APPLIED OCEANOGRAPHY

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SERIES PREFACE

Ocean engineering is both old and new. It is old in that man has concerned himself with specific problems in the ocean for thousands of years. Ship building, prevention of beach erosion, and construction of offshore structures are just a few of the specialties that have been developed by engineers over the ages. Until recently, however, these efforts tended to be restricted to specific areas. Within the past decade an attempt has been made to coordinate the activities of all technologists in ocean work, calling the entire field "ocean engineering." Here we have its newness.

Ocean Engineering: A Wiley Series has been created to introduce engineers and scientists to the various areas of ocean engineering. Books in this series are so written as to enable engineers and scientists easily to learn the fundamental principles and techniques of a specialty other than their own. The books can also serve as textbooks in advanced undergraduate and introductory graduate courses. The topics to be covered in this series include ocean engineering wave mechanics, marine corrosion, coastal engineering, dynamics of marine vehicles, offshore structures, and geotechnical or seafloor engineering. We think that this series fills a great need in the literature of ocean technology.

MICHAEL E. MCCORMICK, EDITOR
RAMESWAR BHATTACHARYYA, ASSOCIATE EDITOR

November 1972

PREFACE

Oceanography books fall into two main categories. Those of the first type detail scientific relationships, giving little attention to their applications; those of the second type develop specific applications, usually with little or no concern for the scientific aspects of the topic. Readers of the first category often find it difficult to relate the material presented to real-world problems. Readers of the second category may never fully appreciate the scientific studies that have laid the groundwork for a particular application.

Given this perspective, the main objectives of this book are:

1. To provide the ocean-user community with a reference work that relates applied oceanography to the science of physical oceanography, where applied oceanography is defined as a system with physical oceanography, marine ecology, economics, and government policy as its four components.
2. To provide an introductory text suitable for both the student and the practitioner of physical oceanography who may also have an interest in the ultimate application of this knowledge to contemporary problems in marine pollution, marine resources, and marine transportation.
3. To separate background scientific information from its applications, giving adequate attention to each.
4. To allow those presently engaged in some aspect of applied oceanography to develop a basic understanding of additional topics, and thereby to promote "cross-fertilization" within the field. For example, the major naval powers of the world have developed advanced techniques to predict ocean thermal structure for anti-submarine operations. The same prediction techniques could also be applied to locating temperature-sensitive fish species.

The book is organized into two major parts. In Part One, consisting of five chapters, basic concepts of physical oceanography are outlined, with emphasis on the development of information related to the applied topics covered in later chapters. In Part Two, consisting of nine chapters, applied oceanography is addressed, with examples of applications in marine pollution, marine resources, and marine transportation.

The information presented in the following pages represents an effort to communicate my understanding of the newly developing field of applied oceanography. It does not represent a complete and comprehensive development of individual topics within the field, but rather a summary of information considered appropriate based on my background and interests. Regardless, the topics as developed will serve as a point of departure for those interested in, working in, or in need of information on how physical oceanography can be applied to solve real-world problems of contemporary interest.

JOSEPH M. BISHOP

Washington, D.C.
April 1984

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Throughout the preparation of this book I tried to condense the work of a number of investigators engaged in various aspects of applied oceanography. I acknowledge their contributions and hope that I have reported their work adequately and correctly. I was also fortunate to be able to draw upon the fine efforts of a few special people who worked with me to get the manuscript "clean" enough to send to the typesetter. The first, Elizabeth Haynes, of the National Oceanographic and Atmospheric Administration, is a meteorologist turned fisheries oceanographer. Elizabeth carefully used her sharp red pencil on at least two drafts of the original text. I thank her for giving generously of her time to review the manuscript. Second, I would like to thank Kathryn Bush, a physical oceanographer with Marine Environments Corporation, for her careful technical editing of the final manuscript. In addition, credit must go to Amikam Gilad of Marine Environments Corporation, who completed many of the illustrations in the book. Thanks also go to Dr. Richard James of the U.S. Navy, Dr. Carvel Blair of Old Dominion University, and Mr. Richard Hayes of the U.S. Coast Guard for reviewing portions of the manuscript. Finally, I would like to thank Dr. Marshall Earle, President of Marine Environments Corporation, for his review of the technical aspects of the book.

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PART

ONE

A SURVEY OF PHYSICAL OCEANOGRAPHY

A main objective of the book is to introduce the field of applied oceanography to the ocean-user community. The subject is addressed with a primary focus on physical oceanography. Therefore, a survey of physical oceanography is presented to give a basis from which to develop various topics in applied oceanography. This information is intended to serve as a review for those involved in physical oceanography and as introductory material for those not well versed in the subject. The major areas covered include basic meteorology and oceanography, ocean currents, ocean waves, and the advection and mixing of contaminants at sea. The survey will be developed with an applications orientation, thereby giving a different perspective from that usually presented in typical reference works on physical oceanography.

Chapter One

THE OCEANS: SEA AND AIR

In this chapter we will develop fundamental relationships important to both meteorology and oceanography. We begin with a discussion of how the sun provides the radiant energy that ultimately drives the circulation of the oceans of sea and air that cover the globe. Accordingly, atmospheric winds and oceanic currents are described as nature's way of spreading the excess low-latitude solar energy across the Earth's surface.

Meteorologists and oceanographers have classically employed specialized charts of such physical parameters as wind, current, temperature, pressure, and density to study oceanic and atmospheric exchange processes. For example, sea–air temperature difference charts are used to estimate heat exchange across the sea–air interface, and surface wind charts are used to calculate momentum flux to ocean waves and currents. This approach has led to the application of relationships commonly used in meterology, a more advanced environmental science, to physical oceanography. Analogies between air masses and water masses and between atmospheric fronts and oceanic fronts have provided valuable insights into the physics and dynamics of the ocean.

Meteorological parameters commonly charted include air temperature, air pressure, and water-vapor content, which are related to air density by a theoretically derived equation of state. Distributions of these variables of state are dynamically related to winds. Oceanographic parameters charted include sea temperature, sea pressure, and salinity, which are related to sea water density by an empirical equation of state. Distributions of the oceanic variables of state are dynamically related to ocean currents.

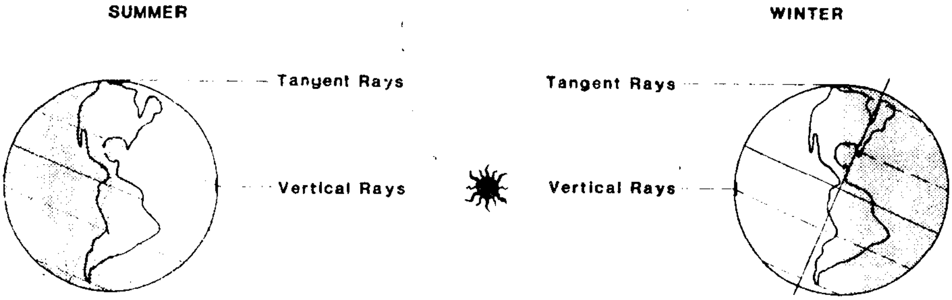

Figure 1.1. Radiation from the sun strikes the Earth's surface more directly in the Northern Hemisphere in the summer than in the winter.

1.1. THE ENERGY SOURCE

The Earth travels in an elliptical orbit around the sun at an average distance of about 150 million kilometers. It also rotates on its axis once each day, producing alternate days and nights. The Earth's axis ~~of rotation~~ is inclined 23.5° to the plane of its orbit around the sun. The annual orbit, coupled with the inclination of the Earth's axis, produces seasonal variations in the intensity of incoming solar radiation, as shown in Figure 1.1.

The sun radiates electromagnetic energy over a spectrum of wavelengths from short-wave, high-frequency x-rays to long-wave, lower-frequency infrared waves and even longer radio waves. Visible light, a mixture of such familiar colors as violet, blue, green, and red, is located in the highest energy portion of this spectrum. Approximately 40 percent of the total solar radiation received at the Earth's upper atmosphere is either scattered by atmospheric particles or reflected back into space. In addition, about 15 percent of the incoming solar radiation is absorbed by the atmosphere. The remaining energy reaches and heats the Earth's surface. The Earth then re-radiates this heat in the infrared portion of the electromagnetic spectrum. Outgoing terrestrial radiation is selectively absorbed by atmospheric carbon dioxide and water vapor in the lower atmosphere. This process is commonly referred to as the "greenhouse effect," since the atmosphere acts like the glass of a greenhouse, admitting incoming and trapping outgoing radiation. The greenhouse effect accounts for the typical decrease in temperature with altitude in the Earth's lower atmosphere.

1.2. THE GENERAL CIRCULATION OF THE ATMOSPHERE

The Earth's equatorial regions are far warmer than the poles because they receive direct solar radiation, as illustrated in Figure 1.1. At the Earth's surface in equatorial latitudes vast amounts of warmed air rise into the upper atmosphere, forming a surface low-pressure region known as the Intertropical Convergence Zone (ITCZ). The ITCZ is generally located north of the geographic equator, and is often visible on weather satellite images as a band of clouds that nearly circles the globe. The rising air reaches altitudes of 15 to 20 km and then flows north and south toward the poles. A portion of this air sinks back toward the Earth's surface at approximately 30°N and 30°S latitudes, producing the subtropical high-pressure zones. The cold dense air over the polar regions also sinks, producing additional surface high-pressure zones. Subtropical high-pressure zones that are formed over warm ocean areas produce warm, moist air masses, while high-pressure zones formed over the poles generally produce cold, dry air masses. The subtropical and polar high-pressure regions are separated by bands of low pressure located at about 60°N and 60°S latitudes. These regions, known as the polar fronts, tend to move poleward in the summer and equatorward in the winter. Like the ITCZ, the polar fronts can be identified by their cloud cover, storminess, upward air flow at the Earth's surface, and relatively low surface atmospheric pressure.

Pressure differences between these global high- and low-pressure zones produce a wind flowing toward lower pressure. The greater the pressure gradient (the pressure change over a given distance), the faster this wind blows. The Earth's west to east rotation modifies the direct flow toward low pressure. Viewed from the Earth, there is a turning of the original wind direction to the right of the flow in the Northern Hemisphere and to the left in the Southern Hemisphere. This deflection is known as the Coriolis effect, and plays a key role in the dynamics of large-scale atmospheric and oceanic flow. In the Northern Hemisphere the Coriolis effect causes poleward air flow to turn east and equatorward air flow to turn west. The opposite occurs in the Southern Hemisphere.

As an example of how global-scale pressure gradients and the Coriolis effect combine to produce global-scale wind patterns, consider the northeast trade winds in the Northern Hemisphere. Between the subtropical high-pressure zone (at 30°N) and the ITCZ the pressure gradient is directed toward the equator. The wind initially blows in that direction, but is deflected to the right (west) by the Coriolis effect, resulting in the northeast trade-wind belt. The prevailing westerlies and the polar easterlies of both hemispheres can be explained similarly. In short, the general circulation of the atmosphere, as shown in Figure 1.2, can be described in simple terms as a response to global-scale pressure gradients and the Earth's rotation.

1.3. UNITS AND DIMENSIONS

The CGS system of units, which consists of the metric units centimeters (cm), grams (g), and seconds (s), is commonly used in meteorology and oceanography and will be used in this book. In addition, the MKS system, consisting of the meter (1 m = 100 cm), the kilogram (1 kg = 1000 g), and the

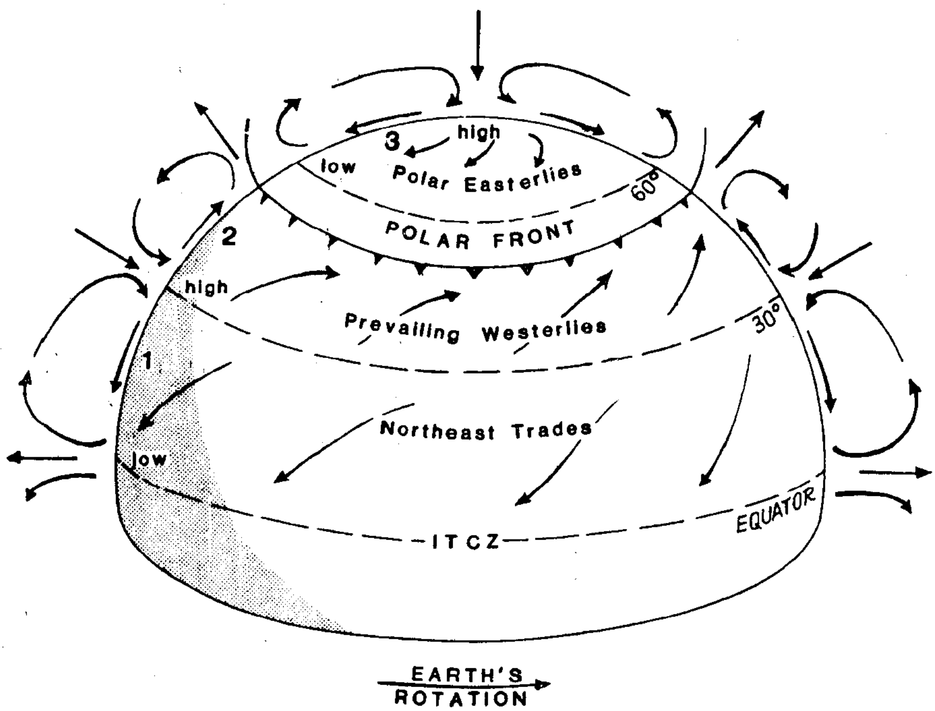

Figure 1.2. The general circulation of the Northern Hemisphere is shown to be the result of the three global-scale pressure gradients (numbered 1, 2, and 3) and the Earth's rotation.

second, will be used interchangeably with the CGS system, with the appropriate conversion. Units such as the kilometer (1 km = 1000 m), foot (30.48 cm), nautical mile (1853m = 1.853 km), statute mile (1609 m = 1.609 km), and knot (51.47 cm/s) may also be used on occasion.

Quantities can be expressed in terms of the basic dimensions of length (L), mass (M), time (T), and temperature (t). Some of the more commonly used metric quantities are shown in Table 1.1. Attention to the units and dimensions of a quantity can help in the verification of equations and in some cases in the development of new relationships among variables.

1.4. THE VARIABLES OF STATE

A classical approach to oceanography and meterology is to study fluid processes by mapping the variables of state. Observed data are generally plotted on synoptic charts, which show observations taken at about the same time, or on climatic charts, which show observations that have been averaged over time and space. These charts have been used to develop mathematical relations between the variables of state and to gain insight into fluid-dynamical processes. For example, the average January sea- and air-