Ocean Dynamics and the Carbon Cycle: Principles and Mechanisms

The oceans play a crucial role in the climate system by redistributing heat and carbon across the planet through a complex interplay of physical, chemical and biological processes. This textbook for advanced undergraduate and graduate students presents a modern, multidisciplinary approach – essential for a complete understanding of ocean circulation and how it drives and controls marine biogeochemistry and biological productivity at a global scale.

Background chapters on ocean physics, chemistry and biology provide students from a variety of disciplines with a solid platform of knowledge to then examine the range of large-scale physical and dynamic phenomena that control the ocean carbon cycle and its interaction with the atmosphere. Throughout the text, observational data are integrated with basic physical theory to address cuttingedge research questions in ocean biogeochemistry.

- Simple theoretical models, data plots and schematic illustrations are used to summarise key results and connect the physical theory to real observations.
- Advanced mathematics is provided in boxes and the appendix where it can be drawn on as needed to put theory into practice.
- Numerous worked examples and homework exercises encourage students to develop first-hand experience and skills with real data and research problems.
- Further reading lists at the end of each chapter and a comprehensive glossary provide students and instructors with a complete learning package.

Ric Williams obtained a Ph.D. in Physical Oceanography from University of East Anglia in 1987. He worked as a researcher at Imperial College and as a research Fellow at the Massachusetts Institute of Technology before taking up a Lectureship at the University of Liverpool in 1993. In 2004, he was promoted to a Professor with a Chair in Ocean Dynamics and Biogeochemistry, and he is now Director of a Research Centre in Marine Sciences and Climate Change in Liverpool. Professor Williams' research focusses on understanding how the ocean circulates and its role in the climate system and he teaches undergraduate courses in 'Climate, Atmospheres and Oceans' and 'Ocean Dynamics'.

Mick Follows obtained a Ph.D. in Atmospheric Sciences from the University of East Anglia in 1991. After a year as a Royal Society Post-Doctoral Fellow at the Max Planck Institute for Chemistry in Mainz, Germany, he moved to the Massachusetts Institute of Technology where he is now a Senior Research Scientist in the Program for Atmospheres, Oceans and Climate. His research is focussed on understanding the interplay of physical, chemical and biological processes which determines the distributions and fluxes of elements in the ocean, and the relationship between marine ecosystems and their environment.

Cover illustrations (front and back): snapshots of surface current speed and the abundance of phytoplankton from a global ocean model (see linked website for animated views). Bright whites indicate fast speed revealing coherent streams linked to the ocean currents. The intensity of green represents the abundance of modelled phytoplankton, revealing the strong influence of the current structure. Model integrations and image processing by Oliver Jahn with Chris Hill, Stephanie Dutkiewicz and Mick Follows. Cambridge University Press 978-0-521-84369-0 - Ocean Dynamics and the Carbon Cycle: Principles and Mechanisms Richard G. Williams and Michael J. Follows Frontmatter More information Cambridge University Press 978-0-521-84369-0 - Ocean Dynamics and the Carbon Cycle: Principles and Mechanisms Richard G. Williams and Michael J. Follows Frontmatter More information

Ocean Dynamics and the Carbon Cycle

Principles and Mechanisms

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Preface

We are all aware of how climate is continually changing on the Earth, but what is the role of the ocean in the climate system? To address this challenge, one needs to understand how the ocean circulates, how life flourishes in this environment and how carbon is stored and redistributed in the ocean. Understanding these issues requires an interdisciplinary approach, including fundamental knowledge and skills in physics, chemistry and biology.

This book is designed to provide a starting guide for any student or researcher enquiring as to how the ocean operates on the planet, bringing together the fundamentals needed to understand how the ocean behaves and a discussion of largescale phenomena. The main themes addressed in the book are:

- How does the ocean circulate? Which are the principal physical phenomena in the ocean and how are they formed?
- How is the ocean ecosystem shaped by biological, physical and chemical processes?
- How is the ocean carbon cycle controlled and how is carbon dioxide exchanged between the atmosphere and ocean?

Our approach is to focus on the fundamental processes and mechanisms using observational data whenever possible to motivate our discussion. To make the material accessible, we have selected the appropriate theory that we feel is most relevant for interpreting the observational signals, rather than provide a more comprehensive theoretical review.

The book is divided into four parts. Part I provides an overall introduction: Chapter 1 starts with a broad-ranging context as to why the ocean is important for the planet, and Chapter 2 a descriptive and preliminary view of the themes addressed in more detail in the book – how the ocean circulates, where phytoplankton grow in the ocean and how carbon is cycled on the planet.

Part II applies basic undergraduate physics, chemistry and biology to address the underlying fundamental principles at work in the ocean: the transport concepts of advection, diffusion and eddy transfer; the physical concepts of large-scale flow and atmospheric forcing; the basic biological principles of cell growth and production of organic matter; and the chemical concepts of mass balance, energetics and charge balance regulating the carbon cycle.

Part III addresses a range of physical phenomena and their effects on the biogeochemistry and cycling of carbon, including the following themes: how seasonality varies; why there are gyres and boundary currents; how ocean eddies form and their large-scale effect; how surface waters are transferred to the ocean interior; how the interplay of physical and biological processes affect the carbon cycle; and how the deep ocean overturns.

Part IV provides two integrated frameworks to understand, firstly, how carbon is cycled and partitioned between the atmosphere and ocean, and secondly, how water masses are formed over the globe. Finally, we provide concluding remarks about the way forward.

Colour plates are used to provide a mini atlas, conveying how physical and biogeochemical properties vary throughout the ocean, complementing the black and white figures used throughout the book.

The book is designed for two different audiences: Honours or graduate students wishing to gain an understanding of how the ocean behaves, with a firm emphasis on observational signals, as well as researchers in a particular discipline who wish to acquire a broader, more interdisciplinary view of the ocean. Students are recommended to read through Part I to gain a preliminary view, then work through the Fundamental chapters in Part II, before embarking on the more advanced material in Part III. More experienced researchers are recommended to work through the Fundamental chapters outside their own expertise in Part II, then examine the more detailed description of physical phenomena and their impacts on the carbon cycle in Part III, and the integrated frameworks in Part IV.

x PREFACE

Understanding these topics can often be challenging at times and the language and level of mathematics off-putting. Consequently, we have designed this book to be as accessible as possible for an interdisciplinary audience. The scientific questions are discussed through a combination of data-based diagnostics, schematic illustrations and, in some cases, theoretical balances requiring an understanding of calculus, where a more quantitative understanding can be gained by working through the equations governing rates of change or identifying equilibrium states. More formal material is included in boxes and the appendix detailing derivations and mathematical tools, as well as in targeted questions to work through at the end of the chapters. Hopefully, readers can find the appropriate level to suit themselves.

Finally, we have presented our own perspective in addressing these questions and, in some cases, there is no clear consensus and readers need to be aware that many of the research topics are ongoing and merit further investigation.

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