How Mathematical Models Can Aid Understanding of Climate

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

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About 40 researchers attended a conference by the Institute for 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 researchers 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 speakers gave broad 1-hour lectures to set the scene for the contributed talks and posters; they were Daan Crommelin (Centrum Wiskunde & Informatica), Michael Ghil (Ecole Normale Supérieure and University of California, Los Angeles), Chris Jones (University of Warwick), Jonathan Rougier (University of Bristol), and Joe Tribbia (National Center for Atmospheric Research). Many of 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 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 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 of the Intergovernmental Panel on Climate Change. 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. 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.

The authors of this meeting report gratefully acknowledge support from the remainder of the scientific organizing committee: Colin Cotter, Mike Davey, Christopher Ferro, and David Stainforth.

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