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Modeling Methods for Marine Science

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climate, cover a continent with ash, and reset evolution. The term super volcano, popularized by the Discovery Channel, does not begin to describe the phenomenon, which leaves some evidence in geological, archaeological, and DNA records, but blows most of it away. Civilization, certainly, and humankind, probably, will not survive the next one. Clive Oppenheimer's *Eruptions That Shook the World* makes the case that we should understand these events. It also inadvertently makes the case that contemporary theories about the ultimate causes of world-class eruptions are as myth-driven as those involving Hades and Poseidon.

Oppenheimer, a reader at the University of Cambridge, argues that volcanoes and life have been intertwined throughout time. Did volcanic eruptions extinguish dinosaurs, change evolution, help humans evolve, decimate human populations 73 000 years ago, and contribute to the French Revolution? Oppenheimer uses all sorts of evidence to unravel the stories behind some of the greatest and most significant volcanic cataclysms. The book is well illustrated, including many examples of magnificent mushroom clouds—volcanic plumes—that bear startling resemblances to the cartoon in chapter 1 showing "killer plumes" in Earth's interior. Each chapter starts with a well-selected quote and ends with a useful summary.

Eruptions That Shook the World opens with the profound statement, "The Earth is cooling down!" The implications of that cooling are far-reaching and are even now not fully appreciated, 150 years after Lord Kelvin's spat with geologists. The mantle still retains enormous quantities of original heat. Volcanoes do not require heating or the importation of heat and matter from Earth's remote, deep interior. They occur because the mantle melts as it rises, in response to tectonic forces, or because it already contains magma that waits to be tapped. The relatively trivial effects of glaciers are enough to trigger eruptions by changing the load on or the orientation of the least compressive axis in the crust. Cooling, stretching, and breaking of large insulating plates allow the underlying magma to erupt: Hawaii and Yellowstone are prominent examples. Gas pressure and changing stress—not deep hot jets—trigger the release of magma.

Oppenheimer argues that recycled crust covers the core and converts core heat into killer plumes. However, that mechanism for raising or maintaining temperatures is 10 times more efficient at the top of the mantle. Moreover, the largest of the million-year-long eruption episodes signaling the breakup of plates empties out only a fraction of the magma that is stored in the shallow mantle beneath the plates. The large volume of available shallow magma was recently confirmed by Scott Bryan, Edgardo Cañón Tapia, and the late Paul Silver.

What Oppenheimer does not mention is that the understanding of the origin of large volcanic provinces is undergoing a classic paradigm shift—a shift back to the theories that favor top-down, stress-guide, low-pressure, and athermal shear-driven plate tectonic–related processes. This book presents the bottom-up, pot-on-the-stove analogy as noncontroversial conventional wisdom for the formation of killer plumes. That analogy is motivated by the shapes of thunderheads and volcanic plumes in the atmosphere, with no regard for scale or physics.

Mantle cooling drives convection and affects the geotherm in nonintuitive ways. Heat generated by radioactive decay modulates that cooling (see the Letters discussion, PHYSICS TODAY, November 2010, page 8). The competing processes of conductive cooling, radioactive heating, and thermal convection and advection, acting in the upper mantle, create a thermal bump—the cause of the asthenosphere and the source of most magma. J. Tuzo Wilson, one of the fathers of the plate-tectonic and hot-spot hypotheses, proposed that volcanic chains such as the Hawaiian Islands arose from the depths just below the rapidly moving plates.

I recommend *Eruptions That Shook the World* as motivational reading for physics students looking for a thesis topic in Earth or environmental sciences. The book may encourage physicists to take up the fascinating but challenging mission of understanding the workings of deep Earth and the claims that are made for it. The deep-Earth sections need to be read in parallel with Gillian Folger's *Plates vs Plumes: A Geological Controversy* (Wiley-Blackwell, 2010) to get a balanced view of the issues (see also http://www.mantleplumes.org).

Ironically, the early views of Walter Elsasser and others on plate tectonics and mantle convection as top-down processes with volcanoes as by-products can be understood without invoking deep-Earth physics. However, appreciation of the effects of secular cooling, self-compression and scale, and the classical physics of Elsasser, Francis Birch, Peter Debye, and Eduard Grüneisen is required if scientists want to avoid the fundamental errors that occur in existing canonical models of mantle dynamics and geochemistry. Birch noted that words such as "dubious" and "vague suggestion" become "undoubtedly" and "positive proof" when applied to deep-Earth theories. By extension, "killer plumes" is merely a "high-pressure" name for volcanoes or a thick series of lava flows.

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Modeling Methods for Marine Science

David M. Glover, William J. Jenkins, and Scott C. Doney
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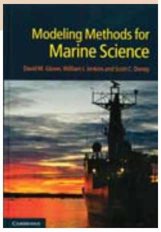

The use of mathematical and computational models is now commonplace in interdisciplinary scientific fields. Yet students entering graduate school in those fields come from diverse undergraduate backgrounds, and many are unfamiliar with the mathematical and numerical techniques they will meet in their careers. For graduate students and researchers in marine science who wish to learn how to develop and use computer models, the deficiency has been addressed by *Modeling Methods for Marine Science*, written by biogeochemists David Glover, William Jenkins, and Scott Doney.

The research fields of those highly accomplished and respected authors, who all work at Woods Hole Oceanographic Institution, are reflected in the book's concentration on the tools needed for biogeochemical and ecosystem modeling. The largely self-contained text includes coverage of a broad range of topics and emphasizes a practical, hands-on approach to modeling. Most chapters have a good selection of exercises, and many of the examples in the text include Matlab numerical code.

Modeling Methods for Marine Science is divided into three parts. The first seven chapters provide a brief introduction to Matlab and broad coverage of data-analysis techniques. Those techniques include basic probability and error analysis, regression, and common geoscience multivariate techniques such as empirical orthogonal function analysis, time series, and objective-mapping methods. The data-analysis coverage is a valuable and novel aspect of the book because the techniques considered are generally not found in modeling texts even though they are essential tools for relating models to data and observations.

The next five chapters present a whirlwind tour of numerical techniques for solving ordinary and partial differential equations. Most of the material is standard, but two chapters stand out: One contains an excellent tutorial on how to build computational models from scratch, including many strategies that modelers use daily, and another describes how to optimize models and assess results. Both topics are often neglected in textbooks.

In the remaining seven chapters, the authors highlight various illustrative models used in marine science—for example, a sediment diagenesis model and one- and two-dimensional upper-ocean models. The authors make the models accessible to a broad audience by explaining the rationale and background for each, and they provide detailed Matlab code in each case. Their examples, based on published models, could easily be adapted for classes in environmental physics or engineering. Two chapters give brief introductions to more advanced topics: 3D general circulation models, inverse models, and data-assimilation techniques. The final chapter, on scientific visualization, offers some good advice on presenting the results of models and simulations.

In their goal to write a text that is accessible to students with a wide range of backgrounds, the authors have succeeded. However, achieving that goal has produced both strengths and some minor weaknesses. The book's impressive breadth sometimes comes at the expense of depth; an annotated list of further reading at the end of each chapter would have been a useful addition. The authors motivate, rather than rigorously derive, the chosen methods and formulas. That is a reasonable choice, given the intended audience, but the crucial assumptions are not always made clear for the reader. Therefore, course instructors will have to provide supplementary material.

Students will find that the included Matlab code is an excellent resource, showing them how to translate the mathematical problem into a computational one. However, the authors' style of programming is somewhat idiosyncratic. For example, consecutively run scripts are generally used instead of functions. That style may be easier for novice programmers to come to grips with, but it is better that students learn good programming habits early. Lastly, the book's informal, conversational style may not appeal to all readers.

Despite its minor weaknesses, *Modeling Methods for Marine Science* is an accessible introduction to modeling and thus fills a serious gap in the literature. The detailed examples are an excellent resource for students and teachers, and the book should justifiably become a standard text in the personal libraries of aspiring and established researchers interested in modeling marine and environmental systems.

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