Institution:	The University of Oxford
Unit of Assessment:	9
Title of case study:	[2] Climate*prediction*.net: engaging the public in climate science

1. Summary of the impact

A novel approach to climate science has resulted in over 260,000 members of the public worldwide choosing to engage in a climate modelling project. By contributing resources that require their time and attention, they have become 'citizen scientists'. The project has resulted in greater interest, understanding and engagement with climate science by participants; wider public discussion of climate science; and influence on policy and practice. Over 3000 people, including professionals in developing countries, have benefitted through education and training. The project has also advanced the development and awareness of 'volunteer computing'.

2. Underpinning research

In 2000, climate science was facing a three-fold challenge: the need for uncertainty estimates in model-based climate forecasts; a potentially prohibitive computational cost of conventional Monte Carlo methods; and a public suspicion that climate modelling was an activity in which models were simply tuned to give a desired outcome. That year, Myles Allen joined the Climate Dynamics group in the Department of Physics at Oxford and in 2001, together with Oxford research assistant David Stainforth and external collaborators, developed the design and first implementation of his concept of a robust ensemble of climate models that would use public participation to obtain the necessary computing power. In 2002 they set out the formal methodology of this approach and its advantages over conventional methods [1]. The crucial advance was that the *parameters* of the model would be varied, not only the initial conditions, and then that a constrained ensemble of models could be formed by weighting the parameter sets by the agreement of each set of results with recent climate observations. This was in contrast to a conventional 'expert judgement' to choose the parameters with which forecasts would be made.

Allen and Stainforth's practical implementation of this idea took the form of a parameter perturbation analysis of a standard climate model (the HadCM3 model developed in the 1990s by the Met Office, still one of the most realistic global atmosphere-ocean models available), in which each member of a Monte Carlo ensemble was run on a personal computer volunteered by the general public. In 2002, Allen was awarded NERC funding for the climate*prediction.*net project, to use this 'citizen science' approach to obtain the world's first probabilistic forecast of anthropogenic climate change. Core partners in the project were the University of Oxford (Physics and eResearch Centre), the Rutherford Appleton Laboratory, The Open University and the UK Meteorological Office. Since 2004, the project has used software from the Berkeley Open Infrastructure for Network Computing (BOINC), to which climate*prediction*.net members in the Oxford eResearch Centre made significant contributions.

The initial experiment was launched in September 2003 [2], exploring the equilibrium response to doubling carbon dioxide levels in a model with a realistic atmosphere but idealised representation of the ocean, applied to the years 1950 to 2050. The hypothesis that sufficient simulations would be performed through this experiment proved correct and the results were published in 2005 [3,4]. The experiment showed a strong asymmetry in the response of the "climate sensitivity" (equilibrium warming response to doubling carbon dioxide) to plausible perturbations of parameters. Increases in sensitivity tended to be much larger than the reductions, leading to a risk that the temperature rise would prove to be substantially higher than the 1.5 – 4.5°C range in widespread use at that time.

In 2006, the project released a significantly more sophisticated experiment, using both a fully dynamic/interactive ocean model and a time-varying (transient) forcing scenario. It accumulated the first multi-thousand member ensemble of simulations using a complex coupled atmosphere-

ocean climate model and addressed some of the uncertainties that previous forecasts may have overlooked. Results were similar to the earlier experiment in that, relative to other ensembles (notably CMIP-3), they indicated a similar low end to the distribution of projected warming, but a somewhat higher upper end that could not be ruled out by arguments that models were not a good fit to observations. They suggested that a global warming of 3°C by 2050, relative to the 1961-1990 average, was as plausible as a rise of 1.4°C [5]. This range was derived from the set of simulations that accurately reproduced observed temperature changes over the last 50 years. They implied that the world is very likely to cross the '2 degrees barrier' at some point this century if emissions continue unabated, and that warming of up to 3 degrees by 2050 is possible even on a mid-range emission scenario. This was a faster rate of warming than most other models predicted.

Myles Allen joined Oxford as a NERC Advanced Fellow (2000-03), took up a Lectureship (2003-11) and is now Professor of Geosystem Science (2011-present). David Stainforth was a PDRA (1998-2003) then a NERC Research Fellow in Physics (2003-06). Other team members in Oxford included PDRAs Claudio Piani (2000-06), David Frame (2002-06), Sylvia Knight (2003-06), Nick Faull (2005-07, previously graduate student 2001-06), Daíthí Stone (2005-08) and Dan Rowlands (2011-12, previously graduate student 2003-11); and a software engineer, Tolu Aina (2003-08).

3. References to the research (Oxford authors underlined; * denotes best indicators of quality)

1. M. Allen, J. Kettleborough and D. Stainforth (2002). Model Error in Weather and Climate Forecasting, from the *Proceedings of the 2002 ECMWF Predictability Seminar*, European Centre for Medium Range Weather Forecasting, Reading, UK, pp. 275-294. http://www.ecmwf.int/publications/library/ecpublications/_pdf/seminar/2002/sem02_allen.pdf
   This paper sets out in detail the new methodology for stable, reliable, probabilistic forecasting.

2. M. Allen (2003), Possible or probable?*, Nature* **425**, 242. doi:10.1038/425242a
   This 'Concepts' paper explained the probabilistic approach as a response to forecasting difficulties and reported the launch of the climateprediction.net project. [8 citations, Scopus]

3. *D.A. Stainforth, T. Aina, C. Christensen, M. Collins, N. Faull, D.J. Frame, J.A. Kettleborough, S. Knight, A. Martin, J.M. Murphy, C. Piani, D. Sexton, L.A. Smith, R.A. Spicer, A.J. Thorpe and M.R. Allen (2005), Uncertainty in predictions of the climate response to rising levels of greenhouse gases*, Nature* **433** 403-406. doi:10.1038/nature03301
   This paper presented early results from the project's first major experiment, which represented the first time that such a large ensemble of global climate models had ever been made available, and validated the new approach taken to climate forecasting. [469 citations, Scopus]

4. *C. Piani, D.J. Frame, D.A. Stainforth and M.R. Allen (2005), Constraints on climate change from a multi-thousand member ensemble of simulations*, Geophysical Review Letters* **32**, L23825. doi:10.1029/2005GL024452
   With more results accumulated than had been available for [3], this paper demonstrated the increasing power of the method to analyse climate sensitivity. [92 citations, Scopus]

5. *D.J. Rowlands et al [13 authors from Oxford including M.R. Allen] (2012), Broad range of 2050 warming from an observationally constrained large climate model ensemble, *Nature Geoscience* **5**, 256–260. doi:10.1038/ngeo1430
   This paper gave the first results from the more sophisticated, 'transient' experiment performed since 2006. It was highlighted in that issue of Nature's 'News & Views' and led to wider impact via implications of the distributions of forecast temperatures. Rowlands performed the analysis and wrote the paper; Allen made significant contributions. [20 citations, Scopus]

4. Details of the impact

Engagement and commitment by members of the public

To participate in the project, a volunteer – the 'citizen scientist' – installs software on their own PC and then uses it to run one or more climate modelling simulations with parameter sets downloaded

from the project server. Each assignment typically takes several weeks or months to complete, and commonly requires some degree of effort to configure the software, monitor progress or restart a run. The successful completion of over 130 million model years (January 2013) thus indicates a significant commitment of time and effort by individual users. The number of active participants, defined as having contributed effort within the previous month, is therefore considerably smaller than the total of 260,000 registered users and in May 2012 it numbered approximately 20,000.

The project's message boards, maintained by volunteer moderators, helped newcomers join the project and resolved issues with running the software and 238 discussion threads were active during the 12 months to May 2012. Many discussions on these boards were centred around the results from participants' individual models, and were stimulated by users being able to investigate how his or her particular simulation was progressing using a graphics package from the project.

Global reach and value of donated CPU time

Since 2008, over 100,000 users have joined; over 40,000 distinct users have successfully completed one or more model simulations; and of the total computational cycles in the project, all effectively donated by users, over 60% have been performed since that date. A snapshot of activity was taken in May 2012 [A]. At that time, the 20,000 active users contributed approximately 27,000 active host PCs, with a combined power of 35 TFlops. Of the 82 BOINC projects, climate*prediction*.net was the 4th most popular by work-units in progress and 5th in attracting new users. Registered users were located in 221 countries. Although the project has been running since Sept 2003, 9 of the 10 busiest days have been since Jan 2008 and in May 2012 around 30-40 new users joined each day.

The computing time required for all the model simulations run successfully since 2008 is equivalent to a 32,220 core machine running full time for one year and producing 100% successful results: the value of this CPU time has been estimated as $22.5M, based on the rate of the Amazon Elastic Compute Cloud Standard Spot Instance ($0.08/hour in 2012).

Significance to participants

Volunteers participating in the project benefitted through increased understanding of and interest in climate science, and higher levels of engagement with science more widely. A survey in 2013 gathered responses from 127 participants, only 3 of whom had never run the model themselves while 82 ran it daily [B]. Of those that answered detailed questions, 78% would feel confident describing how it worked to a friend, 59% had recommended it to friends and 46% had contributed to help or climate discussion boards. Of 57 identifying a favourite aspect, 38% cited the contribution they were making and 31% mentioned climate. One explained, *"Hearing about results was rewarding, the project also increased my knowledge of climate change as well as encouraged me to study it more in depth at my university."*

As a result of taking part, respondents reported having

- developed understanding of climate science (75%) and how research is carried out (59%)
- considered climate science to be more interesting (80%) and/or more important (73%)
- changed their behaviour to address climate change (44%)
- read further information or educational resources on climate science (67%)
- read or watched more media coverage of science (55%)

Only 35% of respondents had a degree in physics and approximately half were aged over 50.

Recognition and development of volunteer computing

The project has also contributed to wider adoption and recognition of the 'citizen science' methodology and, for example, was cited in 2010 as one of several exemplars in *The Telegraph*, where Roger Highfield wrote, "*But what is breathtaking is the scale of what is now possible.*" [C]. The methodology for assembling the very large dataset proved sufficiently robust for acceptance by *Nature Geoscience* [5]: even disregarding the outcome for research, this demonstrates the effectiveness of the approach to a formidable computational task. The project has also stimulated

discussions about its own carbon footprint [D]. The impact of the BOINC platform, now enabling an average of over 7 PetaFLOPS of volunteer computing, is also reliant in part on developments in security made for climate*prediction*.net and team member Tolu Aina was acknowledged by BOINC as an external ('volunteer') developer [E]. The project was shortlisted in 2012 for a *Guardian* University Award for Outstanding Research Impact [F].

Education and dissemination

The climate*education*.net programme has delivered two online courses in climate science, which drew on the concepts and methodology of the project, in a collaboration between the University of Oxford's climate*prediction*.net team, its Department for Continuing Education, and the UK Met Office Hadley Centre's PRECIS team. A free online course had 3188 participants by March 2013 from over 171 nations, 45% of whom were from developing countries. A second course in 2012 was aimed at professionals requiring a more in-depth understanding of climate science; all but one of the eighteen students enrolled were from developing countries (defined by ISI list, 2013). Climate*prediction*.net also featured in the exhibition entitled 'Atmospheres, Investigating the Weather from Aristotle to Ozone' in the Museum of History of Science, Oxford from November 2011 to March 2012, during which time approximately 50,200 people visited the museum. Downloads of teaching resources from the project website in 2013 were exceeding 150 per month.

Influence on opinion, policy and practice

Brian Appleyard, a commentator for *The Sunday Times*, reported in 2009 that his views on climate change were altered by discussion with Allen, amongst others, and wrote of climate*prediction*.net, "*Try it. You should. … All complex systems are uncertain. But, for two closely related reasons, the denialists are wrong to claim this as an argument in their favour."* [G]. The results released in 2012 [5] attracted global press coverage, e.g. in *USA Today* [H], for the 4.5°C warming scenario.

Allen's 2002 methodology paper [1] was cited in the 2007 Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (working group I, Chapters 9 & 10), which has stimulated policy discussions globally ever since. The IPCC 5th Assessment Report (2013) was released in draft to governments on 7th June 2013 and its content has been influenced by results of this research: for example, Rowlands et al 2012 [5] is cited three times. In particular, Chapter 11 acknowledges the variation that results from perturbations in a climate model and draws implications for a '*pragmatic approach*' to the definitions of 'likelihood' in climate predictions (section 11.3.6.3 and Figure 11.25; no author of [5] was author or reviewer of that chapter).

5. Sources to corroborate the impact (indicative maximum of 10 references)

Reach: magnitude and value of contributed CPU time:

[A] Climateprediction.net user statistics, May 2012: http://boincstats.com/en/stats/2/project/detail

Significance to participants:

[B] Survey results from 127 visitors to the website, Jan-Jun 2012, held on file.

Recognition and development of volunteer computing:

[C] Roger Highfield, *The Telegraph*, Nov 2010: http://www.telegraph.co.uk/science/roger-highfield/8153252/Crowdsourcing-and-open-source-knowledge-is-a-gift.html
[D] Coverage by *The Guardian*, Damian Carrington, Nov 2010 and comments from readers debating power consumption: http://www.guardian.co.uk/environment/2010/nov/17/weatherathome-climate-change-weather-project
[E] Acknowledgement of Aina's contribution to BOINC, http://boinc.berkeley.edu/
[F] Guardian University Award for Outstanding Research Impact shortlist: http://www.guardian.co.uk/higher-education-network/2012/dec/17/university-awards-shortlist

Influence on opinion and policy:

[G] Coverage by *The Sunday Times Magazine*, Bryan Appleyard, 29/9/2009, p10-14
[H] Coverage by *USA Today* online, Doyle Rice, 25/3/2012, http://content.usatoday.com/communities/sciencefair/post/2012/03/climate-change-global-warming-temperature-rise-model-predict/1