Evolution of Physical Oceanography

Introduction

The technical section of this book is divided into four general categories:

General Ocean Circulation (chapters 1–7);
Physical Processes in Oceanography (chapters 8–13);
Techniques of Investigation (chapters 14–16);
Ocean and Atmosphere (chapters 17–18).

Within each of these categories will be found several chapters, each of which discusses a broad aspect of physical oceanography or its relationship to an allied field. We asked the authors to respond to the question, "What is the state of the subject today and how did we arrive there?" Where appropriate, we sought emphasis on a description of the evolution of the subject over the past 40 years. Thus, most of these chapters differ from conventional review articles both in their historical sweep and in their depth of coverage. The book looks both backward and forward in time.

A substantial fraction of physical oceanography is covered in what follows, consistent with the diversity of Henry Stommel's interests. Indeed, we believe that this book could serve as a textbook in advanced courses on the subject. As with any writing that attempts to be up-to-date, some of the material here is speculative. Nonetheless, we believe that we have in this book a nearly comprehensive description of physical oceanography as it was understood toward the end of the twentieth century.

The first part of the text is devoted to what might be thought of as "large-scale" or perhaps, classical, oceanography. It deals, in several chapters, with the overall distribution and circulation of water properties—a problem that has its roots deep in the nineteenth century. How the different waters move, and why, is treated both in terms of observation and theory. The chapters range from poles to equator, treating the peculiar kinematics and dynamics of these extremes.

Much of dynamical oceanography has focused on the Gulf Stream System, and this book is no exception. The Atlantic is comparatively small, making this current accessible to European scientists from the earliest days, and the Gulf Stream immediately confronts oceanographers on the east coast of North America. Thus the subject has periodically obsessed many of the leading oceanographers of the past 100 years. Much of the flowering of circulation modeling, which began in the late 1940s and remains one of the great accomplishments of modern geophysical fluid dynamics, was motivated toward understanding the Gulf Stream. The section concludes with a chapter on estuaries and shelf circulations. The latter in particular was an area of great interest around the turn of the century and has only comparatively recently reacquired the attention of oceanographers, who for many years tended to focus upon the open sea. The reader will find that many of the most important unresolved questions pertain to the interaction of the shelves with the deep-sea, large-scale circulation.

The second part is devoted to chapters that examine some of the physical processes underlying the larger scale circulations and distributions treated in the first part. Oceanic mixing processes, of all kinds and on all scales, have been, and remain, among the most important and enigmatic parts of oceanography. Here there is often an intricate interaction between the time-dependent components of oceanic motion and the large-scale distribution of properties—including momentum and energy. With the development of modern electronic instrumentation in the past two decades, completely unsuspected physical processes have been discovered (for example, thermal and haline microstructure). The advent of computers and of instruments capable of measuring oceanic time series has permitted attempts at linking physical phenomena previously studied wholly independently (for example, internal waves and resultant mixing). Many of the quantitative relationships remain obscure.

Included in the second part is a discussion of problems of biological oceanography. This subject is clearly evolving in parallel with physical oceanography, displaying a need for better understanding of the physical and chemical context, and for an appreciation that the biological sampling problems are at least as difficult as those beginning to be solved by physical oceanographers.

The third part, techniques of investigation, contains a description of some of the major tools of physical oceanography. Unlike many sciences, but in common with the other earth and astronomical sciences, oceanography is a field in which experiments as commonly described to students cannot usually be done. One must make sense of observations in a completely uncontrolled environment. Thus it becomes important to examine the observational basis of this science and to understand how the evolution of the field has followed very closely the development of new instruments and techniques. This part also contains a description of those comparatively rare, but extremely important, laboratory experiments that have shed light on important oceanographic phenomena. We have also included a chapter on radioisotope tracers; this field is, of course, a branch of chemical oceanography, and it stands as a science on its own apart from its usefulness to physical oceanographers. But a discussion is included because exploitation of such tracers will probably be one of the most fruitful *future* techniques for understanding many of the phenomena described in this book—those ranging from the largest circulation scales down to the finest near-molecular mixing mechanisms.

The fourth part contains two chapters on oceans and atmospheres. The first is directed at the actual physical coupling between air and sea. This, one of the most difficult problems in oceanography, is an area of increasing activity and interest, with a growing concern for climatic interaction of the two fluids. The other chapter is directed at the large-scale dynamical analogues between atmospheric and oceanic motions. Oceanography and meteorology are sister sciences, with each contributing ideas and insights to the other. One day they will undoubtedly be treated as a unified field. But study of the atmosphere has greatly benefited from the abundance of observations required for practical weather forecasts and the comparative ease of measurement, and meteorology is the more advanced subject. Thus it seems fitting to end this volume with a chapter on the not-always-obvious analogues of atmospheric motions to be found in the sea.

We have tried to tie the individual chapters together in a variety of ways. The book includes a general index of subjects and names, and also a reference list that gives the page number for each citation in the text. We hope that these features will make possible a rapid entry into the book by anyone seeking a discussion of a particular piece of work. Special care was taken in compiling the reference list to correct many common miscitations, some of which extend back nearly 100 years. The reader will notice overlap between chapters and even some dispute among them. We regard this as inevitable and healthy in a field undergoing the ferment of active progress. A consequence of this activity is that we did not attempt to impose a common notation upon the book, but we did ask the authors to avoid idiosyncratic schemes.

In the context of the question to the authors posed above, we are impressed in reading these chapters with how far we have come. When Henry Stommel entered physical oceanography in the early 1940s, the three authors of *The Oceans*, H. U. Sverdrup, Martin W. Johnson, and Richard H. Fleming, could cover authoritatively, in one volume, the entirety of oceanography—physics, chemistry, biology, and geology. Today no single volume could cover one of these fields, and probably no three authors would have the temerity to attempt comprehensive descriptions of any. But we believe that the reader will find here a broad description of the present state and the historical evolution of physical oceanography.

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