THE DYNAMICS OF COASTAL MODELS

Coastal basins are defined as estuaries, lagoons, and embayments. This book deals with the science of coastal basins using simple models, many of which are presented in either analytical form or through numerical code in Microsoft Excel or MATLAB™. The book introduces simple hydrodynamics and its applications to mixing, flushing, roughness, coral reefs, sediment dynamics, and Stommel transitions. The topics covered extend from the use of simple box and one-dimensional models to flow over coral reefs, highlighting applications to biogeochemical processes. The book also emphasizes models as a scientific tool in our understanding of coasts, and introduces the value of the most modern flexible mesh combined wave–current models. The author has picked examples from shallow basins around the world to illustrate the wonders of the scientific method and the power of simple dynamics.

This book is ideal for use as an advanced textbook for students and as an introduction to the topic for researchers, especially those from other fields of science needing a basic understanding of the fundamental ideas of the dynamics of coastal embayments and the way that they can be modeled.

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CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521807401

First published 2008

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

ISBN 978-0-521-80740-1 hardback

Cambridge University Press
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Preface

My intention is to cover the material that would normally be relevant to an environment study but only in so far as this can be represented by comparatively simple models. It is not my intention to consider very specific models that describe particular systems in great detail. Indeed that would distract from the very purpose of the book which is to illustrate basic concepts in terms of simple models. Furthermore, modeling real coastal basins starts with the simple models described in this book. The models can then be extended in terms of detail and aggregated so that they become realistic simulations of actual coastal basins. In so doing, most of the fundamental processes represented by the models remain essentially unchanged. Simple models deal with individual processes and fortunately real systems can usually be simulated (to a first approximation) by the sum of these processes (although understanding of the interaction between these processes is often critical at a later stage) . Modelers tend to assess the basic science of coastal basins by implementing such elementary models and their *modus operandi*, in the initial stages of investigating coastal basins, is to keep models fairly simple. Models are built slowly as more data become available, and the structure of the basic scientific ingredients changes very little as sophistication is added.

I have added a very extensive bibliography of books (as "Further reading") at the end of each chapter. This includes both recent and newer textbooks that deal with the basic science of coastal basins and models. I have not hesitated to include some texts which may be more difficult to obtain since they are often unique in terms of their presentations. The present book deals with a wide spectrum of science and data analysis and I have broadened the bibliographies appropriately. My intention is that the book should be read as a *textbook*, and so I have presented the modeling ideas in an educational context and not as an extensive review of recent research. For that reason, I have limited references within the text and have adopted a colloquial style in which I try to mention something of the contributions made by distinguished scientists as their work is mentioned. My apologies for so much important work that is omitted, and the reader will find much more detail in books devoted to particular aspects of coastal and ocean science some of which are included in the bibliography.

There are changes in meanings of terms in different branches of science and the dynamics of coastal basins certainly straddles several of these divides. The meaning of the word *model*, or *modeling*, is a classic case which I have explored in some detail in Chapter 1 but there are other, less obvious, cases that do cause considerable confusion. Good examples are the trio of terms *estuarine circulation*, *density driven flow*, and *stratified basin* which describe various states, and processes, in a coastal basin which are discussed in the later chapters of this book. Caution is needed in using these terms without the necessary qualification as to their meaning and they should often be avoided in a technical context.

My intention is that this book should present models as tools for understanding science and as a direct challenge to the notion that *models are for modelers*. Models are simply a way of articulating scientific ideas and are a simple application of mathematics which is the basis of all science.

Acknowledgements

The book reflects lectures given to a mixture of classes in several continents. I have had the advantage of discussions and research with many colleagues with deep understanding of the science of coastal basins and many of whom have become close personal friends. They are too numerous to name but I want to record my very special thanks to my late colleagues Cyril A. Hogarth and Paul N. Butcher, and to my advisor Peter T. Landsberg, from whom I learnt the joy of simple analytical models as a way of conceptualizing ideas about processes. My fundamental interests in the properties of non-linear processes in coastal basins comes from years at the University of Warwick with George Rowlands and these are discussed in Chapters 2, 8, and 10. My early interest in physical processes in the ocean came from conversations with Henry Stommel when I was at Harvard University and this is reflected in the text on *Stommel transitions* in Chapter 10. My interest in shallow coastal basins came originally from my work with John H. Simpson and then Jörg Imberger. My interest in biological processes in coastal basins, and especially coral reefs, stems from work with Bruce G. Hatcher, Stephen V. Smith, Arthur J. McComb, and Marlin Atkinson. The discussion of the coastal boundary zone in Chapter 11 was motivated by conversations with William M. Hamner during my time at the University of California at Los Angeles. Individual parts of the book use model technology and ideas for which a special gratitude is due to several individuals and companies who are acknowledged in the text. Kimberley K. Yates has been responsible for much of my appreciation of the value of modeling in the context of integrated systems and to her go very special thanks. I owe a special debt of gratitude to Dr. John R. Hunter of the University of Tasmania with whom I worked on many projects in modeling, and parts of Chapter 8 come from an idea that he and I pursued together. This book was completed during the time that I was engaged on the Integrated Science Study of Tampa Bay in Florida, and I acknowledge the support of the US Geological Survey and ETI Professionals Inc. I have included reference to models and data for Tampa Bay because of my personal involvement in that project and because they represent good example of the ideas presented in the book. The model development in Tampa Bay is the cumulative effort of many scientists at the US Geological Survey, University of South Florida, colleagues at DHI, and the Danish Technical University in Copenhagen. To all these scientists and colleagues go my special thanks. I am grateful to my friends at Delft Hydraulics and the Technical University of Delft (Netherlands) for making my time working with them on models of coastal basins so very productive in that historic town.

The task of removing typographical errors and other inconsistencies has been performed to the best of my ability but there are, no doubt, many remaining and I appreciate the time of any readers in pointing them out to me. My thanks to the staff at Cambridge University Press for so much help and all my colleagues in the US Geological Survey for their support.

Note on mathematics and model codes

I will not generally present detailed computer codes for the simple models given in the book except where it is possible to use easily available software such as *MS Excel*, or the Mathworks *Matlab* programs. The codes that are presented here are sufficiently simple that they should provide valuable insight into the basic science which is the *raison d'être* for this book. I feel that the languages of both mathematics, and computer code, can assist our understanding of the basis processes of coastal basins, but should never be allowed to obscure the fundamental science. For this reason, I will very deliberately minimize mathematics and avoid any attempt at code beyond a little occasional *Excel* and some simple *Matlab* scripts. However, it is unfortunately impossible to discuss basic processes without some mathematics. I have successfully taught this material to university and college graduates, and undergraduates, with only very limited mathematical training. The basic mathematical requirement is a knowledge of simple differential and integral calculus and the methods by which we can represent derivatives by finite differences. I make no excuse for the inclusion of material based on this elementary calculus, and indeed mathematics is the basic language with which physical scientists establish and exchange ideas. The book is aimed at a wide spectrum of scientists interested in coastal basins with the caveat that they have a minimal mathematical knowledge. This includes biologists, chemists, geologists, and physical scientists starting to work in coastal basins, plus students of any undergraduate, or graduate, course in oceanography, marine science, or environmental science. I have tried to make the book one that delivers results and usability based on simple models. Each such model will be largely self-contained, and so it should be possible to consider each model separately although, there will be references made between the models in the sense that one model may be a progression of an earlier model (usually in the same chapter).

I have tried to avoid double use of mathematical symbols as far as possible but occasionally this would only be possible at the expense of producing mathematics that is quite difficult to read and my philosophy is that price is too high. As an undergraduate, I had classes from a professor who would just pull notation out of the air and said this was a good way of making sure one really understood the physical meaning of mathematics. With that I did not agree at the time, and still do not agree, but on the other hand we have cases like the symbol f used for the Coriolis parameter. To change that symbol makes a text on physical oceanography very obscure to the eye of most modelers. Yet f is used so naturally in applied mathematics to denote *some function* that we are bound to have double use of the symbol. Similarly ϕ is used for the fineness scale of sediments and to use any other symbol would be unthinkable and yet in other contexts, ϕ is used universally as an angle and especially for latitude on the Earth. The use of the same symbol for different quantities is usually safe provided that the usage is in very different aspects of a subject but danger does lurk in cross-disciplinary studies; there are few theoreticians who have not caused themselves hours of worry over a confusion of that type. But that is a difference between a textbook and a piece of personal analysis. So, I have been careful with symbols but occasionally one symbol is used for different entities but hopefully in different parts of the book. I have often (but not always) used a convention adopted in fluid mechanics of using a double symbol for dimensionless numbers such as Reynolds number Re, Ekman number Ek, Froude number Fr, and many others. My personal view is that these double symbols can cause confusion in equations and to avoid that mathematical confusion, I often revert to a single symbol sometimes with a subscript.