses of a large number of versions of a model from a single climate centre (although we ultimately intend to include any number of different model structures). The resulting climate forecast is the distribution of responses resulting from systematically varying model parameters and running forecasts. If the number of model versions considered is large enough, and a sufficiently large number of model versions have been discarded due to their inconsistency with the observed record, then we have reason to believe the forecast distribution will span the possible range of uncertainty. It must be emphasised that even this direct probabilistic approach is limited. Results will tell us nothing about uncertainty associated with processes which cannot be represented in any of the model versions considered. Given, however, our current level of understanding of the climate system, information about the uncertainty intrinsic to forecasts from our best climate models is an excellent starting point.

## 3. Experimental design

The experimental design is of obvious importance to the success of the project, but is not the point of this paper. Much of the information in this section is aimed at aficionados and may confuse the general reader; skipping the section will not diminish the reader's ability to appreciate the remainder of the paper.

The Casino-21 experiment will be carried out in two stages; the first over the period 1950-2000, the second over the period 2000-2050. In the first, participants will be requested to attempt to simulate the period 1950-2000 under the influence of observed anthropogenic, solar and volcanic forcing, using a model-version obtained by perturbing selected forcing parameterisations and physics packages in the current standard model. The response time of the ocean is much smaller than that of the atmosphere, so to ensure that individual runs are initialised with ocean states that are consistent with each possible combination of ocean parameter values, oceans will be spun up with realistic forcing for the period 1860-1950. It is currently envisioned that there will only be two ocean parameters considered, so with each parameter taking on only five different values, there are only 25 spun-up ocean states that need to be provided. Additionally, each model version will be individually flux-corrected to ensure it has a reasonably stable unperturbed climate. During the model run, an automatic comparison with observed large-scale temperature and precipitation changes over the 1950-2000 period will be carried out, and all runs which fail the test of consistency with the observed record at some level of probability (taking into account the internal variability of the climate system) will be terminated. Rejection criteria will be adjusted as the experiment proceeds to ensure that participants experience on average 2-3 terminations during the course of the experiment (this would still allow an overall rejection rate of over 95%). Only if large numbers of model versions are rejected can we be confident that we have explored the full range of possible outcomes consistent with the observed record. Participants will be given the choice of restarting from 1950 with a new, unexplored set of parameter values, or restarting at various times within the 1950-2000 window using parameter values that have (so far) survived in another participant's simulation. If a participant chooses to restart with an existing parameter set they will initialise with initial conditions different from those used by any other participant. In this way we are able to span both model uncertainty space and uncertainty in initial conditions.

In the second stage, model-versions that survive the comparison with observations over 1950-2000 will be integrated forward to 2050 using one of $\sim$20 scenarios for future forcing, including both anthropogenic and natural components based on standard economic scenarios and stochastic modeling respectively. With only 20 scenarios it will be impossible to span uncertainty in future forcing comprehensively, but quantifying the impact of this source of uncertainty is not the primary goal of this experiment. It is included primarily to examine the impact of future forcing on the complexity of the response and to stress to participants that this is an additional source of uncertainty.

The experiment will be designed to accommodate up to two million participants. The experience of the SETI@home project indicates that this level of participation is not unrealistic if the idea catches on (their current participation rate is 1.7 million, many of whom are in control of multiple CPUs). Results will still be useful with a significantly smaller level of participation: if we only distribute 50,000 versions of the model it would still represent well over an order of magnitude increase in the raw CPU available to climate research in the UK.

Even with two million participants, it will only be possible to explore the uncertainty space associated with 5 different values of 9 different parameters ($5^9 = 1953125$). This implies one must be careful when choosing which parameters will be included in the experiment. Currently, we propose (*i*) direct sulphate forcing, by perturbation of parameters in the sulphur cycle model; (*ii*) indirect sulphate forcing, by perturbation of background aerosol levels used in the off line calculation of perturbation cloud albedo; (*iii*) solar forcing, initially by varying between published estimates, although we may subsequently wish to include an off-line calculation of the possible ozone response; (*iv*) volcanic forcing, ditto; (*v*) cloud albedo feedbacks, by varying the temperature-dependency of cloud ice fraction; (*vi*) convection scheme, using a range of published schemes already implemented in the UK Unified Model; (*vii*) strength of the hydrological cycle, by perturbation of parameters (e.g. rooting depth) in the land surface scheme and bulk aerodynamic formulae; (*viii*) ocean thickness diffusion, through application of large scale perturbations on the patterns of diffusion coefficients; (*ix*) ocean vertical diffusion coefficient.

Imagine that the Casino-21 experiment has taken place and upwards of two million model responses are in hand; a critical question at this point is how does one know if the results are meaningful? Indeed, how does one assess a probabilistic description of a single event that won't even happen for 50 years? The short answer is that one can't, and that a different question should be asked, namely, how does one know that the results have *converged*. It is possible to test for convergence, but only for the parameters varied in the experiment. The experiment will not provide information about the uncertainty associated with unperturbed parameters, but it is nevertheless hoped that it will be possible to draw some conclusions about the range and type of responses in the model as a whole.

An important administrative side-bar is the question of what diagnostics should be sent from the participant's PC to the project's central server and with what frequency. Ideally, every participant would send the entire state of the climate model (atmosphere and ocean) every, say, model month. But, as each of these files would be upwards of 7 to 8MB in size, this would imply 15 terrabytes of data being sent to a central server every six hours. This is clearly undesirable and motivates the design of summary diagnostics that are capable of capturing the gross behaviour of a climate model. Such diagnostics have been developed by the climate change detection and attribution community (Tett (1999)), and will be used as a starting point for the Casino-21 project.

## 4. Public understanding of science

Running a full-scale climate model will be significantly more demanding than the SETI@home analysis programme: as noted in the previous section, benchmark tests indicate that each 50-year integration will take approximately six months of CPU time (thus up to a year of real time assuming a pessimistic 50% prior utilisation rate) on an up-to-date PC. Such a long timescale necessitates that the project is suitably interesting and/or exciting to engage the participants' interest over the course of at least one year. We feel we have some advantages which should help maintain public interest over the course of the project. Each participant will be running a self-contained model and the comparison with observations will be carried out automatically by their PC. This will minimise the need for participants to download data from the project's central server during the course of the experiment, which often tends to be a bottle-neck for distributed computing exercises. Moreover, every model-version / future forcing scenario combination will be unique, and users will be able to view selected diagnostics (e.g. animations of modeled and observed surface temperature, time-series of temperature and precipitation where they live and so forth) as the experiment proceeds. We hope the majority will develop a sufficient sense of ownership of their ensemble member to stay the course.

We can enhance this sense of ownership by providing participants with the opportunity to learn more about the climate system. Perhaps the most powerful aspect of the Casino-21 project is its ability to act as a catalyst for and gateway to additional information about the climate system, climate modeling, climate change, and their impacts. If running a climate model on your home PC doesn't provide the catalyst for learning more about the climate system, then nothing (short of finding your Florida vacation home under water) will. The Casino-21 application must provide an attractive and intuitive interface not only to the output of a participant's model but also to information about the climate system.

### 4.1. The interface

The design of the Casino-21 interface will play a crucial role in the project's success. We currently envision that the interface will consist of a dedicated Casino-21 application that incorporates web browser-like capabilities. The interface will be completely de-coupled from the model itself (which will run continuously in the background) and will display diagnostic information that the model has output to disk.

While the climate model itself will run in the background, we envision that the Casino-21 interface will be in the form of a screen saver. After a certain amount of inactivity, the screen saver will be launched and display selected diagnostics from the participant's model run. These diagnostics might include animations of global or regional temperature or precipitation change, time-series of temperature or precipitation change for a model grid-box that contains the participant's city, or even socio-economical impacts arising from the output of the participant's model. This last diagnostic is particularly intriguing as it opens an avenue for collaboration with other branches of climate change science. Groups that specialise in impact modeling can develop "plug-in" applications for inclusion in the Casino-21 release. These applications take output from the participant's climate model and return, for example, the change in malarial zones as a result of temperature change, or the change in coastlines due to sea level rise.

Each of the diagnostics discussed above has the potential to act as a catalyst to inspire a participant to learn more about the climate system. For example, upon viewing an animation of global patterns of temperature change as predicted by their version of the climate model, a participant may want to view a historical record of global temperature, or perhaps want to learn more about how the ocean effects the rate of warming in a forced scenario. This is where web browser-like capability of the Casino-21 interface would come to the fore. When viewing the global temperature change diagnostic, the application could also display a window with hyperlinks to information relevant to the diagnostic. These links need not lead to pages that exist on the Casino-21 project's server, but rather to web sites that specialise in this type of information. In order to maintain the uniform appearance of the interface, we hope to partner with such web sites and request that they provide a dedicated region of their server that mirror the relevant web pages but put them in a format that is consistent with the aesthetic of the Casino-21 interface. This would only be necessary for the first layer or two of information. If the participant desires more information, subsequent links could launch the participant's web browser and revert to the web site's original pages. Such an approach should not be limited to hard science; links to information on issues such as impacts, energy use, etc. will be included.

Adults are not the only group who will be participating in the experiment. The project has received a large amount of interest from schools around the world who wish to run climate models on the school's PCs. In addition to being an excellent source of CPU, such an arrangement suggests that specialised pages should be developed to help teachers generate lesson plans about the climate system, and use the Casino-21 interface in their teaching.

As participants learn more about how the climate system works, they can apply their knowledge to the output generated by their particular version of the climate model. We envision a situation in which participants ask questions and share their results through dedicated Internet discussion groups. These groups will act as a forum in which any number of issues associated with climate change can be addressed, and we hope to obtain the cooperation of scientists from a number of fields who agree to periodically play the role of "expert" and respond to specific questions or post essays on issues associated with a particular discussion group. The discussion group approach will also provide a framework in which participants can post and receive technical information about setting up and maintaining a Casino-21 application.

Ultimately the design of the interface will be limited not by our imagination but rather by the more mundane restrictions of time and money. However, we recognise that the Casino-21 project offers an unprecedented opportunity to educate the public about the climate system, and every effort will be made to ensure the interface is attractive, intuitive and informative.

## 5. Project status

### 5.1. Where are we now?

The project has attracted a great deal of public support. The response to the original Casino-21 article (Allen (1999)) was encouraging. 15,000 people, in control of over 50,000 CPUs, used the Internet to register their interest in their project in the first couple of weeks after the article appeared, prompted by limited coverage on some Internet-based news sites. Aspects of the project have captured the imagination of the media, particularly the idea that one of the younger participants may be able to tell their grandchildren that they were the one who made the most accurate forecast of global mean temperature in 2050. Representatives of BBC's "Tomorrow's World" programme have requested exclusive television rights to the launch, and the National Museum of Science and Technology is proposing to make this experiment a component of the climate change exhibition in their new Energy Gallery opening in 2001.

The atmospheric component of a state-of-the-art coupled climate model has been ported to

PC architecture and precision using the Linux operating system. Preliminary benchmarks suggest that a 650MHz CPU with 128MB of memory requires 13 minutes to integrate one model day of the atmosphere. This number will come down as the model is optimised for the PC, but suggests that a 50 year integration will take under 6 months to complete. The ocean component of the same climate model is currently undergoing the port, and should be complete by the commencement of the GW11 conference. The computational cost of the ocean is less than 25% the cost of the atmosphere, so a total integration time of 6 months for 50 years of the coupled model is not beyond reach given the current rate of increase of the CPU power of entry-level PCs.

Funding has been secured to facilitate the appointment of a project coordinator, and several proposals are currently pending to help finance the benchmarking of the ported climate model. Further, we are seeking corporate sponsorship to fund the port to the Microsoft Windows architecture, the design and development of the Casino-21 interface and the design and development of the data handling system.

### 5.2. Where do we go from here?

The gross details of how to proceed are clear. First, it is necessary to complete the port of the climate model's ocean to the PC architecture. Next, benchmarks must be carried out to assess the performance of both the ocean and the coupled model on PCs with various specifications. A number of model runs will be performed in-house to produce the necessary model flux corrections and spun-up ocean states mentioned in section 3.

The initial model port to PC architecture is utilising the Linux operating system, and an Alpha release of the Casino-21 client will take place to Linux users. Aside from the obvious benefit of using the operating system necessary to run the climate model, the Linux community tends to be of a more technical bent than the Windows community, and as Linux is prevalent in the academic community, we hope to target Linux users with high-speed connections to the Internet. The combination of technically-minded participants with high-speed network connections will be a benefit when attempting to solve any problems that might develop; the participants can aid in diagnosing model and/or interface problems and the high bandwidth will allow us to collect large amounts of model output. It is during this stage that we will be implementing the data-management aspect of the project, and having access to large amounts of model output will allow us to optimise the information content of the diagnostics ultimately retrieved from the operational Casino-21 application.

The port of the climate model from Linux to Microsoft Windows will be carried out by professional software developers, as will the development of the Casino-21 interface. Once complete, there are numerous avenues for distribution of the application, including the Internet, compact discs bundled with PC magazines, or even partnering with PC manufacturers who bundle Casino-21 with every PC delivered (Casino-21 could even become an unofficial PC benchmarking application: "Our PC runs the Casino-21 climate model at 9 minutes per model day!").

## 6. Discussion

Casino-21 will happen. We may fall short of our goal of two million participants, but we will port a state-of-the-art climate model to run on PCs and we will distribute versions of this model to as many participants as we are able. There is still a lot of work to do, but we are confident that we have enough scientific and public support to complete the task. We are actively searching for partners who are interested in supplying impact model plug-ins to incorporate into the Casino-21 interface, partners who are willing to develop and/or make available web pages that provide information about the climate system and partners with experience in developing web-based educational resources for schools.

Casino-21 is just the beginning. At the end of the project we will have learned a great deal about the uncertainty associated with the parameterisations of a single coupled climate model. Aside from the issue of educating the public about the climate system, Casino-21's greatest legacy will lie in the infrastructure that it constructs around a particular climate model. The next incarnation of Casino-21 will no doubt include a parameter that selects between climate models from different climate research centres. We hope that Casino-21 changes the way in which climate research is done.

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