AN INTRODUCTION TO WEATHER AND CLIMATE

TREWARTHA

McGRAW-HILL

AN INTRODUCTION
TO
WEATHER AND CLIMATE

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AN INTRODUCTION TO WEATHER AND CLIMATE

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PREFACE
to the Second Edition

In the six years that have elapsed since "An Introduction to Weather and Climate" was first published, advances in the science of the atmosphere have made available important new materials suitable for inclusion in a college textbook on weather and climate. These six additional years of teaching climatology to college students, together with the helpful criticisms of colleagues in the field of geography who have used this book, have also provided the author with new ideas relative to the selection and organization of the materials to be incorporated in the present revision.

As the revision was first considered, the plan called for a book comprised of three parts. Parts I and II were to resemble in general content Parts I and II in the first edition. Part III, which had no counterpart in the earlier edition, was to have been a regional analysis of the climates of the individual continents. The war, with its unusual demands upon the author's time, has made the completion of Part III at this time impossible. It was decided, therefore, not to delay further the publication of the completed Parts I and II, since Part III might not be ready until some indefinite time in the postwar future. It is altogether possible, however, that Part III may be added to the present book before a general revision of its earlier parts is necessary.

Utilizing materials made available by recent advances in atmospheric science, and benefiting by his own and the experiences of others in using "An Introduction to Weather and Climate" in classroom teaching, the author has made the following significant modifications of the earlier edition of this book:

1. Part I, dealing with the elements weather and climate, has been largely rewritten with the purpose in mind both of expanding and of deepening the general content. Numerous topics not touched upon in the earlier edition have been included, and old materials have been amplified and modified. As a result, the whole content of Part I has been lifted to a higher and more advanced level.

2. An entirely new chapter dealing with the origin and modification of air masses, atmospheric fronts, and the air-mass characteristics of some of the continents has been added to Part I.

3. The scheme of climatic classification has been revised, and a new map of world climates has been included. The classification of climates is a modification of the Köppen system. Climatic boundaries are quantitatively defined.

4. Between 90 and 100 new illustrations have been added.

5. The supplementary climatic data have been greatly expanded, and the stations represented have been classified according to climatic types.

6. Part II has been revised and expanded. Much more than in the first edition, air-mass characteristics have been utilized in explanation of regional climates. At the close of the discussion of each climatic type, sections have been added describing the influence of the climate upon native vegetation and soil characteristics. Maps showing world distribution of soils and native vegetation have been added.

GLENN T. TREWARTHA.

MADISON, WISCONSIN,
July, 1943.

PREFACE
to the First Edition

The reason for the publication as a separate volume of the materials contained in this book is the need expressed by geographers for a brief introductory text at college level covering the field of weather and climate apart from the other elements of physical earth. In its present form, as the revised and expanded Sections *A* and *B* of Part I of "Elements of Geography" by Vernor C. Finch and Glenn T. Trewartha, it is in the nature of a handbook designed to provide an outline of content for a general introductory course on the atmosphere. It makes no pretense of being a textbook on meteorology or air physics, for no attempt has been made to cover the variety of topics included within the bounds of that science. Neither does it purport to treat in a comprehensive fashion those topics which have been selected for inclusion. The book is avowedly introductory in character and is climatic rather than meteorological in its point of view. Its principal merit lies in the choice of material that has been included and in the structure of its organization rather than in the completeness of its coverage of subject matter on the atmosphere.

Two relatively distinct but nevertheless intimately interdependent parts comprise the book proper. Part I provides text material covering the general field of weather and climatic elements. It is analytical in character and treats the several climatic elements, such as temperature, precipitation, and storms, individually. Causes and origins are not omitted but that phase of the subject receives less emphasis than does description and world distribution. The criterion employed in the selection of materials to be included in Part I has been their relative significance in contributing to an understanding of

regional climates. Using this standard, it was possible logically to exclude from Part I many topics properly included in books on air physics. The necessity for keeping the book brief and in the nature of a handbook will cause many instructors to feel the necessity for expanding the treatment of numerous topics here introduced. To this end brief bibliographic outlines with page references have been provided at the end of each chapter in Part I. In this way the book offers the instructor and the student a framework upon which to build a more advanced or more comprehensive treatment of the subject.

Part II of the book has as its principal theme regional climates. A brief statement concerning schemes of climatic classification is in the nature of an introduction. This is followed by a relatively detailed explanatory description of the various types of climate and their world distribution. Regional peculiarities within the types are not ignored but on the other hand they do not receive the principal emphasis. A modified Köppen system of classification is employed. Throughout Part II less emphasis is placed upon the exact definitions of the climatic boundaries and more upon items of description, explanation, and distribution.

In the preparation of the manuscript for this book some of the most perplexing problems have arisen out of the fact that weather science today is in a remarkable state of flux. Particularly as a result of the more complete analysis of the upper air, old notions and explanations of atmospheric phenomena are undergoing rapid change and modification. But while these new data frequently have the effect of casting some doubt upon the adequacy of existing explanations, they do not at the same time always promptly provide new ones to take their places. The resulting predicament is obvious. Moreover, most of the standard source materials available for student study of regional weather and climate are not sufficiently modernized to make them useful in exemplifying the latest developments. And those up-to-date materials that are available commonly are too technical for student consumption. One or two illustrations will serve to make the above comments clearer. It is being emphasized, for instance, by some leaders in weather science that the analytical study of the daily weather map should be "based

essentially on the identification and determination of the movement of air masses and fronts rather than of the areas of high and low pressure as the entities of prime importance." This may be true, but until the United States Daily Weather Map contains air-mass and frontal data little progress can be made in current weather analysis by these newer methods in an introductory course on the atmosphere. A similar lag is conspicuous in the field of explanatory climatology. In the light of what is already known concerning air-mass characteristics in a few parts of the world, it is becoming increasingly obvious that many of the standard explanations of regional climates will have to be modified in order to fit the newer information. But air-mass data for much of the earth are still too incomplete to permit a general application of its principles to world climates. In the present book the author has tried to steer a practical middle course which has resulted in the attempt to harmonize the old and new, and not always with complete success. Perhaps sufficient indication has been given in the book concerning the recent trends of development, however, for the student even in an introductory course to sense the principal elements of change.

Individual *articles* of chapters have been numbered serially throughout the book. By experience this device has been found to facilitate the definition of class assignments and to encourage backward and forward reference by the student. In order to train the student in this latter habit numerous article numbers have been inserted parenthetically in the text material.

Climatic data for stations which are representative of the several climatic types have been included in the book at the point where the particular type is under discussion. Supplementary climatic data are to be found in Appendix B. A plate containing a number of coordinate paper blocks provides facilities for the construction of temperature and precipitation graphs for thirty stations. Appendix A provides a more complete analysis of the Köppen and Thornthwaite classifications of climate, together with folded maps showing world distribution of climates according to these two systems.

The indebtedness of the author for ideas, materials, and illustrations included within this book extends in too many directions for him to be able to make specific recognition.

Special acknowledgment, however, is due to Professor John L. Page of the University of Illinois, who read critically large parts of the manuscript. To his colleagues in the Department of Geography at the University of Wisconsin, and particularly to Professor V. C. Finch, the author likewise expresses his gratitude for aid given.

GLENN T. TREWARTHA.

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CONTENTS

The Elements of Weather and Climate

Introduction

1. General Considerations. Surrounding the solid and liquid portions of the earth, and yet as integral a part of the planet as they are, is a gaseous envelope called the atmosphere, which extends to a height of several hundred miles. It is at the zone of contact between the atmosphere, on the one hand, and the solid and liquid earth, on the other, that life in its various forms exists. To be sure, man lives *on* the solid portion of the earth's surface but *in*, and *at the bottom of*, this sea of air which is many times deeper than any ocean. He is, as a consequence, much affected by changes that take place in the gaseous medium that surrounds him. In fact, among the several elements that comprise the natural equipment of a region (climate, native vegetation landforms, minerals, soils, etc.) for human occupancy and use, climate is the single most important one causing variations in the potentialities between the earth's regional subdivisions of the first order of magnitude. This results from the fact that not only is climate in and by itself a major element of a region's natural equipment, but also it directly affects vegetation, soil, and drainage characteristics and, to a degree, the nature of the landforms as well. Thus large areas with similar climates also are likely to have strong resemblances in vegetation and soil.

2. Composition of the Atmosphere. *Pure dry air* near sea level free from all impurities is a mechanical mixture of a number of gases. Two of them, nitrogen (78 per cent) and oxygen

(nearly 21 per cent), together comprise 99 per cent of the total by volume. The remaining 1 per cent is chiefly argon with much smaller amounts of ozone, carbon dioxide, and a number of other gases. The above analysis is scarcely complete, however, for, in addition to those gases named, *ordinary surface air* contains variable amounts of water vapor (up to 5 per cent on very hot and humid days) and numerous organic and inorganic particles classed as dust. In the wet tropics the water-vapor content of the air averages about 2.6 per cent of the total volume; at latitude 50° roughly 0.9 per cent, and in the vicinity of the 70° parallel, 0.2 per cent. Except for water vapor and

COMPOSITION OF THE SURFACE AIR AT ABOUT LATITUDE 50°
(Per cent of total volume)

Nitrogen	77.4
Oxygen	20.8
Argon	0.92
Water vapor	0.9

dust the atmosphere is a homogeneous mixture and continues so at all heights up to the upper part of the stratosphere and beyond. Water vapor and dust are concentrated in the lower atmosphere and show a rapid decrease with height. At and above a height of 5 miles air, even when saturated, contains only a very small amount of water vapor. If all the water vapor in the air were condensed it would be equivalent to a layer of water 1 in. deep over the whole earth.

Of slight significance to the various weather and climatic phenomena are nitrogen and oxygen, even though they comprise so much of the surface air by volume. Certain of the minor gases are much more important. Thus water vapor is the source of all forms of condensation and precipitation (clouds, dew, white frost, sleet, hail, rain, and snow), is the principal absorber of solar energy and of radiated earth energy as well, and is one of the principal energy sources for the development and growth of storms. Very insignificant amounts of both solar energy and terrestrial energy are likewise absorbed by ozone, oxygen, and carbon dioxide. Since water vapor is much more transparent to the sun's rays than to the energy radiated from the earth, it acts as a blanket to keep the earth relatively warmer than it otherwise would be, and freer from great extremes of tempera-

ture. Microscopic dust particles, the vast majority of which are too small to be seen even under a powerful microscope, tend to scatter the incoming sunlight and as a consequence are partly responsible for the sunset and sunrise colors, the blue of the sky, and the occurrence of twilight and dawn. It is estimated that one puff of cigarette smoke may contain as many as 400,000,000 of these minute dust particles. Some of the dust particles which have hygroscopic (water-absorbing) properties provide the nuclei around which atmospheric condensation takes place. Among the more important kinds of hygroscopic dust are minute salt particles derived from sea spray and the sands of seashores, and coal smoke. The more frequent and dense fogs over cities result in part from the abundance of condensation nuclei provided by the city's smoke. Over large cities smoke and dust act as an effective screen against incoming sunlight. As an example, the university weather station at Chicago, Ill., receives during the three winter months (December through February) only 55 per cent of the solar energy recorded by the weather station located on the university campus at Madison, Wis., a smaller and less industrial city.

3. The Elements of Weather and Climate. The condition of the atmosphere at any time or place, *i.e.*, the weather, is expressed by a combination of several elements, primarily (*a*) *temperature* and (*b*) *precipitation* and *humidity* but to a lesser degree by (*c*) *winds* and (*d*) *air pressure* as well. These four are called the *elements of weather and climate* because they are the ingredients out of which various weather and climatic types are compounded. The *weather* of any place is the sum total of its atmospheric conditions (temperature, pressure, winds, moisture, and precipitation) for a *short* period of time. It is the momentary state of the atmosphere. Thus we speak of the weather, not the climate, for today or of last week. *Climate*, on the other hand, is a composite or generalization of the variety of day-to-day weather conditions. It is not just "average weather," for the variations from the mean, or average, are as important as the mean itself. "Certainly no picture of climate is at all true unless it is painted in all the colors of the constant variation of weather and the changes of season which are the really prominent features" (Kendrew). But as compared with meteorology,

which is concerned primarily with the physics of individual weather events, physical climatology deals largely with the composite states of the atmosphere for the world or for certain parts of it.

4. The Controls of Weather and Climate. Weather varies from day to day, and climate differs from place to place, because of variations in the amount, intensity, and areal distribution of these several weather and climatic elements, more particularly temperature and precipitation. One may naturally inquire as to what it is that causes these several climatic elements to vary from place to place and season to season on the earth, resulting in some places and some seasons being hot and others cold, some wet and others dry. The answer is to be found in the *climatic controls*. These are (*a*) latitude or sun, (*b*) distribution of land and water, (*c*) winds, (*d*) altitude, (*e*) mountain barriers, (*f*) the great semipermanent high- and low-pressure centers, (*g*) ocean currents, (*h*) storms of various kinds, and a number of other more minor ones. It is these controls, acting with various intensities and in different combinations, that produce the changes in temperature and precipitation, which in turn give rise to varieties of weather and climate. The following diagram may help to clarify the relationship among (*a*) *elements*, (*b*) *controls*, and (*c*) the resulting weather and climate.

Climatic Controls		*Climatic Elements*		
1. Sun or latitude 2. Land and water 3. Winds and air masses 4. Altitude 5. Mountain barriers 6. Semipermanent low- and high-pressure centers 7. Ocean currents 8. Storms	Acting upon→	1. Temperature 2. Precipitation and humidity 3. Air pressure 4. Winds	Produce→	Types and varieties of weather and climate

Although it is the composite of atmospheric conditions, called climates, and their world distribution, that is of principal interest to geographers, a description of climatic types will be more intelligible if preceded by an analysis of the characteristics, origins, and distributions of the individual elements