METHODS IN CLIMATOLOGY

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PREFACE

CLIMATE influences the surface of the earth, and this conversely, in its varieties, determines the climate under otherwise equal conditions. This intimate mutual connection makes climatology and climatography appear as parts of geography, because they are essentially necessary to describe the surface of the earth and its changes. These ideas find their expression in the fact that generally in colleges and universities, climatology as a whole is treated in the geographical departments. Perhaps the dependent role of climatology may be attributable also to the fact that geographers have so greatly furthered this science.

For the most part, climatographies have been written by geographers. Therefore, geographical methods are kept in the forefront, and specifically climatological methods are not so much used. It would be satisfying if this book offered a bridge connecting the two realms.

To judge from the author's many years of experience in Europe, followed by a few years in the United States, the student in geography has perhaps sufficient knowledge of climatology, but he does not know how to deal with the original data of observations. He is, I should say, familiar with the results but not with the ways of getting them. This holds, particularly, for the different methods of mathematical statistics which can be adapted to an individual representation of the climates; only thus can too-schematical descriptions be avoided.

This book should make the student acquainted with a number of methods of mathematical statistics and theory of probability applicable at once to climatological problems. Approximations are used as much as possible in order to facilitate arithmetic. The student who is interested in the mathematical proofs and derivations as well as in their philosophical background must be referred to the special technical literature.

The general introduction presents climatology as a world science, and its international organization. The number of observations in the meteorological register makes the necessity of statistical methods evident. Their special application to climatological series is discussed. An instruction, easy to understand, is given for computing periodical phenomena by means of harmonic analysis.

In the foregoing, the overwhelming role of the frequency distribution has been emphasized. This idea led L. W. Pollak to introduce a new system of treating climatological observations by means of automatic statistical machines. This system covers the entire body of the observational data and may represent the future of rational climatological statistics. Pollak's method is not discussed here, however, because only with the resources of great institutions is it practicable.

The general representation of climatological elements, factors, etc., is followed by discussions of the special characteristics of the single elements.

The radiation elements are not dealt with. As far as frequencies and different correlations with other elements are concerned, the methods are identical with those applied to other climatological elements, on the one hand. On the other, such a discussion would have had to include the physical and astronomical nature of the subject. This exceeds the range of this book.

The first two parts of the present book are concerned with the variations of the elements in the course of time at one fixed place. The third part presents the comparison of the elements which are observed synchronously at different places, and arrives at their geographical distribution.

Critical scrutiny of the observational data leads to the examination of the homogeneity of climatological series and to the reduction to an identical period. These problems remind me of Hann's quotation of Francis Bacon, the great English philosopher: *Si quis hujusmodi rebus ut nimium exilibus et minutis vacare nolit, imperium in naturam nec obtinere nec regere poterit.*[1]

These efforts are of fundamental importance not only for the climatologist but also for everybody who is interested in climatological series, as are the long-range forecaster and those dealing with periodicities and tree-growth analysis.

Comparisons of data at different places reveal the concept of coherent and non-coherent climatic regions and of the climatic divide. These ideas show also clearly that the theory of correlation in the realm of climatology should play a significant role. An intermediate chapter deals with this subject.

[1] "A scholar who is unwilling to take pains over such investigations because they seem too insignificant and microscopic will be able neither to gain nor to maintain mastery over nature."

Climatological examples demonstrate the computations so that everyone with high-school training should be able to understand the mathematical procedure. Linear correlation, simplifications of the calculation, and regression equations are discussed. Finally, the formulas of partial correlation of three variants are added. Rather much space is devoted to graphical methods of representation, especially in connection with mountainous regions. The great importance of anomalies and isanomals is shown and supported by examples. At the end of this chapter, air-mass climatology, continentality, etc., are mentioned.

The fourth section gives suggestions for the arrangement of a more or less complete climatography.

In the appendix, models for climatic tables are presented, a table for easy calculation of the probable error, an auxiliary table for computing the equivalent temperature, and a table giving the numbers of the consecutive days of the year.

The content and order of treatment in this book reflect, for the greater part, the experience the author acquired in his lectures in climatology and in supervising the theses of his pupils at the University of Vienna, Austria. A number of the examples are taken from the author's papers.

It is with the greatest pleasure that the author expresses his gratitude to Professor Charles F. Brooks of Harvard University for his repeated encouragement to summarize in book form the methods of climatology. Thanks are also due to Dr. Brooks for his reading of the manuscript and many suggestions as well as for constant help in facilitating the routine work connected with this book.

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Blue Hill Meteorological Observatory, provided the necessary literature, always very helpfully and promptly.

Owing to the present war, it has been impossible to obtain permission from the respective scientists and publishers to reproduce here a number of graphs. The author offers his sincere apologies for this omission and assures all concerned that, in normal times, he would have waited until he had received permission, before publishing. In this book, he has at least been careful to see that in the legend every figure taken from another work has been duly attributed to the scholar who originated it.

V. C.

Cambridge, Mass.
October 1, 1944

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INTRODUCTION

CLIMATOGRAPHY describes the climate, climatology explains it. Climatography prepares the raw material supplied by observation; it is the foundation of climatology. This seems a vicious circle, because it is hardly possible to make a climatography without a knowledge of climatology. This is the present state in which the two branches of science supplement each other. In its early beginning, climatography was an occasional description in words and pictures by travelers, chroniclers, writers, poets, and painters.

The invention of the thermometer and its regular use for observing air temperature was the first step toward a quantitative climatography. Galileo Galilei invented the thermometer in 1597. It became an accurate physical instrument in 1780 when de Luc introduced mercury as a thermometrical substance. Rain gauges are supposed to have been used in India in the fourth century B.C. The oldest regular quantitative measurements of rain were made in Palestine in the first century A.D. With these observations at hand, it has been possible to compare the hydrometeoric climate of ancient Palestine with the present one in an exact way. The invention and development of other instruments has furthered regular quantitative climatological observations. Elements which cannot be observed by instruments are estimated by means of arbitrary scales.

A single observation, picked from a series, has usually no climatological meaning. Only the chronological arrangement and, generally, the combination of observations, are sufficient basis for computing average variations and average states. A single observation can be compared to a single exposure of a movie film, which has no real meaning until it is combined in its proper sequence with the rest.

The nature of our subject determines the necessary analytical and synthetical methods. First of all, the meaning of *climate* may be explained:

Climate is the average state of the atmosphere above a certain place or region of the earth's surface, related to a certain epoch and consider-

ing the average and extreme variations to which the atmospheric state is subject.[1]

Observations are made at isolated points. Only by comparing these data can the climate of the whole region be interpolated. *It is therefore the principal and fundamental aim of climatological methods to make the climatological series comparable.* The more fully this goal is approached the more reliable are the indications of a climatography.

Long-range forecasts or investigations in hidden periodicities depend even more on reliability and exactness, and therefore upon the comparableness of climatic series. Only with comparable climatic series can true averages, true variations, true probabilities be determined and used for making further estimates and inferences.

[1] V. Conrad, "Die klimatischen Elemente und ihre Abhängigkeit von terrestrischen Einflüssen," *Handbuch der Klimatologie*, ed. by W. Köppen and R. Geiger, vol. IB (Berlin, 1936).

PART I

GENERAL METHODS

CHAPTER I

CLIMATOLOGICAL ELEMENTS. COMPARABLENESS OF CLIMATOLOGICAL SERIES

CLIMATOLOGICAL ELEMENTS result from the analysis of the state of the atmosphere. The combination of all elements occurring at a given moment makes the weather; the average weather means the average state of the atmosphere, that is, the climate.

It is not possible to enumerate all the elements, because their number can be increased arbitrarily, but the following may be listed:

1) Radiation of sun and sky
2) Temperature of the air and of the surface of the earth
3) Wind direction and velocity
4) Humidity and evaporation
5) Cloudiness and sunshine
6) Precipitation
7) Snow cover
8) Air pressure, because of its intimate relation to the instantaneous and average state of weather and atmosphere.

The difficulty is that these items do not represent single elements, but groups of elements. The radiation of sun and sky, as an example, is divided into two main groups: direct radiation from the sun, and radiation from the sky. Each group can be subdivided into any number of elements. There is the total radiation, including the energy of the entire spectrum, which can be divided into the elements characterized by the energy of parts of the spectrum, for example the infrared, the visible, the ultraviolet portions. Other radiation elements deal with the transmission coefficients of certain wave-lengths, with the turbidity factor, the blueness of the sky, photometrical and photochemical