How Mathematical Models Can Aid our Understanding of Climate

Conference on the Mathematics of the Climate System; University of Reading, Reading, United Kingdom, 13-15 September 2011

Around forty researchers attended a conference run by The Institute of Mathematics and its Applications (IMA) to discuss the mathematics of the climate system. The conference focused on the construction and use of mathematical and computational models. The entire hierarchy of models was considered, from the conceptual to the comprehensive. Conceptual models provide understandable paradigms for dynamical climate-system behavior, enabling us to assess and interpret comprehensive models.

The conference considered four related contemporary challenges in mathematical climate science: extracting deterministic and stochastic models from measurements and simulations of the climate system; determining the properties and dynamics of reduced-complexity models; confronting scientific hypotheses about the climate system with data; and using data from comprehensive models and reanalyses to perform mathematically-based diagnostic studies of climate dynamics and statistics.

Five invited speakers gave broad one-hour lectures to set the scene for the contributed talks and posters; they were Daan Crommelin, Michael Ghil, Chris Jones, Jonathan Rougier, and Joe Tribbia. All the presentations are available at http://www.ima.org.uk/Conferences/mcs2011.html. Selected papers will be published in a special issue of *Philosophical Transactions of the Royal Society A*, entitled "Mathematics Applied to the Climate System".

One way of developing an understanding of the climate system, and hence a predictive capability, is to attempt to explain the observed variability in terms of simple stochastic models. These are usually ordinary stochastic differential equations, with the partial differential equation aspect covered through modeling of the coupling between variables as a stochastic process.

The process of fitting such models to data by estimating the parameters is an inverse problem of the type encountered in many other applications, such as atmospheric data assimilation and oil reservoir modeling. As such, there is a strong commonality between the tools used in each case, and this was well represented at the meeting. Data assimilation contributes directly to prediction, but it is also used to construct stochastic differential equation models, so it contributes indirectly to understanding.

There is an increased emphasis on decadal prediction in, for example, the forthcoming Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Thus, definition of the initial conditions for the slowly evolving components of the climate system, such as the deep ocean and the cryosphere, will be essential. Clearly, further improvement of assimilation techniques will be required for slowly evolving models that are inherently imperfect.

Finally, the conference considered the verification and validation of climate model computer codes. All complex models have errors, and suggestions for verifying the models included using subjective human intuition to "ring alarm bells", using modularity to compartmentalize the software, and employing

professional software engineers. Models must be validated as well as verified, because they are expected to perform beyond the range of reliable intuition. Palaeoclimate records, theory, and physically based simple models of parts of the climate system, all make useful validation tools.

Paul D. Williams, University of Reading, Reading, United Kingdom; E-mail: p.d.williams@reading.ac.uk; Michael J. P. Cullen, Met Office, Exeter, United Kingdom; and John M. Huthnance, National Oceanography Centre, Liverpool, United Kingdom.