



**REGIONAL
OCEANOGRAPHY:
AN INTRODUCTION**

MATTHIAS TOMCZAK

*Professor of Oceanography,
School of Earth Studies,
The Flinders University of
South Australia*

J. STUART GODFREY

*Senior Principal Research
Scientist, CSIRO,
Division of Oceanography,
Australia*

pdf version 1.0

pdf version history

Version 1.0	published December 2001 Error in Figure 14.9 corrected, May 2002
Version 1.1	published May 2002 (Chapter 14 only) Error in text on page 245 corrected, September 2002 published September 2002 (Chapter 14 only) error in wind direction on page 40 corrected, October 2004 published October 2004 (Chapter 4 only) Figure 8.25 changed to southern hemisphere, March 2005 data source for Figure 6.4 clarified, March 2005 missing reference Keffer and Holloway added, March 2005 published March 2005 (Chapters 6 and 8, References only)

The first edition was published by Pergamon in 1994 and is now out of print.
This online version is available at the following servers:

Australia:

<http://www.es.flinders.edu.au/~mattom/regoc/pdfversion.html>

Asia:

<http://www.incois.gov.in/Tutor/regoc/pdfversion.html>

Europe:

<http://www.cmima.csic.es/mirror/mattom/regoc/pdfversion.html>

North America:

<http://gyre.umeoce.maine.edu/physicalocean/Tomczak/regoc/pdfversion.html>

South America:

<http://www.lei.furg.br/ocfis/mattom/regoc/pdfversion.html>

Africa:

<http://www.egs.uct.ac.za/webmirror/regoc/pdfversion.html>

**REGIONAL OCEANOGRAPHY:
AN INTRODUCTION**

MATTHIAS TOMCZAK

*School of Earth Sciences
The Flinders University of South Australia*

and

J. STUART GODFREY

CSIRO Division of Oceanography, Tasmania, Australia

pdf version 1.0

2001

impressum of the first edition:

U.K.	Elsevier Science Ltd, Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Elsevier Science Inc, 660 White Plains Road, Tarrytown, New York 10591-5153, U.S.A.
JAPAN	Elsevier Science Japan, Tsunashima Building Annex, 3-20-12 Yushima, Bunkyo-ku, Tokyo 113, Japan

Copyright © 1994 M. Tomczak and J. S. Godfrey

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic tape, mechanical, photocopying, recording or otherwise, without permission in writing from the publishers.

First edition 1994

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library.

Library of Congress Cataloguing-in-Publication Data

Tomczak, M., 1941

Regional oceanography: an introduction/by Matthias Tomczak and J. Stuart Godfrey.

p. cm.

Includes index.

I. Oceanography.

I. Godfrey, J. Stuart. II. Title.

GC11.2.T66 1993

551.46—dc20

0 08 041021 9 Hardcover

0 08 041020 0 Flexicover

Printed and bound in Great Britain by
Butler & Tanner Ltd, Frome and London

This edition published online 2001
© M. Tomczak and J. S. Godfrey

Preface to the Pergamon (1994) edition:

This book developed from lectures for undergraduate students of marine sciences in Sydney. Following a good tradition, the curriculum at the university began with an interdisciplinary introduction into all sciences of the oceans. A similar curriculum operates at the Flinders University of South Australia, where the introductory course on regional oceanography brings together students of marine geology, biology, chemistry, geography, and physical oceanography. The choice of textbook for such a course usually follows the rule of the lowest common denominator. This eliminates most textbooks commonly used in physical oceanography because they require some understanding of mathematics and theoretical physics which not all students bring to the course.

When looking around for alternatives we were dissatisfied with the available material. Non-mathematical texts were either written for high school or college use and considered too elementary for a university curriculum, or they were outdated, leaving too large a gap between what students were taught and what they find in research publications. We decided that it was time to produce a set of lectures which would take into account modern findings and modern ideas and present them on a level suitable for an introductory undergraduate course.

This book is the result of our efforts. Originally the material presented to our students was covered in 21 one hour lectures. When we decided to develop it into a book the material grew in response to comments and suggestions from colleagues who were asked by Pergamon Press to comment on our proposal. In writing this book we have been surprised to learn how much of the ocean's behaviour as a component of climate - the particular reasons why it absorbs heat in one region, or restores it to the atmosphere in another - can be understood by combining an understanding of simple physical principles with knowledge of the ocean's geographical features. We therefore expanded on some aspects of the ocean's role in climate in this book; however, we have tried to give a simple account of that role, which should prove useful in more advanced studies, aimed towards actual prediction of possible climate changes. The division into chapters has been retained, but in its present form it is unrealistic to cover them all in 21 hours.

Most horizontal property distributions are shown in the Peters projection which combines fidelity of area with a rectangular coordinate grid (Peters, 1989). Although the problem which projection is appropriate for a given task is not a trivial one, oceanographers usually do not even realize that there is a problem. A basic requirement for a regional description of the world ocean is fidelity of area. The Mercator projection, which will remain the ideal charting tool at sea, grossly overemphasizes the temperate and subpolar regions, at the expense of the tropics and subtropics to which most of the world ocean belongs. Most commonly used projections with fidelity of area are based on curved coordinates and therefore require a latitude/longitude grid across the map for the location of features. The Peters projection keeps the map surface free for the information of interest while doing justice to the relative roles of all climatic regions. Distortions of distance are severe only in the polar regions. To rectify this, pole-centred stereographic projections are used in the discussion of the Arctic and Antarctic oceans.

Although the list of references is long, it is obvious that an introductory text is not the place for a bibliography on regional oceanographic studies. Readers have to be aware of the eclectic character of our reference list. The fact that a certain paper is not quoted does not

mean that we did not consider it important, nor can it be concluded that inclusion in the list of references puts a paper into the "very important" category. Our approach to the vexed question of references in elementary textbooks is that we follow accepted procedures and generally acknowledge sources of figures, preferring those which highlight the essentials of a situation to those with more detail or priority of thought. Beyond that, we restrict documentation with references to those parts of the text where new information leads us to modify or contradict earlier work. Where reference is not made to the original source it can always be found by following up the references given in the quoted literature.

A substantial part of this book was prepared while one of us (M.T.) was on study leave at the Institut für Meereskunde an der Universität Kiel. The hospitality and facilities of that institution are gratefully acknowledged. Various colleagues from Kiel commented on early drafts of the text, particularly the chapters on the Southern and Atlantic Oceans. We thank in particular Ray Peterson, Lothar Stramma, and Walter Zenk for helpful suggestions. We are indebted to Birgit Klein for information from her work not published at the time. Among our Sydney colleagues we thank John Luick for his attentive reading of early drafts. Janet Sprintall prepared most of the computer-generated figures, and she and You Yuzhu gave us generous access to work in progress at the time. Cesar Villanoy provided valuable assistance with chapter 13 and assisted in the preparation of many computer-generated figures. Brenda Durie skilfully converted the GEBCO topography into the topographic charts of this book. Drafting staff at Pergamon Press guaranteed high standards by preparing most figures from our often rough drafts. At Flinders University, Gail Jackson drafted many figures with never-flinching dedication to highest figure standards; without her help this book would not have gone through the printer's presses for another twelve months.

The *Oceanographic Literature Review* section of *Deep-Sea Research* proved invaluable during the preparation of this book, and we express our sincere appreciation to the people behind this excellent research tool.

Finally, we note a few things which regrettably did not get the attention they deserve. Much can be learned about the oceanic circulation and the life cycle of the various water masses by combining information from CTD and current meter data with information on oxygen, nutrients, and other chemical tracers. Unfortunately marine chemistry has always been among the authors' weak points, and the treatment of the chemical tracers in this book is below acceptable level - it cannot even be called elementary. Should this text prove its usefulness with students and lecturers, to the extent that a revised edition seems justified, a first improvement should be proper coverage of the distribution of all major chemical tracers in the world ocean. Also, our text is clearly a product of what is known as the "Western World": It is based nearly exclusively on research reported in English and published in North America or Europe. While there is no need for apologies in that respect, it is true that in a field such as regional oceanography significant research is sometimes reported in a journal published closer to the regions of interest. It is likely that more accurate descriptions of the oceanography particularly of some of the marginal seas exist in Japanese, Russian, Chinese, or other languages. We welcome the assistance of oceanographers who know of such descriptions and communicate relevant information to us.

Adelaide and Hobart, May 1993
Matthias Tomczak

J. Stuart Godfrey

Preface to the pdf edition:

When the printed edition got out of print in late 2000 I started receiving email enquiries about the availability of the book from various parts of the world. By that time ownership of the publishing company and the copyright to the book had changed hands several times, and the new publisher was not interested in another print run.

Six years is a long time in the information technology area, and significant changes occurred between 1994, when *Regional Oceanography: an Introduction* was first published, and 2000, when it went out of print. It is now possible to publish books at near professional print quality on the web, using full colour illustrations and drawings. As anyone who teaches in a university will know, this not only opened up new avenues to support teaching in the classroom with appealing support material, it also raised the expectations of students. Black and white line drawings were more or less the standard for textbooks before 1994 – today a textbook that does not support its material with colour illustrations is regarded as outdated by students. Moving the book to the web made this transition relatively straightforward.

Publishing on the web has the additional advantage that it can bring the responsibilities of author and publisher under one umbrella. The 1994 edition of *Regional Oceanography: an Introduction* suffered severely from communication problems between the authors and the publisher, to the extent that many equations were simply unintelligible and several figures incomplete.

These experiences and the new opportunities offered by the web led to the decision to proceed with a web edition of *Regional Oceanography: an Introduction*. Having the book on the web (or on a CD) presents one clear disadvantage: As a user of the text I cannot study sitting on a park bench in summer or next to a fireplace in winter. I have always been and continue to be a determined supporter of the printed book, which I can take on the bus or train and read on the way to work. There are, however, several advantages to web publication which, in my view, outweigh the single disadvantage:

Firstly, the book is no longer a static product. It can be updated at any time. Critique and suggestions from users can be accommodated immediately; users do not have to wait for years before errors are corrected.

Secondly, the book becomes available to students at a very reasonable price. The pdf version is not the end of the printed book, it is in fact designed to be printed and bound into a book. But it allows the user a choice of value for money because it can be printed in low quality at low cost or in near professional quality at higher cost. Even the high cost option will be less expensive than the purchase of a comparable book in a bookshop.

Thirdly, modern lecture theatres have facilities to project web pages on a large screen for class use. Illustrations from a web based book can be used in the classroom directly from the web or from a CD. The pdf format allows the display of material at a range of magnifications, so illustrations can be called up in class at any level of detail, as long as the resolution of the pdf file is adequate.

The pdf version of *Regional Oceanography: an Introduction* has a resolution of 600 bpi. As a result, the text and figures can be magnified on the screen without loss of quality,

which makes it possible to use the illustrations for teaching in the classroom. The high resolution is also the prerequisite for good print output. In most situations the print quality is limited only by the printer resolution. Colour laser printers will produce output that comes very close to true book quality.

High resolution comes at the price of large file size. This suggests that the book should be stored on CD and used from the CD, whether it is for private study or for classroom use. To keep download times within reasonable limits each chapter is stored on the web in its own file. Most files are about 1 – 4 MB in size.

The fluidity of the web medium requires good documentation of changes to the book. A pdf version history is therefore an integral part of any printout. The current version is indicated at the bottom of every page. In addition, a complete version history is included on the inside back cover.

Finally a few remarks about use of the text in class. My own experience covers a second year undergraduate course and supervision of graduate students. The graduate students find the book valuable as a reference. The structure of the book, which presents each major ocean as a distinct section of the text, is quite appropriate for this kind of use. It is not so well suited for undergraduate teaching, where time, level of student interest and depth of enquiry are insufficient to go through a detailed discussion of every ocean.

From my years of teaching second year classes I found that a presentation based on physical processes rather than geography is more appropriate to keep the students interested. In other words, rather than dividing the presentation into Pacific, Atlantic and Indian Ocean I divide it into integrated flow, equatorial current system, western boundary currents, and eastern boundary currents and discuss all three oceans in each section together. The next major reworking of the text will probably be based on such a structure.

Adelaide,
December 2001

Matthias Tomczak

Regional Oceanography: An Introduction

Matthias Tomczak and J. Stuart Godfrey

Contents

1.	Introduction. What drives the ocean currents?	1
2.	Temperature, salinity, density and the oceanic pressure field.	15
3.	The Coriolis force, geostrophy, Rossby waves and the westward intensification	29
4.	Ekman layer transports, Ekman pumping, and the Sverdrup balance	39
5.	Water mass formation, subduction and the oceanic heat budget	51
6.	Antarctic oceanography	63
7.	Arctic oceanography; the path of North Atlantic Deep Water	83
8.	The Pacific Ocean	105
9.	Hydrology of the Pacific Ocean	137
10.	Adjacent Seas of the Pacific Ocean	157
11.	The Indian Ocean	175
12.	Hydrology of the Indian Ocean	199
13.	Adjacent Seas of the Indian Ocean and the Australasian Mediterranean Sea (the Indonesian throughflow)	215
14.	The Atlantic Ocean	229
15.	Hydrology of the Atlantic Ocean	253
16.	Adjacent Seas of the Atlantic Ocean	271
17.	Aspects of advanced regional oceanography	299
18.	The oceans and the world's mean climate	311
19.	El Niño and the Southern Oscillation (ENSO)	329
20.	The ocean and climate change	349
	References	365
	Glossary	379
	Index	383