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 cutting-edge 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.

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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.

Ocean Dynamics and the Carbon Cycle

Principles and Mechanisms

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Frontmatter
More information

Contents

Preface — *page* ix
Acknowledgements — xi
Illustration credit — xii

Part I Introduction — 1

1 Why is the ocean important? — 3

1.1 What is special about water? — 3
1.2 How does the ocean store and transfer heat? — 5
1.3 What is the role of the ocean in the global carbon cycle? — 7
1.4 How have climate and life evolved on the planet? — 10
1.5 Summary and outlook — 15
1.6 Recommended reading — 16

2 An introductory view of the ocean — 17

2.1 Ocean circulation — 17
2.2 Atmospheric circulation — 26
2.3 Life and nutrient cycles in the ocean — 30
2.4 The carbon cycle in the ocean — 34
2.5 Summary — 38
2.6 Questions — 38
2.7 Recommended reading — 40

Part II Fundamentals — 41

3 Transport fundamentals — 43

3.1 How do tracers spread? — 43
3.2 Tracer conservation and transport — 49
3.3 What is the effect of a time-varying, eddy circulation? — 55
3.4 Summary — 62
3.5 Questions — 63
3.6 Recommended reading — 65

4 Physics fundamentals — 66

4.1 Which forces are important for the ocean circulation? — 66
4.2 How is the surface circulation determined? — 68
4.3 How is the interior circulation determined? — 76
4.4 Global-scale patterns of atmospheric forcing — 80
4.5 Summary — 89
4.6 Questions — 90
4.7 Recommended reading — 92

5 Biological fundamentals 93

5.1 Photosynthesis and respiration 93
5.2 What are marine microbes made of? 94
5.3 How is phytoplankton growth affected by the environment? 98
5.4 Phytoplankton community structure 106
5.5 Primary production and the fate of organic matter 110
5.6 Consequences for ocean biogeochemistry 115
5.7 Summary 121
5.8 Questions 122
5.9 Recommended reading 124

6 Carbonate chemistry fundamentals 125

6.1 Solubility of carbon dioxide 125
6.2 What are the reactions of the carbonate system in seawater? 128
6.3 What controls DIC in the surface ocean? 131
6.4 Coupling of DIC and alkalinity cycles with depth 139
6.5 How are changes in pCO_2 related to changes in DIC? 142
6.6 Air–sea exchange of carbon dioxide 145
6.7 Summary 152
6.8 Questions 154
6.9 Recommended reading 155

Part III Physical Phenomena and their Biogeochemical Signals 157

7 Seasonality of the upper ocean 159

7.1 Seasonality in the physics 159
7.2 Seasonality in phytoplankton 164
7.3 Seasonality in the carbon cycle 172
7.4 Seasonality in the shelf and coastal seas 175
7.5 Summary 179
7.6 Questions 180
7.7 Recommended reading 182

8 Ocean gyres and intense currents 183

8.1 What are ocean gyres? 183
8.2 What are western boundary currents? 189
8.3 A theoretical view of ocean gyres and boundary currents 191
8.4 How is the Southern Ocean different to the rest of the globe? 203
8.5 Summary 206
8.6 Questions 208
8.7 Recommended reading 210

9 | Ocean eddies 211

9.1 How does eddy variability alter over the globe? 211
9.2 A theoretical view of ocean eddy variability 215
9.3 Eddy fluxes of tracers 222
9.4 Summary 233
9.5 Questions 233
9.6 Recommended reading 235

10 | Ventilation 236

10.1 How does ventilation vary over the globe? 236
10.2 A mechanistic view of ventilation 243
10.3 Summary 257
10.4 Questions 258
10.5 Recommended reading 259

11 | Cycling and transport of nutrients and carbon 260

11.1 How are basin-scale contrasts in biological productivity maintained? 260
11.2 How is biological productivity sustained in ocean deserts? 267
11.3 What sets the nutrient distributions in the ocean interior? 276
11.4 Quantifying the ocean's carbon reservoirs 280
11.5 Summary 287
11.6 Questions 287
11.7 Recommended reading 288

12 | The deep ocean and overturning 290

12.1 Why is the deep ocean important? 290
12.2 How does dense water form, mix and spread? 300
12.3 How does the deep ocean circulate? 311
12.4 How is dense water returned to the surface? 316
12.5 Summary 324
12.6 Questions 324
12.7 Recommended reading 326

Part IV | Synthesis 327

13 | Integral frameworks 329

13.1 Variations in the ocean–atmosphere carbon cycle 329
13.2 What is the fate of fossil-fuel carbon dioxide? 331
13.3 Glacial–interglacial changes in atmospheric CO_2 338
13.4 Water-mass formation and transformation 344
13.5 Summary 350
13.6 Questions 351
13.7 Recommended reading 352

14 | Overview and further challenges 354

14.1 Interconnections between the physics, chemistry and biology 354
14.2 Research approaches 356
14.3 Challenges 357

Appendix 360
A.1 Mathematical definitions 360
A.2 Derivation of the momentum equations 362
A.3 Solving the carbonate chemistry system 368
Symbols and definitions 370
Biological and chemical symbols 370
Physical symbols 371
Mathematical definitions 374
Glossary 375
Biological glossary 375
Chemical glossary 376
Physical glossary 377
Answers 381
References 388
Index 400

The colour plates are situated between pages 20 and 21.

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 large-scale 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.

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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