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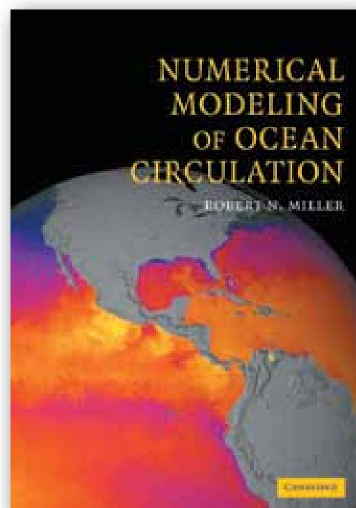
Numerical Modeling of Ocean Circulation



By Robert N. Miller, Cambridge University Press, 2007, 242 pages, ISBN 052178182, Hardcover, $65 US

REVIEWED BY ROBERT HALLBERG

Numerical ocean models have become increasingly valuable tools as we strive to understand the nature of the ocean's dynamics. They have progressed from the necessarily crude and idealized tools of decades past to capture much of the complexity and beauty of the real ocean. Many oceanographic research projects utilize numerical models as a fully equal partner and complement to the long-established physical oceanographic approaches of seagoing observational inference, theory, and fluids lab experimentation. As computers continue to increase in speed and availability at ever lower cost, this trend will clearly continue. Therefore, a solid background in knowing how to use numerical models to test hypotheses, when to trust their results and when not to, and how to relate the output of ocean models to observations has become an indispensable part of the education of an aspiring oceanographer.

Numerical Modeling of Ocean Circulation aims to fill this need as a text for preparing graduate students for modeling studies of large-scale physical ocean circulation. To quote from the preface, "this work is intended as a text. It is not intended to review the state of the ocean modeling art. Rather its aim is to provide the student with the context in which discussion of numerical modeling is conducted." To be read profitably, this book requires an introductory familiarity with geophysical fluid dynamics, consistent with the author's assumed

UPCOMING BOOK REVIEWS

Ebb and Flow: Tides and Life on our Planet
by Tom Koppel, The Dundern Group, 292 pages

Lagrangian Analysis and Prediction of Coastal and Ocean Dynamics
by A. Griffa, A.D. Kirwan Jr., A.J. Mariano, T. Özgökmen, and T. Rossby, Cambridge University Press, 487 pages

Ocean Circulation: Mechanisms and Impacts
edited by A. Schmittner, J.C. Chiang, and S.R. Hemming, American Geophysical Union, 392 pages

The Silent Deep: The Discovery, Ecology, and Conservation of the Deep Sea
by Tony Koslow, University of Chicago Press, 270 pages

The Unnatural History of the Sea
by Callum Roberts, Island Press, 435 pages

audience of second-year physical oceanography students. Unfortunately, many critical topics are covered with such a dated exposition that this book will probably only have limited success in meeting this worthwhile aim.

The first two chapters are exceedingly brief. The first chapter is a single-page introduction tying numerical ocean modeling back to the pioneering work of L.F. Richardson in the 1920s. The second chapter is a short (30-page) introduction to basic numerical analysis, with detailed analysis limited to the rudimentary approaches of second-order centered differencing and leapfrog time stepping. Finite element methods and higher-order finite differencing are mentioned to draw attention to their existence, but for more than a cursory exposure to numerical techniques the reader is referred to other texts (such as the excellent, if not particularly oceanographic, book by Dale R. Durran: *Numerical Methods for Wave Equations in Geophysical Fluid Dynamics*, 1999, Springer, 465 pp.).

The third chapter, on shallow-water models, is where this book really hits its stride. It explores the various wave modes and dynamical balances that are present in the shallow-water equations, and how these can influence the choice of appropriate numerics. It uses these equations in a nice exposition of the issues of open boundary conditions, and concludes with a useful series of examples illustrating how numerical shallow-water models can be used to elucidate the dynamics of fluid flows, and how knowledge of the dynamical balances influences the choice of parameters in shallow-water models. This chapter should provide a solid basis for further work using numerical models.

The fourth chapter, however, on primitive equation models, is strikingly dated. As primitive equation models are the basis for most regional- and large-scale ocean studies, this is a serious flaw. There is an extended discussion of the dynamics of rigid lid models, and how the rigid lid should be treated numerically, but only the barest mention of the split-explicit or split-implicit treatment of the external mode that has been used almost exclusively for a decade. There is a careful and detailed description of the algorithms of the well-known Bryan-Cox model of the 1970s and 1980s, but almost no mention at all of the developments of the past decade—such as the Gent-McWilliams eddy closure, the partial cell treatment of topography, improved discretizations of tracer advection, or proper rotation of the diffusion tensor—that have made this class of model such a powerful tool for climate studies. Even more alarmingly, this chapter describes the purpose of using a rotated diffusion tensor as *increasing* the vertical mixing in models. Instead, the primary challenge for Z-coordinate climate models for the past 20 years has been to limit the levels of diapycnal mixing to the very weak values we now know the ocean to exhibit, and a properly rotated diffusion tensor is a key step in *reducing* spurious diapycnal mixing. There are numerous other glaring anachronisms in this chapter. Isopycnal (layer) models are described as being unable to represent the flow of Antarctic Bottom Water under North Atlantic Deep Water due to the use of potential density referenced to the surface as the vertical coordinate, but the solution to this issue has been known and widely used for a decade now—using potential density referenced 2000 dbar as the vertical coordinate along with a careful treatment of the effects of the nonlinear equation of state when calculating pressure gradients. In describing terrain-following-coordinate models, the challenges arising from the pressure gradient errors over steep topography are described, but the past decade's progress in dramatically reducing this issue, particularly by the Regional Ocean Modeling System

(ROMS) group, is wholly ignored. The poor representation of topographically constrained flows in traditional, full-cell, Z-coordinate models is described, but not the partial cell numerics that have so dramatically reduced these biases. There is no meaningful discussion of the treatment of tracer equations—something that has become more and more prominent as predicting the carbon cycle, ecosystem management, and water-quality issues emerge as increasingly important applications of ocean models. This chapter may be useful for historical documentation of the considerations that once pertained to ocean models, but the student trained with this book will be ill prepared to use modern ocean models.

The fifth chapter is a brief (nine-page) and cogent introduction to quasi-geostrophic numerical models.

The sixth chapter presents the use of analytical and numerical models to study coastal ocean variability, and the examples here are more recent, dealing particularly with the waves and flow structures found off the Oregon coast. Perhaps this reflects an area of more active interest for the author, but even here the presentation of the numerical issues that coastal (terrain-following-coordinate) models must deal with completely ignores the past decade of notable progress.

The seventh and final chapter is an examination of tropical wave dynamics, similar to that found in several classic geophysical fluid dynamics textbooks, with a few examples of how they were represented in numerical models in the mid 1980s, 20 years ago.

One surprising omission from this book is any discussion of data assimilation. This is an increasingly important topic in ocean modeling. Given the author's prominent work on data assimilation, its exclusion from this book seems quite unfortunate.

The great strength of this book is the way that it works to tie ocean models to their use to answer real questions about the ocean's dynamics. This skill is timeless and should easily transcend the changes that have made today's ocean models dramatically more proficient than their predecessors. This book is also valuable for encouraging a healthy skepticism about what questions ocean models are and are not reliable for answering, even if many of the specific issues discussed in detail are much less pressing today than they once were.

This book is essentially a good description of the state of ocean modeling as of the early 1990s. The median publication year of the references therein, 1989, reflects this by now quite dated depiction. For a mature field, such adherence to long-established practice may be reasonable, but numerical ocean modeling is still a very rapidly developing field, and such an archaic presentation is lamentable. This would have been a fine book had it been published 15 years ago, but it is already so out of date, even compared to several numerical ocean modeling texts published a decade ago, that I am reticent to recommend its use as a primary text for graduate courses, and strongly urge that it not be used as a reference.

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