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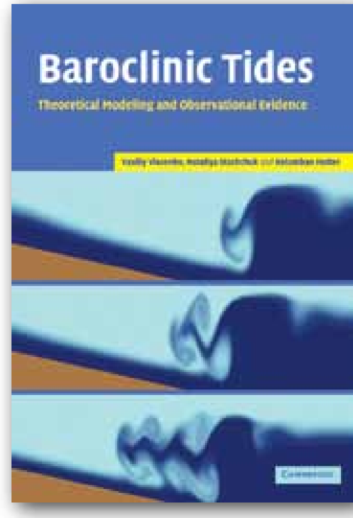
Baroclinic Tides

Theoretical Modeling and Observational Evidence



By Vasiliy Vlasenko, Nataliya Stashchuck, and Kolumban Hutter, Cambridge University Press, 2005, 351 pages, ISBN 0521843952, Hardcover, $120 US

REVIEWED BY PETER MÜLLER

This is a timely book. Baroclinic tides have emerged at the forefront of research in physical oceanography as they might provide a link between large-scale circulation and small-scale mixing. This book summarizes the theories, numerical models, and observations that form the basis of our current understanding of the generation and evolution of baroclinic tides. It is required reading for anyone who wants to get involved in this exciting field of research.

Baroclinic tides are internal gravity waves of tidal frequency. They are generated when the astronomically forced barotropic tidal currents encounter topographic slopes and displace density surfaces. For a long time these baroclinic tides were regarded as an odd part of the oceanic internal wave field. Much of this field is a statistically homogeneous and stationary superposition of many waves that have different frequencies and wave numbers and that propagate in all horizontal and vertical directions. This part is well described by the celebrated Garrett and Munk spectrum. In contrast, baroclinic tides exhibit strong geographic variations, are highly directional, and are often confined to a few low modes. Many of the past efforts were devoted to finding a dynamical explanation for the Garrett and Munk part, while the baroclinic tidal part was largely ignored. Only the acoustic community had an active stake in it, because baroclinic tides are often the major internal wave signal that affects acoustic propagation.

Similarly, the study of barotropic tides has also been isolated from the rest of physical oceanography for a long time. In contrast to most other oceanographic phenomena, the forcing field (the gravitational potential of the moon and sun) is extremely well known and the oceanic response (the barotropic tide) is nearly linear. Fairly accurate predictions had been achieved by solving the Laplace tidal equation. Only recently, issues such as tidal loading, earth tides, and gravitational self-attraction have increased the complexity of tidal modeling.

This all changed when Walter Munk and Carl Wunsch pushed issues of ocean energetics to the forefront of physical oceanography; barotropic tides, baroclinic tides, mixing, and the general circulation all became entangled. Consider the pycnocline. It is viewed as being maintained by a balance of upwelling and vertical mixing caused by breaking internal gravity waves, ignoring mixing by double diffusive processes. Because vertical mixing increases the potential energy of the water column, the breaking internal waves must provide this energy. Where do the internal waves get their energy from? One major source is the conversion of barotropic tidal energy to baroclinic tidal energy at topographic slopes.[1] Thus, the astronomically forced barotropic tides convert energy to the baroclinic tides. The baroclinic tides then transfer their energy to other internal waves, which eventually break and provide the energy for ocean mixing, which affects the oceanic general circulation, which in turn affects climate, with abundant interesting feedback mechanisms. The connection between baroclinic tides and climate makes this book about baroclinic tides all the more important.

In writing the book, the authors could draw on more than twenty years of active research in developing analytic and numerical models of baroclinic tides and in applying these models to concrete oceanic situations. The book covers most of our conceptual knowledge about the generation of linear and nonlinear baroclinic tides over variable bottom topogra-

[1] The other important source is the generation of inertial oscillations in the surface mixed layer by changes in the atmospheric wind stress. Part of this energy leaks into the ocean interior as near-inertial internal gravity waves.

phy and their subsequent evolution. This conceptual knowledge is all based on a simplified geometric configuration: only two spatial dimensions (the vertical and one horizontal) and localized topographic obstacles, either an underwater ridge or a slope shelf configuration. One can thus neatly define reflected and transmitted waves. Some of these simplified models can be solved analytically, but the book spends much effort to define the limits of these analytic solutions and extend them by numerical means. It identifies the three most important parameters of the problem: the ratio of the topographic slope to the slope of the internal wave group velocity, the Froude number, and the critical latitude. If the topographic slope is much smaller than the slope of the group velocity, the topography can be regarded as "flat" or subcritical. If the topographic slope is larger than the slope of the group velocity, the topography must be regarded as "steep" or supercritical. The Froude number is the ratio of the barotropic tidal current to the horizontal phase speed of the generated baroclinic waves. For small Froude numbers, the generation process and subsequent evolution are essentially linear. If the Froude number increases, nonlinear effects come into play. The critical latitude delineates the free from the forced wave response. Equatorward of it, linear baroclinic tides can propagate as free waves; poleward of it, they cannot.

All this conceptual knowledge is derived from basic equations using different analytic and numerical tools and substantiated by selected observations. It is neatly summarized in *Baroclinic Tides* in a table, which is reproduced here as Figure 1. This table contains in concise form most of what we know about the generation and evolution of baroclinic tides. At small Froude numbers, first mode baroclinic tides are generated at flat topography, and multimodal baroclinic tidal beams at steep topography. When the Froude number increases, a whole suite of new phenomena appears, including bores, nonlinear wave packets, solitary waves, solibores, and wave breaking. If you are interested in the theories, numerical models, and observations that lead to the results in the table, you have to consult the book. There it is all laid out: analyses of the general wave equation, the Korteweg-deVries equation, and Long's equation; modal, level, and layer models with often excruciating algorithmic details; and observations in the Barents Sea, on the Portuguese shelf, and at Oporto Seamount. Details of the results depend, of course, on additional parameters as well, such as the height of the topographic obstacle to the water depth (adjusted for stratification) and the ratio of the barotropic tidal excursion to

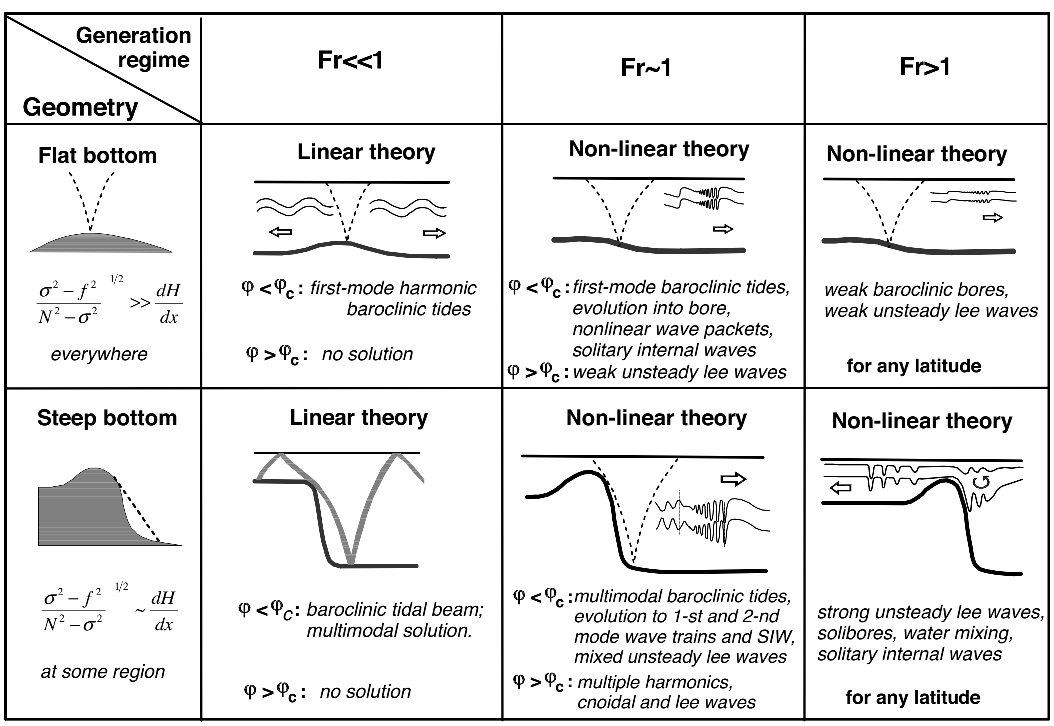


Figure 1. Schematic representation of the generation and evolution of baroclinic tides for different oceanic conditions. *Fr* denotes the Froude number and ϕ_c the critical latitude. Reproduced with permission.

the horizontal scale of the topography. Nevertheless, this table represents in a nutshell most of what we know about the generation and evolution of baroclinic tides and what we use as conceptual models when we must analyze more complex situations, where the topography is not two-dimensional and the oceanic environment is more variable. This can be seen in the special issue of the *Journal of Physical Oceanography* on the Hawaiian Ocean Mixing Experiment (HOME), which will appear at about the same time that this book review will appear. HOME is a multi-faceted study of tidal energy conversion and related processes along the Hawaiian Ridge. In their articles, the HOME investigators make abundant use of the concepts in the table in order to understand what exactly is happening at the Hawaiian Ridge.

In summary, I would like to congratulate the authors on putting together this book at this time. It will be of great value to researchers in this new and exciting field.

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Computer Modelling in Atmospheric and Oceanic Sciences

Building Knowledge

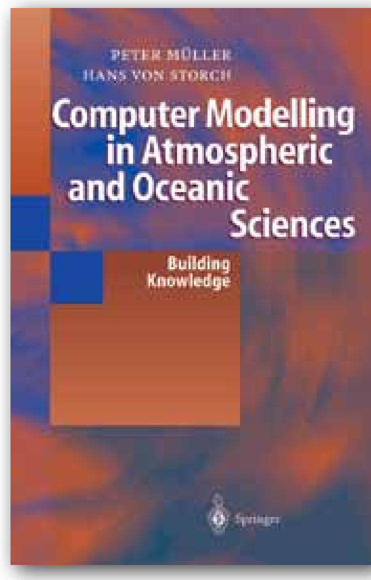
By Peter Müller and Hans von Storch, Springen-Verlag, 2004, 304 pages, ISBN 3540404783, $89.95 US

REVIEWED BY JAMES J. O'BRIEN

This book is sewed together into seven chapters of 200 pages and another 100 pages of appendices. Because this reviewer knows both of these eminent oceanographers, it is straightforward to assign an author to each section. *Computer Modelling* contains much useful information, but it would not work well as a textbook in an Earth system modeling class either for the atmosphere or the ocean. Experienced numerical modelers will find some nice discussion of old and modern concepts. The text contains lengthy discussions of the authors' philosophies with regard to models. It is unusual to find such opinions in a text.

The seven chapters are: (1) Introduction, (2) Computer Models, (3) Models and Data, (4) The Dynamics of Tides and Climate, (5) Modeling in Applied Environmental Sciences, (6) Modeling in Fundamental Environmental Sciences, and (7) Issues and Conclusions.

The Introduction sets the tone for the book with a review of tide and climate modeling. Chapter 2 reviews the fundamental laws and the classical closure problem for a turbulent fluid. Unless the readers have studied these concepts before, they will have a difficult job of understanding this section. In addition, this chapter includes a short discussion of models as dynamical systems and stochastic systems as well as limits to predictability. Chapter 3, Models and Data, contains a useful discussion of validation and assimilation. These concepts are difficult for the new scientist to grasp and they will need additional material. Chapter 4 reviews the tidal problem and modeling the complex climate system. Here we really begin to see



some shortcomings of the text. Already in the previous chapters, many concepts are introduced without definitions (e.g., isentropic coordinate system). It seems as if the authors have not decided who their readers are to be. They explain many concepts from fundamental principles, but often skip over "new" words. In discussing tides, the authors reduce the discussion to a very simple problem to show computer details. Then, they include incorrect finite difference equations. An expert who knows this will not be harmed, but a novice will be lost. In