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BOOK REVIEW

Andrew Fowler: Mathematical Geoscience

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Jean-Claude Mareschal

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The word model is one of the most used and often abused in the geosciences. It has taken several different meanings: when physicists talk about the Bohr–Sommerfeld or the standard models, they refer to fundamental explanations. When geoscientists refer to a model, they sometimes refer to a collection of data (gravity model *xyz* of the Earth's gravity field, for instance, or seismic tomography model abc of the Earth's mantle). A numerical model is really a set of numerical experiments. Mathematical modeling is a different thing, it is the formulation and solution of (geo)physical problems in mathematical terms usually with analytical solutions. It extracts the essence of a physical problem and reduces it to a tractable mathematical problem. Mathematical modeling requires technical skills, but, first and foremost, it is an art: it demands at least as much physical intuition as mathematical technique. Andrew Fowler, the author of *Mathematical Geoscience*, has been teaching applied mathematics for geoscientists at the University of Oxford. He has devoted most of his research career to mathematical modeling of different problems in the geosciences. He has a long and diverse experience in the field, and, most importantly, he is a great artist!

Mathematical Geoscience covers many different topics related to the earth, oceans, and atmosphere, but one can see that they all belong to the very wide field of geophysical fluid dynamics. They include climate, atmospheric physics, oceanography, geomorphology, glaciology, petrology and volcanology and mantle convection. Geophysical fluid dynamics belongs to a British tradition in applied mathematics; a tradition based on the works of John Scott Russell, Lord Rayleigh, Sir Horace Lamb, Sir Harold Jeffreys, G.I. Taylor, Batchelor, and many others. One of the characteristics of the British school of applied mathematics is its empirical approach; these mathematicians can even devise experiments to refine their mathematical models.

J.-C. Mareschal (✉)
University of Quebec, Montreal, Canada
e-mail: mareschal.jean-claude@uqam.ca

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The book contains 11 chapters of variable lengths, and several short appendices. The first chapter is a general and short introduction to the methods of mathematical modeling. It is not an absolute prerequisite to the following chapters, but it is useful to read it first. All the following chapters can be read independently of each other, and there is very little overlap between them. The following chapters cover climate dynamics, oceans and atmosphere, river flow, dunes, landscape evolution, groundwater flow, mantle convection, magma transport, glaciers and ice sheets, and Jökulhlaups, an unfamiliar term before reading this book (it is in fact an Icelandic word meaning glacier burst). Each chapter includes a useful review of the topic and of the issues that the author intends to address. A mantle geodynamicist will easily find his way through the chapter on climate, a glaciologist will not be lost in mantle convection and an atmospheric scientist will understand the thermodynamics of magma. Each chapter ends with notes and references for further reading. These notes provide a critical review of the available literature and a discussion of the open questions and controversies in the field.

One cannot expect each chapter address in detail all the facets of the topic that it covers. For instance, mantle convection is treated in some 75 pages, including the notes and introduction, while the now standard book on mantle convection by Schubert, Turcotte, and Olson is almost 1000 pages long. It could be argued however that the 75 pages of *Mathematical Geoscience* provide all the elements necessary to understand thermal convection and how it might work in the Earth. Topics include linear stability analysis for the onset of convection, the stability of plan forms in the Bénard cells, the boundary layer approach in high Rayleigh number convection, convection with variable viscosity and the formation of plumes, rheology of mantle rocks near the Earth surface and subduction (for example why does plate tectonics occur on the Earth?), and some speculations on the tectonics of Venus. The notes include a short but high-quality discussion of the active controversies and recent discoveries (such as the role of plumes in mantle convection, the Archean paradox, the post-perovskite transition, and more). Like physical experiments, mathematical models do not aim at reproducing every detail of mantle convection but to provide physical insight. We understand better how mantle convection operates by looking at these models even if the mantle is very different from them. Geophysical data, seismic tomography as well as long wavelength gravity, are conspicuously absent from this presentation. Geological constraints (such as plate tectonics) are covered more thoroughly than geophysical ones. Seismic tomography images are not indispensable but may serve to strengthen this presentation. Nevertheless, students looking for a solid introduction to the physics of mantle convection would be encouraged to read the corresponding chapter in this book before getting lost inside more comprehensive treatments.

Some of the other chapters are entirely outside this reviewer's field of expertise. Even though I skipped many of the technical details, I have enjoyed reading them. Several chapters in this book are devoted to surface processes, from river flow to dune formation. Adrian Scheidegger's book *Theoretical Geomorphology* showed many years ago that geomorphology is not only about describing landscape, but that simple mathematical models are useful and necessary to understand how landscapes form and evolve. Rutherford once said that all science is either physics or stamp collecting. *Mathematical Geoscience* demonstrates that geomorphology does not need to be stamp collecting!

The appendices are very useful, particularly the appendix on phase changes and melting. Thermodynamics is needed in different sections of this book, and I found in the appendix a clear introduction to all the advanced thermodynamics that is required. Each chapter contains a set of exercises. These exercises are well exposed and developed, but I must confess that I found most of them extremely challenging. I have no doubt that the students who can work their way through all of them could compete for the title of senior wrangler. *Mathematical Geoscience* is not only an excellent textbook for an advanced course in mathematical modeling for geoscientists and applied mathematicians, but also an invaluable reference for researchers, as I found out by my own experience. Recently, as I was trying to tackle some problems on the thermal regime of ice sheets, I went through the chapter on glaciers and ice sheets and found both the information and the tools that I needed to solve my problem.

Nothing illustrates better the link between applied mathematics and the physical reality than photographs of fluid dynamics phenomena. In the tradition of many fluid dynamics texts, this book includes a number of such photographs. Gravity waves in the atmosphere, roll waves and tidal bores, layered intrusions, and glacial landforms are all illustrated by spectacular photographs. I am particularly fond of two pictures of tidal bores on the river Severn, in England, that illustrate the beauty of fluid dynamics. These images remind us that mathematical models must always remain close to the physical world. This approach is in line with the tradition of the British school of applied mathematics. A great tradition!