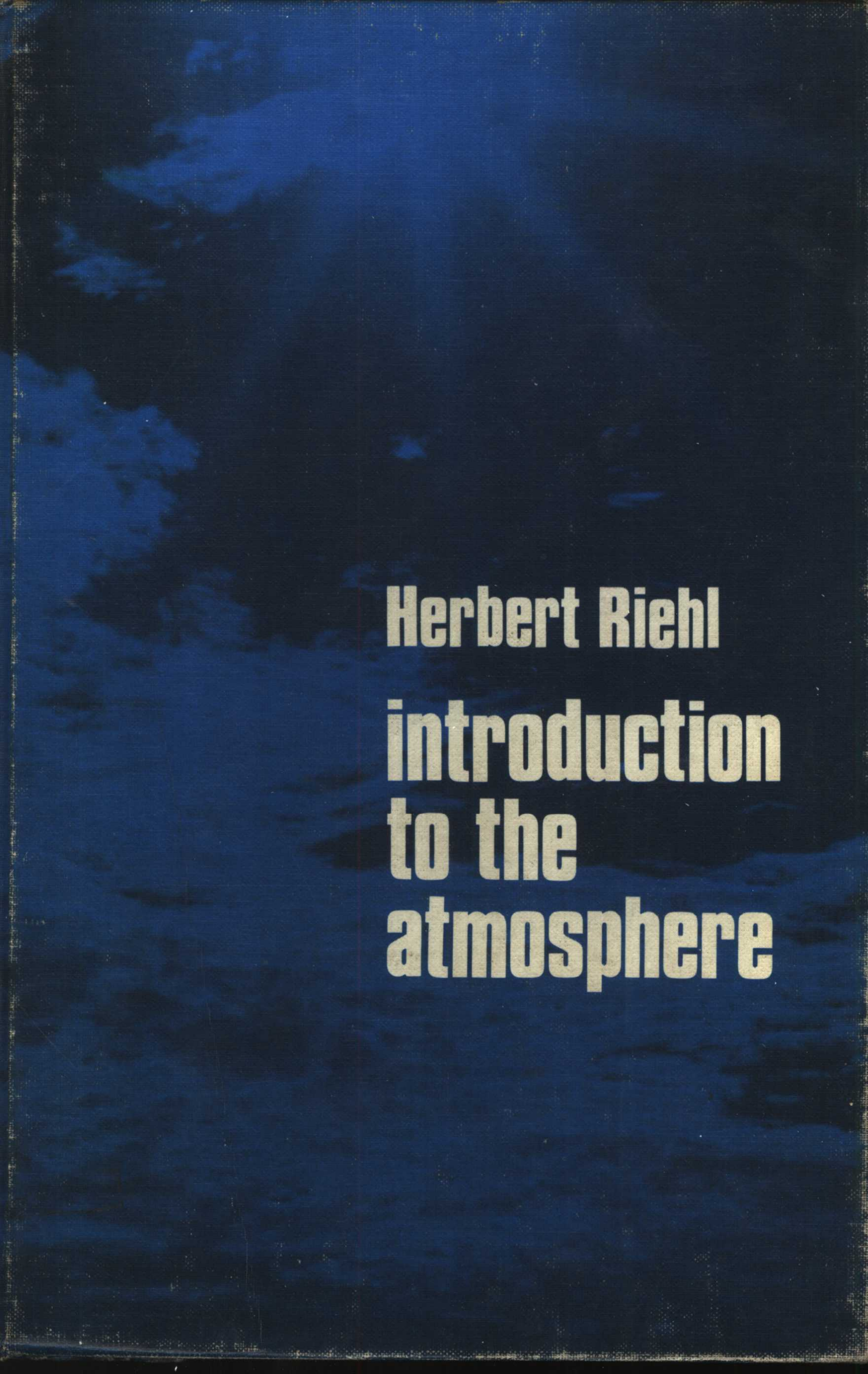

Herbert Riehl

introduction to the atmosphere

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McGRAW-HILL BOOK COMPANY

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Library of Congress Catalog Card Number 73-163846

07-052653-2

1 2 3 4 5 6 7 8 9 0 MAMM 7 9 8 7 6 5 4 3 2 1

This book was set in Caledonia by Monotype Composition Company, Inc., and printed and bound by The Maple Press Company. The designer was Marsha Cohen; the drawings were done by John Cordes, J. & R. Technical Services, Inc. The editors were Bradford Bayne, Anne Marie Horowitz, and Michael Gardner. Sally Ellyson supervised production.

preface to the second edition

Two major events since the 1965 publication of the first edition of this text have affected the atmospheric science field: (1) the continuing spectacular advance of satellite technology as an observational tool and (2) the worldwide rise in awareness of the dangers to environmental equilibrium posed by man's activities.

In line with the aim of presenting and whenever possible anticipating important trends in the subject, the second edition contains many illustrations drawn from satellite observations and an expanded discussion of remote-sensing techniques in general. There was no fear of going beyond what the general student in terminal courses could grasp because presentation of satellite information in news media has become so widespread that students enrolling in a general atmospheric course can be expected to be well indoctrinated and receptive to this additional information.

Discussion of the atmosphere as a prime means for environmental modification has been greatly amplified, not only in such obvious subjects as air pollution but also in more subtle aspects of man's unintentional interference with nature. An enlarged survey of practical applications includes the antilocust operations in the deserts and transoceanic ship routing.

Thanks are due to many friends who have made recommendations for improvements in many chapters; in particular, the author is obliged to Dr. Charles L. Jordan, of Florida State University, as a result of whose suggestions Chap. 1 has been extensively recast and substantial changes have been made in other chapters to aid instructors in classroom presentation of the various topics.

The author has also responded to considerable demand for problems and exercises, drawing mainly on material he has used himself. Emphasis has been placed on establishing a bridge between the course and the student's live surroundings and experiences rather than on technical calculations and problems, which for the most part would have to be trivial. Weather and climate stand so much in the foreground of important decisions about many facets of life that it seems appropriate to arouse the student's awareness of this fact and exploit it. Oddly, perhaps, this bridge is not obvious except to a very few; it is hoped that the type of challenge conveyed by the problems and questions will heighten the student's interest and stimulate him to explore some connection between the atmosphere and life on earth. Thus he would also be made fully aware of the highly interdisciplinary status of the whole subject of atmospheric studies.

For convenience, the problems have been divided into general class assignments and special-interest topics, which might be investigated by one or more students curious about a particular subject, or which are suitable for a term paper. Instructors and students will think of many subjects beyond those listed, which are intended primarily as a guide and stimulus for new ideas.

Editorial and typing assistance by Patricia Johnson is gratefully acknowledged.

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preface to the first edition

During the years that have passed since about 1940, the advances in knowledge of the atmosphere have been rapid and exciting. In part, they have come about through increasing understanding of the physical processes, in part through great expansion of observing networks and development of instruments to measure the atmosphere. When the author took his first meteorology course, telemetering of pressure, temperature, and humidity aloft to the ground from rising balloons was the latest technological advance. Nowadays, we take it in stride when weather satellites bring news about storms over distant oceans, when rockets report jet-stream winds at great heights, and when large computers grind out weather forecasts for large parts of the world in minutes.

The advances in knowledge have brought, as a corollary, ever-increasing interest in atmospheric science and its relation to other branches of science. Widening use is made of information about weather in public and private enterprises. At many universities instruction in atmospheric science has been started as part of geophysics curricula; numerous non-specialist "terminal" courses have become part of science offerings. It is for the students in such instruction programs, desiring a concise yet thorough view of the field, that this book is primarily intended. The author hopes, further, that it will prove useful as a volume for study and reference to engineers and other professional men and women whose work requires some understanding and judgment about the atmosphere.

With these objectives, the book is short and nonmathematical. Subject matter has been held to a limited range of topics, with emphasis on the basic aspects of the science. Even so, considerable room remains for an instructor's selection and, of course, for enlargement in areas of his choice. At Colorado State University, the course is offered for students with general science background.

The modern views about the atmosphere, and the problems for the future, are stressed throughout the book. The author has not hesitated to present subjects such as large-scale wave motion in the upper air under the influence of the earth's rotation. This is a most important topic for understanding daily weather changes, warm or cold winters, and even climates. Controversial subjects like weather modification are also included. Further, the author wishes to convey that, although atmospheric science is a field for rigorous and useful inquiry, it is also fun, and exciting in its future prospects.

The author is grateful to the several copyright holders and to his many friends who have placed illustrations at his disposal. He also wishes to express thanks to his colleagues, especially Dr. Patrick Squires, of the National Center for Atmospheric Research, Boulder, Colorado, for critical reading of parts of the text, and to Ann Ewing and Jamia Cone for editorial assistance.

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For 5 years before the French Revolution began in 1789, Thomas Jefferson, then U.S. Minister to France, observed at close range the ferment that led to the conflict. After noting that all attempts at progressive measures were nullified by the influence of Queen and Court, he commented in his autobiography on the 1788–1789 winter in Paris:

But the hand of heaven weighed heavily indeed on the machinations of this junto [Queen and Court]; producing collateral incidents, not arising out of the case, yet powerfully co-exciting the nation to force a regeneration of its government, and overwhelming with accumulated difficulties, this liberticide resistance. For, while laboring under the want of money for even ordinary purposes, in a government which required a million livres a day, and driven to the last ditch by the universal call for liberty, there came on a winter of such severe cold, as was without example in the memory of man, or in the written records of history. The mercury was at times 50° below the freezing point of Fahrenheit, and 22° below that of Reaumur. All out-door labor was suspended, and the poor, without the wages of labor, were, of course, without either bread or fuel. The government found its necessities aggravated by that of procuring immense quantities of fire-wood, and of keeping great fires at all the cross streets, around which the people gathered in crowds, to avoid perishing with cold.

In these lines, Jefferson has made a shrewd observation of how weather, especially extreme weather, can affect the affairs of men. History abounds with examples of how floods and droughts, prolonged cold, hurricanes and other violent winds, and just plain good weather when it was least wanted have left their mark on the fate of nations. What brings temperatures of −18°F to Paris? The answer to this question is well understood today. Occasionally, in winter, winds blow persistently toward western Europe from the reservoir of very cold air over Russia and Siberia. Upon arrival of this cold air Paris experiences a rare taste of Moscow winter—rare, because a long passage of air from the interior of Asia is distinctly abnormal.

The roots for such abnormal air motions, as well as for normal ones, lie in the reaction of the air to the motion of the sun, to the rotation of the earth about its axis, to the distribution of continents and oceans, and to large mountain ranges—among many factors. Atmospheric science[1] is the branch of physics concerned with understanding the processes taking place in the *atmosphere,* the *gaseous* or *vaporous shell* surrounding the earth's solid body. When the state of the atmosphere is viewed at an instant of time, as in the frontispiece of this text, that particular state is termed *weather.* When the weather is observed long enough in different parts of the world to reveal permanent differences of importance—warm winters in Miami, cold winters in Boston—we speak of *climate.* The term denotes *inclination* in Greek, the inclination of the earth's surface with respect to the sun's rays, revealing how early in history solar control of life on earth was recognized.

The atmospheric processes and the weather and climate they produce are the subjects of this book. We begin by noting which variables of nature communicate these processes to man and all

[1] Also called *meteorology* (literally "the tale of that which is suspended up high").

other living things, in considerable measure governing their existence.

SURVEY OF THE PRINCIPAL VARIABLES

Temperature. Emphasized in all routine weather news releases, temperature is perhaps the most important factor for the user of weather information. Broadcasts usually give the current temperature, the highest and lowest temperature during the preceding day and night, and the outlook for high and low temperature during the next 24 hr. During very hot or cold weather it is mentioned whether the record has been broken, i.e., whether temperature has risen high enough or fallen low enough to exceed any previous value for that date observed in the history of the site where the measurement is made. When records go back for 50 or 100 years, breaking the record indeed becomes impressive.

There are other concerns, e.g., whether temperature will cross a certain *threshold*. The most important threshold is the freezing point, particularly important in spring, when late-season frosts threaten agriculture. From another point of view, the rise of temperature above this threshold is vital to the engineer who watches with concern the breakup of frozen lakes and rivers and the onset of general melting; he has high river stages to worry about and ice drift threatening to sweep away bridges.

Sometimes longer *time scales*, such as a week, a month, or a year are important. For analyzing these time scales, the average temperature of each day must be determined first. A good daily average is obtained when a thermometer is read every hour; the twenty-four hourly values are then added, and the sum is divided by 24. Often the average is formed simply by adding the highest and lowest temperature for a day and dividing by 2, a quick but approximate procedure. The daily mean temperatures may be added for, say, a month and the sum divided by 30 or 31. The monthly temperature so obtained is directly informative. Of major concern, for instance, is whether a month has been warmer or colder than normal. Where climatic records exist for, say, a century or more, such information can also be used to detect any rhythm of prolonged warm or cold periods lasting years and whether a *long-term trend* is in evidence, suggesting a *change of climate.* We know that during the last century the air warmed slowly but that this trend halted and reversed itself around 1950. Temperature changes are largest in the high latitudes, raising or lowering the general economic outlook for the nations in that part of the globe.

Precipitation. The moisture supply is almost as important as temperature. As a variable of weather and climate, it differs from temperature in that it is intermittent whereas temperature is continuous. Further, precipitation comes down in various forms—rain, snow, and occasionally hail. Thus, the questions raised about precipitation are quite unlike those about temperature. Has precipitation been adequate or insufficient to meet the demand for water? What is the outlook for the future? These questions cannot be answered on the time scale of a day or a week but only by considering totals for weeks, months, or seasons. To gather the requisite information, precipitation measured, say, once daily is *accumulated* by adding the values on successive days. When a month has passed, the accumulation for the month can be compared with a normal. The monthly excess or deficit, when added over several successive months, shows in particular whether there has been a drought and how severe it is. By going over a long climatic record (preferably 100 years) such analysis will determine whether prolonged successions of wet or dry years have occurred and how much water storage in reservoirs is needed to protect against shortage. As with temperature, such records also reveal whether a climatic shift to drier or wetter conditions has occurred or is still going on.

Precipitation has a second focus of interest at short to very short time scales, since heavy rains lead to flooding. The record may be studied for very heavy rains lasting, say, 1, 5, 10, 30, and 60 min, 3, 6, 12 and 24 hr, and 1, 2, and 3 days. The heavy rain, lasting for instance 5 min, may be the largest such rain that can be expected on the average once in 1, 5, 10, 50, 100, or even 1,000 years. This information about cloudbursts must be used to determine the design of culverts for highway construction, to prevent