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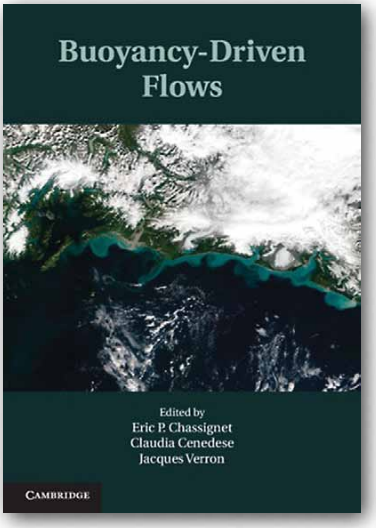
Buoyancy-Driven Flows

Edited by Eric Chassignet, Claudia Cenedese, and Jacques Verron, Cambridge University Press, 2012, 444 pages, ISBN 978-1-107-00887-8, Hardcover, $120 US

REVIEWED BY ECKART MEIBURG



Buoyancy forces, and their interplay with pressure, inertia, and rotation, represent a key ingredient in a wide range of oceanic and atmospheric flow processes. They strongly influence global ocean circulation, and hence the variability of Earth's climate, by driving the formation of deep water. On a smaller scale, buoyancy forces play a significant role in maintaining the health of local ecosystems by affecting the transport of nutrients, sediment, pollutants, and heat. The book *Buoyancy-Driven Flows*, with 10 chapters contributed by distinguished authors, reviews and analyzes many of the flow phenomena that result from buoyancy forces, with a primary focus on the ocean. It introduces the reader to the fundamental fluid mechanical principles behind such varied mechanisms as surface buoyancy or wind forcing, overflow and exchange flows, the role of Earth's rotation, and the influence of local seafloor topography. Furthermore, the book reviews efforts to account for these effects in global and regional climate models, and it extends the discussion to related subaerial flows such as dust storms, volcanic eruptions, snow avalanches, and debris flows. The individual chapters are based on lectures given at the 2010 Alpine Summer School on Buoyancy-Driven Flow directed by the book's three editors; the authors and editors are to be commended for following a unified didactic approach and similar presentation styles. Throughout the book, individual themes are based on environmental observations. There is a clear focus on formulating fundamental scaling relationships, on deriving similarity laws, and on establishing the governing dimensionless parameters. These theoretical considerations are frequently illustrated by conceptually simple laboratory experiments and/or numerical simulations. This approach renders the book accessible to advanced students who have taken an introductory graduate level class in fluid mechanics and have been exposed to the fundamentals of stratified and rotating flows.

The first five chapters focus on fundamental fluid mechanical considerations, whereas Chapters 6 through 10 address more applied and complex themes such as ocean and atmospheric climate modeling, volcanic eruptions, and avalanches. Specifically, Chapter 1 (by P.F. Linden) addresses the topic of gravity currents forming as a result of horizontal density variations. It presents a concise review of the classical theoretical models for the constant velocity phase by von Karman, Yih, and Benjamin, along with a more recent model by the author. The chapter also discusses the force balances governing the similarity and viscous phases of gravity currents as well as self-similar solutions based on shallow water theory and internal wave generation in stratified ambients.

Chapter 2 (by J. Pedlosky) reviews the theoretical principles underlying the description of rotating, stratified flows, motivated specifically by the desire to understand deepwater formation in the ocean as a result of surface cooling. After introducing such fundamental concepts as blocked flow, the Rossby deformation radius, and potential vorticity, this chapter addresses a range of linear versus nonlinear situations and analyzes the asymptotic structure of boundary layers and interior regions along with how they match up. These mostly theoretical considerations are elucidated by frequent references to simple laboratory experiments.

Many of the dominant water masses in the world's ocean originate from buoyancy-forced marginal seas, whose dynamics are addressed in Chapter 3 (by M.A. Spall). As a result of their sensitivity to surface heat and wind forcing, and to topographical features such as boundaries and sloping bottoms, it is a challenge to accurately account for them in large-scale climate models. The underlying mechanisms are elucidated by frequent reference to long-term simulation results obtained with the MIT general circulation model.

As a result of Earth's rotation, river outflows frequently turn and follow the coast for long distances before dispersing. Chapter 4 (by S. Lentz) explains the dynamics of such buoyant coastal currents, how they can contribute to hypoxia of subsurface waters by inhibiting vertical mixing, and how they might have affected North Atlantic deepwater formation when Lake Agassiz drained approximately 8,000 years ago. Simple model problems are invoked to illustrate the effects of a sloping bottom and of wind forcing, and the governing mechanisms are further elucidated through comparisons with laboratory experiments, numerical models, and field data.

Water masses originating in buoyancy-forced marginal seas and entering the deeper ocean through narrow straits have a significant influence on large-scale ocean circulation. Chapter 5 (by S. Legg) focuses on the dynamics of such dense overflows and their mixing and entrainment properties, and on the ways in which they are influenced by topographical, tidal, and wind forcing, and by Earth's rotation. Examples of exchange flows and hydraulic control at sills are discussed, along with the possible transition to supercritical flow and the subsequent formation of internal hydraulic jumps. Specific attention is given to how the entrainment mechanisms of overflows are distinct from those governing convectively driven flows forced by surface buoyancy loss.

Chapter 6 (by W.G. Large) reviews the state of the art in ocean climate modeling. It elaborates on the need for correctly modeling not just the active tracers of salinity and temperature, but also passive tracers such as O_2, CO_2, and nutrients. After providing a brief historical perspective, it discusses such conceptual simplifications as the hydrostatic assumption and comments on the spatial and temporal resolution of current ocean general circulation models (OGCMs). While the overall presentation is quite clear and succinct, there are a couple of errors in the discussion of such computational constraints as the CFL number and the diffusive time step limitation. The incorporation of a deformable ocean surface is mentioned, along with the treatment of the ocean boundary layer, convective mixing processes, and the parameterization of unresolved processes such as overflows.

The relatively coarse resolution of current global ocean climate models of O(100 km) does not permit direct simulation of dense overflows and their spreading due to the occurrence of mesoscale eddies with scales of O(10–200 km). Hence, there is a need for more detailed, eddy-resolving simulation models with grid spacings of O(10 km) or less. These models are described in Chapter 7 (by A.M. Tréguier, B. Ferron, and R. Dussin), and the underlying assumptions and limitations are explained. The chapter discusses parameterization of subgrid-scale dynamics, along with the choice of coordinates and aspects of numerical discretization.

Chapter 8 (by S. Malardel) reviews the processes that govern the dynamics of the atmosphere. While some of them are similar in nature to corresponding oceanic mechanisms (e.g., wave generation, gravity currents, thermally driven convection), others, such as the atmosphere's compressibility or the phase transitions of its water content, do not have counterparts in the ocean. The chapter discusses the hierarchy of numerical atmospheric models, from global models and regional climate models down to nonhydrostatic, cloud resolving, and large eddy simulation models with grid spacings of less than O(100 m). The related computational issue of filtering, and the parameterization of subgrid-scale processes such as turbulent mixing, cloud physics, and precipitation are highlighted as well.

The role of buoyancy forces in volcanic flows is the subject of Chapter 9 (by A. Woods). The chapter describes subsurface processes in magma chambers and their conduits to the surface, such as mixing, melting, crystal settling, and boiling. A discussion follows of the associated processes above the surface, covering a range of topics from the dynamics of eruption columns to the behavior of pyroclastic ash flows along the ground and their potential for lift-off. The chapter reviews related submarine processes, among them volcanic eruptions, hydrothermal plumes, and CO_2-driven lake eruptions, along with the mechanisms responsible for triggering them.

The tenth and final chapter (by C. Ancey) focuses on particle-laden flows down steep mountain slopes, such as snow avalanches or debris flows. In contrast to their subaqueous counterparts, these are non-Boussinesq in nature, and they can give rise to complex, non-Newtonian rheologies. The chapter discusses difficulties of developing appropriate fluid mechanical models, including boundary conditions at the erodible basal surface. Nevertheless, scaling considerations can provide substantial insight into the underlying dynamics of such flows. Both box models and depth-averaged models are described for a variety of flows ranging from dense to dilute, and comparisons with laboratory experiments and field observations are discussed.

Taken together, these ten chapters provide a comprehensive review of the many processes by which buoyancy influences the dynamics of our ocean and atmosphere, and of related current modeling efforts. Furthermore, they illustrate nicely how a multifaceted research approach combining field observations with scaling analysis, model laboratory experiments, and numerical simulations has been successful in advancing our understanding of a wide range of natural phenomena. Perhaps the only topics that I would have liked to see covered in more depth, even by separate chapters, concern double-diffusive processes and internal/surface waves. While the chapters themselves represent treasure troves of fascinating research problems in the field of geophysical fluid mechanics, the accompanying lists of references will prove helpful to investigators aiming to familiarize themselves more deeply with specific research areas.

Finally, the accumulated body of knowledge presented so accessibly in this book provides a reminder of the complexity of the processes at hand, and it impressively demonstrates the long-term progress that can been achieved through sustained fundamental research. Given the importance of understanding the dynamics of our ocean and atmosphere, and of being able to develop predictive models for their behavior, it is essential that these lines of research be sustained and expanded upon well into the future.

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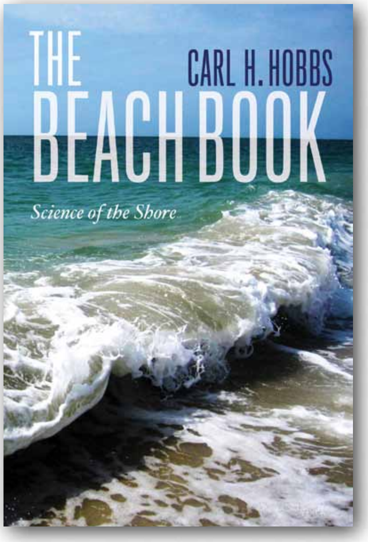
The Beach Book: Science of the Shore



By Carl H. Hobbs, Columbia University Press, 2012, 192 pages, ISBN 978-0-23-1160551, Softcover, $19.50 US

REVIEWED BY ANDREW D. SHORT

The Beach Book is about beaches—but also much more. An alternative title could be "The East Coast of the USA." In addition to beaches, the book covers dunes, barriers, tidal inlets and jetties, marshes, sea level, and human occupation of a stretch of barrier island coast experiencing ongoing sea level rise, shoreline erosion, and the occasional hurricane or nor'easter and their accompanying waves and surges. If you want to know how the US East and Gulf Coasts work, then this book is for you, as most of the examples, photographs, and illustrations are drawn from this region.

Though the title suggests a scientific approach, the brief introduction to the book indicates that it is aimed at the general public. Here, Hobbs states that it "will give readers a better appreciation of beaches," and "appreciation" is the key word. Reading *The Beach Book* is rather like strolling along the shore with the author, who points out and discusses some of its most interesting features. Hobbs prefers to have a conversation with the reader, covering the facts as well as anecdotes about his experiences from a lifetime of working on the shore.

The first chapter, "Beaches," begins this conversation. With no internal heading, it starts off by defining a beach and associated nomenclature, then goes on to describe beach profiles, which then leads to a discussion of closure depth. Next come the topics of alongshore sand transport, edge waves, and beach cusps, and finally beach mineralogy and ecology.

Chapter 2, "Wind," takes the reader through solar heating, albedo, atmospheric pressure, and wind, the impact of wind speed, damaging winds, and hurricane ratings. It also covers air density, duration, and direction, sea breeze, wind-driven circulation including the Ekman spiral, and upwelling.

Chapter 3, titled "Wave Processes," begins with a discussion of wave generation. It is followed by wave motion, deep- to shallow-water waves, and then wave characteristics, including speed, shoaling, and refraction, all accompanied by many helpful diagrams. It finishes with a discussion of sea swell, wave decay, wave