TECHNIQUES OF Climatology

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W. H. FREEMAN AND COMPANY
San Francisco

Printed in the United States of America.

Library of Congress Catalog Card Number: 74-128094

International Standard Book Number: 0-7167-0250-9

Preface

The science of climatology makes use of three groups of techniques: those of the meteorologist, those of the mathematical statistician, and those of the geographer. My purpose in this book is to present a comprehensive review of these techniques. The reader is assumed to be already familiar with the nature and basic principles of climatology, as set out in my companion work, *Foundations of Climatology*.

This book is not elementary in scope or coverage, but rather constitutes a manual for readers who have mastered the companion volume, and who wish to study further, for professional reasons. Such readers will include: persons taking advanced undergraduate and introductory postgraduate courses in climatology in university departments of geography, meteorology and earth sciences; entrants to state meteorology services taking courses in both climatology and meteorology; and specialists in other fields—physical and biological sciences, engineering, medicine, agriculture, forestry, architecture, planning, public health, etc.—who have, for professional reasons, to turn themselves into climatologists in order to solve a specific problem.

The fundamental notion behind *Techniques of Climatology* is that climate constitutes a physical problem. In this, it contrasts strongly with the widely held view of climate as merely "average weather." The important point is that climate as a physical problem involves study of both meteorology and geography; i.e., investigation of both the atmosphere and the Earth's surface is involved.

The meteorologist has long been aware of climate as a physical problem, but he has, until very recently, confined himself to investigations of its atmospheric side. His current incursions into the geographical side of the climatic problem are often geographically naive, and sometimes—especially when "weather control" is involved—positively dangerous. For their part, geographers in general have shown little awareness of the many contributions made to climatology by mathematicians, physical scientists and engineers. The picture of world climates presented by many geography teachers not only lacks intellectual excitement or rigor, but is often scientifically inaccurate. There is a great need for geographers and meteorologists to work together in the study of climate, and I hope that *Techniques of Climatology* will assist this meeting, by showing how each type of specialist has a valid viewpoint *provided* he takes the trouble to understand that of the other.

Although climatology deals with the "normal" behavior of the atmosphere, and as such is clearly the province of the atmospheric scientists (as meteorologists now term themselves), it also deals with local weather and climate. This latter study requires a knowledge of the local landscape and of the basic principles of geomorphology, pedology, and biogeography. Only geographers have formal training both in the rudiments of these sciences and in elementary meteorology. Thus it is to the geography departments of the universities and colleges that one should look for potential climatologists, rather than to the departments of meteorology, physics, or engineering. Although *Techniques of Climatology* is intended primarily as a textbook covering those parts of climatology courses in university geography departments that deal with techniques, I hope it will also guide geography teachers, who often foster in the young an interest in meteorology without at the same time instilling an appreciation of just how scientific this study has now become. As emphasized by Gordon Manley some years ago, properly prepared geographers have much to offer meteorology.* The value of their contribution is proved not only by the work of Manley himself on British weather and climate, but also by the efforts of C. Warren Thornthwaite and F. Kenneth Hare, and their colleagues, in the vastly different fields of micrometeorology and the circulation of the Arctic stratosphere, respectively. It cannot be too strongly emphasized that, although climatology is a geophysical science, whose initial problems and ultimate aims are essentially geographical, its methods and techniques are those of the physicist and mathematician rather than the geographer. If this book helps to provide geography teachers and students with an appreciation of the basic mathematic notation and a few of the physical techniques, both theoretical and practical, that are necessary to follow modern climatology, it will have served a good purpose.

A former President of the Royal Geographical Society once stated that, since geographical exploration in the classic sense is now almost at an end, geographers must extend their interests to new fields if geography is to survive as an active science.† One solution is to extend investigation of the Earth's surface back in time; an alternative is the primary exploration of outer space, and, ultimately, of other planets. Today's pioneer geographical explorers are blazing new trails in the stratosphere and above, rather than on the ground. Climatologists realized the importance of this new development, and the world's first conference on aerospace climatology was held at Washington D.C., in December 1961.‡ Geography teachers have a duty to acquaint

* G. Manley, "The Geographer's Contribution to Meteorology," *QJRMS*, 73 (1947), 1.
† Sir R. Priestley, *Geog. J.*, 128 (1962), 257.
‡ See *BAMS*, 43 (1962) 275.

their pupils with these possibilities. I hope that *Techniques of Climatology* may be a suitable primer for arousing the interest of future geographical explorers of our atmosphere and beyond, whether they will be called geographers, climatologists, meteorologists, aerologists, or aerospace scientists.

ACKNOWLEDGMENTS

As I did for *Foundations of Climatology*, I have to thank my former teachers in the Meteorological Office, almost two decades ago, who kindled my interest in the rigorous approach to climatology. In particular, I thank Professor A. F. Jenkinson for considerable guidance in the field of mathematical statistics, and Mr. P. J. Meade and Mr. K. H. Smith for stimulating thoughts in the fields of dynamic meteorology and synoptic meteorology, respectively. Special thanks are due to Professor David L. Linton, Head of the Department of Geography in the University of Birmingham, for his interest in the book at all stages in its preparation. For many years, Dr. Gordon T. Warwick, Reader in the Department of Geography, has been a most valued and constructive critic. The late Professor R. H. Kinvig, and Mrs. B. Eckstein, also helped me in the initial phases of my climatological career.

My climatological ideas have profited from discussions held with American and Canadian climatologists during a period I spent at McGill University in 1964 as Visiting Professor of Climatology. For providing the opportunities for these discussions, I have to thank Dr. F. Kenneth Hare, Dr. Trevor Lloyd, Professor Theo. L. Hills, Dr. H. E. Landsberg, Mr. Morley K. Thomas, and Dr. John R. Mather.

No little word of thanks is due my publishers, for their patience amid the innumerable delays that have attended the writing of the books, and for their care in preparing it for publication; the efforts of Mr. Aidan A. Kelly, of the Editorial Department, are worthy of special mention. I must also acknowledge with gratitude the care with which Professor Gordon Manley read and commented on the book in its early stages.

The labors of typing the book have been shared between a number of ladies: special thanks are due to Mrs. R. Priestman, Mrs. M. L. Stones, Mrs. J. Needham, Miss D. Morgan, and my wife. Indeed, I must record my sincere appreciation of my wife's forbearance of the last six years, during which the demands of two small sons and a book-finishing husband have been, to say the least, somewhat trying.

Birmingham, England,
July 1971

E. T. Stringer

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PART I

The Basic Techniques

CHAPTER 1

Observing the Weather

Although both meteorology and climatology are becoming increasingly theoretical, study of weather and climate must always be based on observed facts. The amateur meteorologist is usually interested only in facts, and the academic climatologist, however abstract his theories, has always to test them by means of actual data.

Weather facts may be current or historical. The main problem of current weather information is to ensure speedy dissemination, that of historical information, to ensure as wide a geographical coverage as possible, extending as far back in time as prudent, with homogeneity of data.

Historical Weather Data

The primary sources of historical ("climatological") data are the serial publications of state meteorological services. For Britain, these include: (a) The *Daily Weather Report*, containing data for the preceding day in the form of coded reports at six-hour intervals for 55 land stations and eight weather ships, plus six-hour weather charts; (b) the *Daily Aerological Record*, published several days behind, containing coded upper-air reports at 12-hour intervals for nine or ten land stations and two weather ships, plus charts for midnight covering most of the northern hemisphere; (c) the *Monthly Weather Report*, published several months behind, containing monthly means and frequencies for more than 500 climatological stations in Great Britain and Northern Ireland, plus charts of mean pressure, temperature and sunshine, total rainfall, and depression movements throughout the month; (d) *British Rainfall*, an annual volume published several years behind, containing monthly rainfall totals for the 5,000-odd rainfall stations in Britain, plus maps showing such features as percentage differences from average for specific months or years.

Some publications contain data for the whole world. The most useful of these is *World Weather Records*, which, since 1927, has published data for each decade.[1] These volumes contain year-by-year records of monthly values of temperature, pressure, and precipitation. The 1959 volume includes data for 700 stations, including weather ships in the North Atlantic and North Pacific, Antarctic stations, and remote stations in the Southern Ocean. Such publications are expensive and time-consuming to produce, because much statistical checking is necessary before the data can be regarded as homogeneous.

Since daily weather reports must be prepared very rapidly for prompt publication, they contain occasional errors in analysis. Maps prepared by more leisurely analysis are therefore valuable for research, and several series of such maps have been published, notably, the *Northern Hemisphere Synoptic Weather Map Series* of the United States Weather Bureau. This series covers the period 1899 to the present, and consists of monthly volumes of sea-level charts for 1:00 P.M. G.M.T. each day, plus 500-mb charts for 3:00 P.M. G.M.T. (3:00 A.M. at first) from 1945 onward. The time involved in assembling and screening the data for the entire hemisphere means that the current series is usually published a year behind.[2]

Current Weather Data

Much information can of course be obtained from historical weather data, but real knowledge of the weather can only come from trying to understand its day-to-day vicissitudes, for which one must have current data.

Apart from plain-language reports in newspapers and radio or television broadcasts, which are rarely detailed or recent enough for the serious student, there are five main sources of current data: specialized radio broadcasts (for shipping, in particular), wireless-telegraphy (W/T) and radio-telephony (R/T) broadcasts, and radioteleprinter (RTTY) and facsimile transmissions. All these weather messages are designed to international specifications and cater to a wide variety of interests and types of receiving apparatus, but nearly all of them require some familiarity with the international meteorological codes.

The first code was introduced before the First World War by the Permanent Committee of the International Meteorological Organization; the committee met every five or six years, between the congresses of the full organization. The code was for the exchange of weather reports by wireless telegraphy, and consisted of groups of five figures, because each such group was charged as one word.

The code had two primary groups, represented symbolically by BBBDD FFWTT in the British form. BBB represented barometric pressure, DD wind direction, FF wind speed, W weather, and TT temperature. Two supplementary groups, T'T'RRR MMmmS, represented wet-bulb temperature, rainfall, maximum (MM) and minimum (mm) temperatures, and state of the sea, respectively. The continental form had three figures for temperature, two for rainfall, and only one for wind force.[3]

During the First World War, this code was found to be very inadequate, and, largely on the basis of British proposals, new codes were drawn up. During the Second World War, inadequacies again became apparent, and at the Paris meeting of the IMO in 1946, new codes were discussed. At Washington in 1953, the *Commission for Synoptic Meteorology* of the World Meteorological Organization (WMO) standardized the new code for surface observations, and new international codes for upper-air reports and reports from transport aircraft and meteorological reconaissance aircraft were drawn up. Major changes in the code for surface reports came into force on January 1, 1955, and modifications in the upper-air, analysis, and forecast codes on January 1, 1960.

The present codes still largely adhere to five-figure groups, each identified by a code word. Thus SYNOP indicates surface data for a land station, SHIP denotes surface data from a moving or stationary ship, TEMP indicates upper-air reports from land stations, and TEMP SHIP upper-air data from a ship. MESRAN data are collective summaries of upper-air reports, and CLIMAT and CLIMAT TEMP are summaries of monthly mean surface and upper-air data, respectively.

Codes are also available to describe weather charts, both actual and predicted (prognostic): these are the *International Analysis Codes.* The term BARATIC means the actual surface-pressure chart, expressed in code form. PREBARATIC is the code form of the prognostic surface-pressure chart, UCONAL the code for the actual upper-air chart, and PRONTOUR the coded prognostic upper-air chart. The respective codes are ANAL (S), used for baratic and prebaratic charts, and ANAL (U) for uconals and prontours.

Familiarity with the SYNOP and SHIP codes is essential for maximum use of the *Daily Weather Report*, and the TEMP, TEMP SHIP, and PILOT and PILOT SHIP (for upper winds only) codes must be understood before using the *Daily Aerological Record.* (For further details of these codes, see pp. 6–8.)

Reception of Weather Broadcasts

In accordance with WMO technical regulations, each meteorological region of the world must provide three types of broadcast: (a) *continental*, transmitting data for the region, and capable of world-wide reception; (b) *subcontinental,* transmitting data for part of a region, for reception anywhere in that region; and (c) *territorial,* transmitting data for the territory occupied by one member country of the region, for reception at one or more subcontinental centers in that region. For Region IV (Europe) of the WMO, there are four subcontinental centers: London (or the Meteorological Office transmitting station), Paris, Rome, and Moscow. The continental broadcast (call sign GFL) is from London, as is the subcontinental broadcast (GFA), the latter also serving as the United Kingdom territorial broadcast.

Until recently, most meteorological broadcasts were by W/T, using the Morse code. Wavelengths were secured by IMO delegates to International Telecommunications Conferences at Washington (1927), Madrid (1932), and Cairo (1938); since the Second World War, these have been extensively revised.

Transmissions to outstations within a Weather Service are usually by land-line teleprinter, with links to other countries. For example, the International Meteorological Teleprinter Network in Europe (IMTNE) was developed after the Second World War on a quadrilateral pattern, based on London (Dunstable), Paris, and the headquarters

Sections of the International Synoptic Weather Message Codes Normally Published Daily by State Meteorological Services for Climatological Purposes[a]

SURFACE OBSERVATIONS

Land stations (SYNOP code)

Mandatory: IIiii Nddff VVwwW PPPTT NhC_Lh$C_M$$C_H$ TdTdapp RRTxTxE sss (day; RRTnTnE TgTg at night)

Optional: 8NsChshs (repeated if necessary)

Ocean stations (SHIP code)

Mandatory: 99LaLaLa QcLoLoLoLo YYGGiw Nddff VVwwW PPPTT NhC_Lh$C_M$$C_H$ Dsvsapp 0TsTsTdTd 1TwTwTwtT 3PwPw HwHw

Optional: 8 NsChshs (repeated if necessary).

AEROLOGICAL OBSERVATIONS

Full upper-air reports

Land stations (TEMP code)

Standard isobaric surfaces: YYGGgg IIiii hhh *TTTdTd*[b]

Significant levels: IIiii *PPPTTTdTd*[b] PtPtPt HtHt TpTp

Ocean stations (SHIP TEMP code): as for land stations, but preceded by YQLaLaLa LoLoLoGG

Upper wind reports only

Land stations (PILOT code)

Standard levels: YYGGgg *ddff*[c]

Additional levels: *PPP ddff*[c] dmdmfmfm HmHmHmHm

Ocean stations (PILOT SHIP code): as for land stations, but preceded by YQLaLaLa LoLoLoGG

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[a] These are the standard forms as agreed on internationally. Individual state publications may depart from these in minor details.

[b] The group in italics is repeated for each level: surface, 850 mb, 700 mb, 500 mb, 400 mb, 300 mb, and 200 mb; frequently, also for 150 mb and 100 mb; occasionally, also for 70 mb, 50 mb, 30 mb, 20 mb, and 10 mb.

[c] The group in italics is repeated for each level: surface, 1,500 meters, 2,100 m, 3,000 m, 4,200 m, 5,400 m, 7,200 m, 9,000 m, 10,500 m, and 12,000 m; frequently, also for 13,500 m and 15,900 m; occasionally, also for 18,300 m, 30,700 m, 23,700 m, 26,400 m, and 30,900 m.

Key to Code Symbols

a	characteristic of barometric tendency[d]
C	type of cloud[d]
C_L	form of low cloud[d]
C_M	form of medium cloud[d]
C_H	form of high cloud[d]
dd	wind direction (approximately, in degrees)
dmdm	wind direction at level of maximum wind (in hundreds and tens of degrees)
Ds	direction of movement of ship[d]
E	state of ground[d]
ff	windspeed (in knots)
fmfm	windspeed at level of maximum wind (in knots)
GGgg	time of observation in hours and minutes G.M.T.
h	height above ground of base of lowest cloud[d]
hhh	height of standard isobaric surface above mean sea level, in geopotential meters below 500 mb, in decameters at 500 mb and above
hshs	height of base of significant cloud (figures 01–50, times 30, gives height in meters; figures 56–80, times 3 gives height in hundreds of meters)
HtHt	height of tropopause (in geopotential hectometers)
HwHw	height of waves on ocean surface (in units of 0.5 meter)
HmHmHmHm	height of level of maximum wind (in decameters)
iii	station at which observation was made[d]
iw	wind indicator (ship observation)[d]
II	country in which observation was made[d]
LaLaLa	latitude of ship in degrees and tenths
LoLoLo	longitude of ship in degrees and tenths (for aerological reports)
LoLoLoLo	longitude of ship in degrees and tenths (for surface reports)
N	total amount of cloud in eighths
Nh	fraction (eighths) of celestial dome covered by C_L (or by C_M if no C_L)
Ns	amount (eighths) of individual (significant) cloud layer or mass
pp	barometric tendency (in tenths of millibars)
PPP	mean sea-level barometric pressure (last three figures, millibars and tenths)
PwPw	period of waves on ocean surface (seconds)
PtPtPt	pressure at the tropopause (millibars)
Q	octant of the globe[d]
Qc	quadrant of the globe[d]
RR	rainfall (figures 01–55, rainfall in millimeters)[d]

[d] See M.O. Publication no. 510, *Handbook of Weather Messages*, parts I, II, and III (London, 1963), for full specifications of the codes for these items, plus instructions for plotting the data on synoptic charts.

Key to Code Symbols (Continued)

sss	duration of sunshine (hours and tenths)
tT	tenths figure of air temperature
TT	air temperature (in whole degrees Celsius)
TdTd	dewpoint temperature (in whole degrees Celsius)
TgTg	night minimum temperature on grass (in whole degrees Celsius)
TnTn	night minimum air temperature (in whole degrees Celsius)
TpTp	temperature at the tropopause (in whole degrees Celsius)
TsTs	difference between air temperature and sea temperature (in whole degrees Celsius)
TxTx	day maximum temperature (in whole degrees Celsius)
TwTwTw	sea surface temperature in tenths of a degree Celsius
ww	weather at time of observation[a]
W	weather during the six hours immediately preceding the observation[a]
vs	speed of ship (knots)
VV	visibility (figures 01–50, horizontal visual range in tenths of kilometers)[a]
YY	day of the month on which the observation was made[a]
0	indicator figure for TsTsTdTd group for SHIP data
1	indicator figure for TwTwTwtT group for SHIP data
3	indicator figure for PwPwHwHw group for SHIP data
8	indicator figure for NsChshs group for SYNOP and SHIP data.

[a] See M.O. Publication no. 510, *Handbook of Weather Messages*, parts I, II, and III (London, 1963), for full specifications of the codes for these items, plus instructions for plotting the data on synoptic charts.