HORACE ROBERT BYERS, Sc.D.

General Meteorology

FOURTH EDITION

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GENERAL
METEOROLOGY

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PREFACE TO THE FOURTH EDITION

New meteorological knowledge continues to unfold at a rapid rate, offering a challenge to the teacher, the professional, and the textbook writer to keep pace with the developments. Since 1959, when the third edition was published, new areas of interest have developed and our understanding of old concepts has improved. Better quantitative treatments have become possible. At the same time, students entering the field are better equipped to grasp its principles and those of many other fields of science and technology.

This book is intended to present the broad picture of atmospheric processes to the serious student of meteorology before he takes up more complex concepts of fluid mechanics and meteorological analysis and before he branches out into the various meteorological specialties.

Major changes made in this edition include the following: (1) The former chapters on instruments and observations, which are usually treated in a separate course, have been placed in appendixes in order to provide better continuity in the presentation. (2) Exercises have been added at the end of most chapters. (3) An appendix covering the system of units and giving some useful constants has been added. (4) Some of the previous chapters have been combined into one chapter instead of two. (5) An Introduction has been added to lay some groundwork for the course.

(6) Introductory remarks have been added for various chapters and topics to provide a more connected presentation.

Again, the author is indebted to his colleagues, and others, for suggestions and assistance in putting together the material for this book and, in some cases, critically reading the manuscript.

HORACE ROBERT BYERS

EXCERPT FROM THE PREFACE TO THE THIRD EDITION

This book, written at about the level of some of the textbooks of general physics, is intended for the serious student of physical sciences and technology. It presupposes that the reader has taken elementary courses in mechanics and heat and that he has some familiarity with or is concurrently learning calculus. It can form the basis of a course in meteorology to be given as early as the sophomore year for those technical students who have seriously prepared for it, or it may be given as late as the senior year.

This third edition differs from the earlier ones in several aspects. Primarily, of course, it brings the material up to date in this rapidly changing field. Also, the book is now more fundamental in nature than previously. The emphasis on basic material is necessary in order to place the student in a position to branch out into areas of meteorology in which quantitative methods have only recently been used. Furthermore, the applications have become so specialized that a separate book is needed to treat each one, and such specialized books have been appearing in increasing numbers. The author of a book such as this has the satisfaction of knowing that the applications become outdated more rapidly than do the fundamentals.

HORACE ROBERT BYERS

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INTRODUCTION

When astronauts describe their experiences and sensations of space travel, they invariably speak of the majestic beauty of the planet Earth. The most prominent features they see are the great cloud masses marking the major storm areas, covering a large part of the continents and oceans in delicate white veils or dense bands. The clouds are embedded in the faintly tinted blue atmosphere, which deepens in hue around the rim of the planet where the line of sight goes tangentially through a longer atmospheric path.

If time-lapse pictures are taken of the earth, it is noted that the cloud patterns are continually changing. There are swirling masses of clouds in the higher latitudes which can be recognized as tracing the air motion along fronts, and spiraling around the low-pressure disturbances. From the equatorial regions dense white masses may be sending off prominent streams of clouds into middle latitudes.

It is apparent that the earth has a restless atmosphere. That is why we must consider its properties not only in their spatial distributions but also in terms of changes with time. With all its waves and whirls the atmosphere nevertheless rotates with the earth as an integral part of the system. Its internal motions serve to balance the unequal heating and cooling of different parts of the earth.

In this book we shall examine how the heat from the sun is distributed, concentrated in low latitudes, to provide the thermal drive for the atmospheric motions; how the rotation of the earth affects these motions; and how storminess becomes an essential part of the picture.

SOME CHARACTERISTICS OF THE STUDY

We shall place our emphasis on the atmosphere up to 35 km, which is that part in which the activity related to weather occurs. This spherical shell, having a thickness with respect to the size of the earth that is comparable with the skin of an apple, is the seat of the most active natural phenomena that man can observe. The atmosphere may be regarded as a huge thermodynamic engine operating between an equatorial heat source and a sink at the poles. Its circulation is complicated by special effects produced by the rotation of the earth and by reactions to various local drives.

The weather map appearing on television or printed in the newspapers is a greatly simplified version of the complicated, interrelated, three-dimensional structures that evolve in time, which we shall be discussing—the substratospheric jet streams, the wave-like perturbations in the free atmosphere, the great air exchanges that make up the general circulation, as well as the details of modifications caused by phase changes of the water substance, frictional effects, and local heat sources and sinks. All these phenomena can be described in exact mathematical-physical terms. Meteorologists, aided by various forms of automation and advanced numerical computers, are approaching a state of their science where complete and accurate predictions might be possible.

A glance at pages of this book selected at random will indicate the kinds of mathematical-physical relations, diagrams, and map representations used to describe properties and processes. If the student becomes confused, it is not surprising, because he may be accustomed to studying science through controlled experiment rather than in an open system that is running without control. If he finds the drama of the atmosphere exciting and the problems of meteorology challenging, then he has experienced some of the fascination of the subject.

NAMING THE SCIENCE

The Greeks had the word *meteōrologia*, from *meteōros*, meaning things up above, plus *logos*, translated as discourse; but today the study of the atmosphere has become so divided into specialties that the all-inclusive word *meteorology* which we have perpetuated from the ancient Greeks does not satisfy everybody. Thus we have the word *aeronomy* for the study of that part of the atmosphere where ionization and dissociation are important, generally above about 35 km, while *atmospheric science(s)* is favored by some as the inclusive designation. The former International Association of Meteorology has *and Atmospheric Physics* added to its name, and some university meteorology departments have dropped the broad term meteorology in favor of words that mean the same but suggest something different.

Part of the motive in adopting new names, freely admitted by those who have suggested them, is to get rid of a designation that is misunderstood by the general public and even by some scientists. A meteorologist is regarded by too many people as a person who displays a crude map and gives a weather forecast on television or, at best, as a forecaster in a government weather office. His efforts are seen as unscientific or, in some cases, downright amusing. Even the sophisticated citizen is likely to view meteorology as a largely descriptive subject bearing on the study of geography. Then there are those who think meteorologists are a breed of astronomers who study meteors.

The misunderstanding is not helped by the treatment of the subject in some high school and junior college courses. It is often included in a teaching unit with other descriptive material described as "earth sciences." Indeed, geographers, because of their interest in weather and climate as elements in shaping the physical and cultural landscape, are often called upon to teach it.

The student, and perhaps teachers, may be surprised to find that meteorology is a specialized branch of advanced physics, using sophisticated mathematical tools and leaning heavily on all the physical sciences. Chiefly it involves electromagnetic radiation theory, thermodynamics, classical mechanics, physics of fluids, physical chemistry, and boundary-layer theory. If the upper atmosphere is included, then solar physics, spectroscopy, plasma physics, ionization, particle physics, x-ray phenomena, optics, cosmic-ray physics, excitation phenomena, electrodynamics, magnetohydrodynamics, radio propagation, and other related processes must be understood.

CHARTING OUR COURSE

The chapters of this book present topics in a sequence that leads from basic forces to the complicated interactions of the atmosphere. First, in Chap. 2, we consider the source of the energy that drives the atmosphere—the sun—and how its energy is received by the earth. To understand its effects and the response of the earth to the resulting uneven heating, the student learns some fundamental concepts of radiation physics, then applies these to an accounting of the heat budget of the earth and its atmosphere (Chap. 3). With this background, we then take a somewhat detailed look, in Chap. 4, at the distribution of temperature in the global atmosphere.

Air behaves as would any of the ordinary gases under heating and cooling, expansion and compression; so in Chap. 5 we explore gas thermodynamics and learn how and why the pressure changes with height and under what conditions the atmosphere can become thermally unstable, as in thunderstorms, or strongly stable, as in fogs and air-pollution incidents. The air carries a most important substance, water, usually in the invisible-vapor form, but through condensation in clouds and occasional falling as rain or snow, the water not only moistens the land but also produces formidable thermodynamic changes in the atmosphere (Chap. 6).

Having understood the thermal or thermodynamic machinery that drives the atmosphere, we next study the resulting air motions (Chap. 7). Here we encounter something entirely new to most students of physics—a noninertial or apparent force. Because of the rotation of the earth and the need to represent motions in this rotating frame of reference, an apparent deflecting force arises. We show how this force relates to other forces and what the motions (the winds) look like when represented on a weather map. This leads us to more sophisticated concepts of fluid motions applicable to weather prediction and to an understanding of global circulations (Chap. 8).

With our knowledge of thermodynamics and mechanics of the atmosphere, we are ready to examine and explain the general circulation of the air (Chap. 9), which serves to keep various parts of the earth in temperature equilibrium over the long term. We discover the great importance of perturbations (storms) in exchanging air between equatorial and polar regions. The alternating bursts of cold or warm air accompanying these disturbances constitute the mechanism of the weather observed in all latitudes except the tropics (Chap. 10).

We are now looking at day-to-day weather, the tropical and polar air masses and their contrasting properties (Chap. 11). Along with this view of weather, we learn something about the analysis of weather charts for the various levels and in vertical cross sections (Chap. 12). Then, to complete our picture of the weather, we turn our attention to the tropics, where we see a different set of weather problems and the most dramatic phenomenon of all, the hurricane or typhoon (Chap. 13).

We come next to what all the preceding has been leading to—weather prediction (Chap. 14). Although hints at various elements of prediction have been brought up before, we now concentrate on some of the modern numerical methods, such as in the big U.S. National Weather Service prediction center.

In our final two chapters (Chaps. 15 and 16) we examine important smaller-scale phenomena. We consider the physics of clouds and precipitation. (It is on this subject that weather modification is based.) And finally we summarize what is known about thunderstorms and other severe weather manifestations.

The descriptive and quantitative details revealed in the text are more meaningful if accompanied by practical work in observing, measuring, analyzing, and predicting the weather. If the student is not concurrently getting such practice in another course, he should give some attention to displays of weather charts and whatever other materials are at hand. In Appendixes A and B the essentials of common instruments and observations are presented. These can be covered in a separate course, but the student who is lacking such exposure would do well to refer to the appendixes for information on the sources of meteorological data. Appendix C is helpful in providing essential information for quantitative applications and problem solving.

EXERCISES

1 Review the system of units summarized in Appendix C, and

(*a*) Construct a graph relating Fahrenheit temperature to Celsius temperature from −60 to 40°C.

(*b*) Change 600 cal g^{-1} (the heat of vaporization of water near 0°C) to joules per kilogram and 2 g-cal cm^{-2} min^{-1} (the approximate solar heating outside the atmosphere) to watts per square meter.

(*c*) Convert 8.5×10^5 dynes cm^{-2} to newtons per square meter; to millibars; to the equivalent millimeters of mercury; to the equivalent inches of mercury.

(*d*) Convert grams per cubic centimeter to kilograms per cubic meter.

(*e*) Convert miles per hour to meters per second.

(*f*) Compare the volume of an average cloud droplet 5 μm in radius with a raindrop 2 mm in radius and a marble-size hailstone 1 cm in radius; then think about how many cloud droplets have to come together to make a raindrop or a hailstone.

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