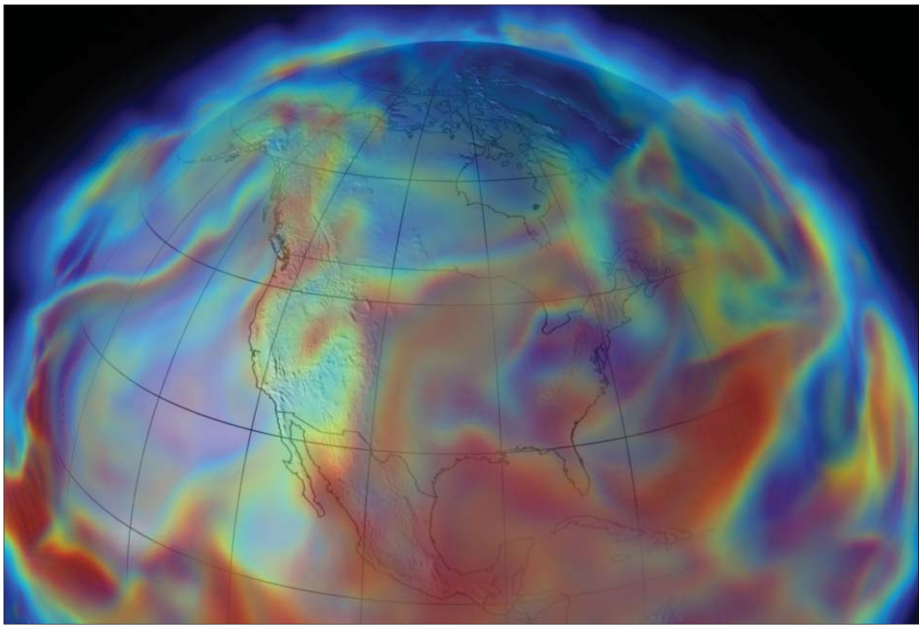
A CERN for climate change

Providing reliable predictions of the climate requires substantial increases in computing power. **Tim Palmer** argues that it is time for a multinational facility fit for studying climate change


Trent Schindler, NASA/Goddard/UMBC

A global approach to a global problem Modelling the climate may require a unified strategy for computing.

This winter has seen unprecedented levels of travel chaos across Europe and the US. In particular, the UK experienced some of the coldest December temperatures on record, with snow and ice causing many airports to close. Indeed, George Osborne, the UK's Chancellor of the Exchequer, attributed the country's declining economy in the last quarter of 2010 to this bad weather. A perfectly sensible question to ask is whether this type of weather will become more likely under climate change? Good question, but the trouble is we do not know the answer with any great confidence.

The key point is that the cold weather was not associated with some "global cooling" but with an anomalous circulation pattern that brought Arctic air to the UK and other parts of Europe. This very same circulation pattern also brought warm temperatures to parts of Canada and south-east Europe. Global mean temperatures were barely affected.

Weather-forecast models, which only have to predict a few days ahead at a time, are able to represent this level of detail very well. Global climate models, however, such as those used in the fourth assessment report by the Intergovernmental Panel on Climate Change (IPCC) to predict weather systems 100 years or more ahead of time, do not work as well. The problem is that simulating these weather patterns in comprehensive numerical models – also known as "simulators" – requires a rather fine grid-point spacing of about a few tens of kilometres or less. The IPCC models, however, typically have a grid spacing of hundreds of kilometres and so such climate simulators cannot assess reliably whether this type of weather pattern – cold in Europe, warm elsewhere – will become more or less likely with increased atmospheric greenhouse-gas concentrations.

Unfortunately, this is but one example of the many uncertainties about regional climate change that are exacerbated by a lack of resolution in climate simulators. Even when considering increases in global mean temperatures, we cannot be sure whether climate change will be a catastrophe for humanity or something we can live with and adapt to. This uncertainty arises, primarily, not because we do not know the relevant physics of the problem, but rather because we do not have the computing power to solve the known partial differential equations of climate science with sufficient accuracy.

In a nonlinear system, which the climate certainly is, getting the detail right can be important for understanding the large-scale structures. A manifestation of this problem is that no contemporary climate model can simulate the Earth's climate without systematic errors in its wind, temperature and rainfall fields. These systematic errors are often as large as the climate-change signals being predicted. In a nonlinear system, this is not a recipe for confidence.

We also have no theoretical framework to tell us how well resolved a climate simulator has to be to reduce the uncertainty in predictions of global mean temperature by a factor of two or more. For example, in order to be able to resolve deep convective cloud systems, known to be crucial in transporting heat moisture and momentum from the planet's surface into the high troposphere, a climate simulator needs to have a grid-point spacing of at least 1 km. But we cannot say, short of actually doing the numerical experiments with such a grid, how much more accurate a climate simulator would be if these deep convective clouds could be properly represented by the laws of physics, rather than represented as part of the set of relatively crude parametrized closure formulae, as is currently the situation.

We do not have sufficient computing power to solve the equations of climate science with sufficient accuracy

That the climate equations are so difficult to solve is exemplified by the fact that even the existence and uniqueness of smooth solutions to the climate equations (in particular the Navier–Stokes fluid-flow equation) is still unproven. Solving this "existence" problem is one of the Clay Mathematics Institute's "millennium million-dollar problems", right up there with the Riemann hypothesis as a key unsolved mathematical problem for the 21st century. Climate is a tough problem; indeed, there is none tougher in computational science.

Computing needs

There are many reasons why the computing needs of today's climate modellers are not being met. Increasing the resolution of models is computationally expensive: halving the grid spacing can increase computational costs by up to a factor of 16. Moreover, national climate-prediction institutes, such as the Meteorological Office in the UK, have many other demands on their computing resources. For one thing, they need to develop numerical algorithms that can simulate not only the fluid dynamics, but also the relevant chemistry and biology of the Earth system that are needed, for example, to represent the planet's carbon cycle. In addition, they have to run large Monte Carlo calculations in order to estimate uncertainty in the effects of inevitable computational approximations. On top of this, they need to not only run the climate simulators centuries into the future, but also on 1000-year integrations over past climatic periods (when abrupt changes were abundant).

However, in the UK, for example, the supercomputers used exclusively for meteorological and climate research barely make the list of the world's top 50 most power computers. The goal here is not a million-dollar maths prize, but rather confidence about the trillion-dollar-plus implications of climate change. A more accurate assessment of the real level of threat posed by climate change is crucial, not only to help to break the current stalemate in mitigation talks, but also if we are to invest wisely in new infrastructure to adapt to climate change. And we will certainly need much more accurate simulators of climate than we currently have, if we are ever to take seriously the issue of climate geoengineering, which concerns deliberately manipulating the Earth's climate to counteract the effects of global warming.

So, given the importance of the problem, surely climate scientists should not have to choose between adding chemistry and biology on the one hand, and increasing simulator resolution on the other. Surely we should be doing all that is humanly possible to ensure that both are achievable, if that is what the science demands.

Calling for collaboration

Climate change is a global problem that requires global solutions. Humanity has repeatedly shown that it is more than able to step up a gear in technical and scientific achievement when there is the desire to do so. For example, countries have come together to build the sort of technological marvels unachievable at the national scale. In Europe, such examples include the ITER fusion facility, which is currently being built in Cadarache, France, the many space missions built by the European Space Agency, and the Large Hadron Collider at CERN near Geneva. These facilities have come about because national budgets have been insufficient to tackle key problems in space physics, particle physics or fusion research.

It is time to start planning for a truly international climate-prediction facility, on a scale such as ITER or CERN. Such a centre would not replace existing national climate centres. Rather, it would allow them to do the sort of research experimentation currently impossible. Indeed, the collaboration between the proposed facility and the national climate centres could be similar to that between CERN and the university groups that devise the experiments run at the lab. There would be collaboration rather than competition.

Such a facility would allow the dedicated use of cutting-edge exascale (10^{18} operations per second) technology for understanding and predicting climate, for the benefit of society worldwide as soon as this technology becomes available in a few years' time. Not a number 50 machine for a number 50 problem, but a number 1 machine for a number 1 problem. It is time to step up a gear if we really want to understand the nature of this climate threat.

Tim Palmer is a Royal Society Research Professor at Oxford University in the UK, and co-director of the programme on predicting climate change at the Oxford Martin School, e-mail t.n.palmer@atm.ox.ac.uk