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reading these narrative captions.

The Deep has few significant flaws. There's some repetition of information among the essays, but not enough to be annoying. As few people will read this book in one sitting, the repetition may go unnoticed. A handful of mistakes appear, but as an editor I am fully aware that as many times as you've read and edited a document and gone over the proofs, no doubt you'll find a mistake within the first three minutes of reviewing the final, printed copy.

As an editor, I also couldn't but help but wonder, "how did the author get so many gorgeous high-resolution photographs when I seem to struggle for one great cover photo every few months?" In the end, the essays and captions offer an enjoyable education about an environment that only a relatively few lucky people have seen close up. This book is well worth the $45 investment. People of all ages and backgrounds will enjoy picking it up time and time again. I know that I will.

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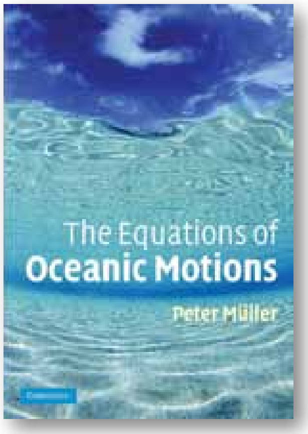
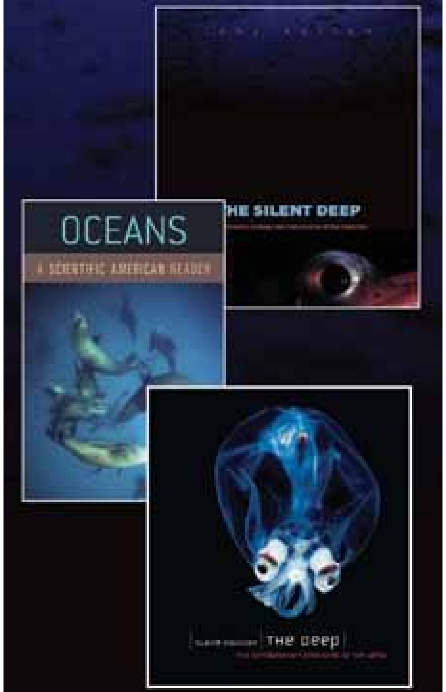
The Equations of Oceanic Motions



By Peter Müller, Cambridge University Press, 2006, 291 pages, ISBN 0521855136, Hardcover $80 US

REVIEWED BY ROLAND DE SZOEKE

The Equations of Oceanic Motions has two primarily pedagogical aims: to establish rigorously the equations of oceanic motions, including the equilibrium thermodynamics of seawater and the molecular transport processes, and to examine systematically the common approximations that are made. In these aims, it succeeds admirably (and very usefully). The book will surely become a standard reference for the ocean dynamicist who wants to get the equations and usual approximations right. For me, the book is already worth the price just for its thorough treatment of the Boussinesq approximation. We all learn the mantra "density in the momentum equation can be replaced everywhere by a constant reference value ρ_0, except when multiplied by g_0 [gravity]." But then, how exactly does one square the conservation of volume (not mass) with the transport equations for heat and salt and the equation of state? Here it's done right, without cutting corners or (to mix metaphors) sweeping dust under the rug. Who are the book's intended audiences? The earnest dynamicist has already been men-



tioned. The novice would find it hard going, while the initiate would appreciate the attention to detail and the uniform notation and framework.

"The book is about equations and theorems, not about solutions," the preface announces. The author feels his task is complete when he has presented derivations with the most explicitly stated and systematically developed approximations. Yet, one feels as if he has been led to water but not allowed to drink, that one has read an exquisite recipe, but not tasted the dish. This sense of incompleteness is, despite the author's disclaimer, the book's systemic weakness. Luckily, Müller is not utterly consistent in his no-solutions promise. He presents a beautiful chapter, one of the most successful in the book, on free wave solutions on a rotating sphere, a chapter that unifies gravity waves (surface and internal), Rossby waves (barotropic and baroclinic), and even sound waves. It struck me that this elegant taxonomy of waves of vastly different scales could have been used to illustrate the delphic remarks in the preface about approximations ("[T]he adequacy of an approximation depends not only on the object, the phenomenon, but also on the subject, the investigator") and the rather brief chapter on asymptotic expansions.

The Equations of Oceanic Motions addresses topics that are rarely found in books on theoretical oceanography. For example, it is very useful to have so unusually thorough and comprehensive a discussion of thermodynamics specific to seawater (Chapter 2, plus an appendix) between the same set of covers with the balance equations, all in a consistent notation for momentum, scalars, and energy. I particularly liked the section on equilibrium thermodynamics of mixing with its fresh perspective on cabbeling in two-component fluids.

In a beautiful treatment on molecular flux laws (Chapter 4), the relations between momentum and scalar fluxes, and gradients of velocity and concentrations, are elegantly (and simultaneously) derived from a principle of entropy production minimization. Much later in the book (Chapter 12), the equations of motion and thermodynamics are ensemble averaged over macroscopic fluctuations and eddies to produce the extra eddy flux divergence terms, for which parametrizations analogous to the molecular ones are given along with discussions of their possible forms relative to isopycnals. This is a very fine and reliable presentation of the material. Yet, when one finds the disclaimer, which would have been common years ago, that "there is no general theory that justifies the diffusion form and allows the calculation of the diffusion tensor," one has a range of reactions. The first reaction is to wonder, perhaps idly, but anyway prompted by the juxtaposition of Chapter 4, whether a meta-entropy production principle, analogous to what was used for molecular fluxes, could be devised for eddy fluxes. The second reaction is to wonder why the author discounts comprehensive theories establishing concentration-gradient diffusion forms (at least for passive scalars) and relating diffusivities to eddy motion correlation statistics. Such theories are not closure theories, it is true, giving evolution equations for second-order covariances of eddy fields, but they are a little more rigorous than the usual hand-waving justifications in terms of mixing lengths.

Chapter 12 provides also a useful discussion of diffusivity tensor orientations and their relation to density surfaces. (But what kind of density is meant: in situ? potential? other? I suspect the ambiguity is intentional as controversies about the correct choice, perhaps inconsequential to the author's main point, persist.) The third reaction, when mathematical theory cannot provide closed forms for the balance equations controlling oceanic motions, is to wonder whether one cannot rely on observational evidence (e.g., microstructure, drifters, dye-release experiments) for turbulent parametrizations and their empirical coefficients (eddy diffusivities and viscosities). The author's ideal is plainly Aristotelian: as far as possible, recreate the equations of ocean science from the operation of pure reason. As much as one sympathizes with this approach, it can slight the connections to the science's observational side.

Indeed, as Müller rarely gives numerical values or even orders of magnitude for, say, eddy coefficients, a reference or two to the observational literature would have been helpful. No examples are provided of the use of eddy flux parametrizations, except in the brief chapter on Ekman layers (another welcome exception to the no-solutions rule). Here, a value is let slip, 0.01 $m^2 s^{-1}$, for the vertical eddy viscosity. But this is too small by more than an order of magnitude to achieve the surface Ekman layer thickness, 50 m, quoted in the same sentence. It is a pity that such an error mars an otherwise fine account, which, among other things, takes the trouble to show that none of the major properties of Ekman layers, such as net horizontal transport or vertical pumping, actually depend on the eddy coefficient.

Under the heading of miscellaneous quirks and oddities, Müller denotes by the term "Navier-Stokes equations" the equations of motion of a *homogeneous* density fluid (and with a constant dynamic viscosity coefficient). This usage surprised me and does not seem to be universal. (G.K. Batchelor's classic *An Introduction to Fluid Dynamics* [Cambridge University Press, 1967] clearly uses the term to cover fluids with variable density and nontrivial thermodynamics and equations of state.)

Müller provides a short account, taking up less than a page, of two-dimensional turbulence, highlighting the fascinating result discovered by Charney and others 30 years ago of the forward spectral cascade (to high wavenumber) of enstrophy and the backward cascade of energy. A Google-Scholar® search of the term yields over 10,000 references. While one easily understands the reluctance to provide a literature review, here, as at many points in the book, the lack of a thoughtful, balanced bibliography is felt (only 20 references in the whole book, eight of them concerning the seawater equation of state or sound speed!). Judicious pointers toward the literature would have been very helpful.

The use of "oblate spheroidal coordinates" may not be as appropriate as it seems for considering the gravitational effects of the nonspherical shape of the earth. Oblate spheroids (as narrowly defined in mathematical physics textbooks) have an unsuitable property: despite their name, they are spaced further apart at the poles than at the equator, while the earth's geopotentials are the opposite, more densely spaced at the poles than at the equator. (This gives a value of gravity about 0.6% larger at the poles.) A significant, and I think undesirable, component of gravity would be felt in the meridional direction with respect to oblate spheroidal coordinates.

About 30 years ago, I first taught a course on theoretical physical oceanography. My students and I sorely lacked a comprehensive textbook. Our conditions were greatly relieved a few years later by the appearance of Gill's and Pedlosky's texts applying the tools of fluid mechanics to a range of problems relevant to meteorology and the emerging field of dynamical oceanography. On many topics, *The Equations of Oceanic Motions* supplements or surpasses these standard books. It amply repays careful study and deserves to become a trusted guide to the basic formulation of physical oceanography.

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