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MANUAL OF BAROMETRY

(WBAN)

Volume I
First Edition

WASHINGTON, D. C.
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VOLUME I

FIRST EDITION

(1963)

Index page 7, first column, 17 lines from bottom: Delete 2-67,.

Index page 7, first column, 8 lines from bottom: Read A2-1, A2-7+ instead of A2-1+.

Index page 9, first column, 29 lines from top: Read Beeckman instead of Beekman.

Index page 10, second column, 10 lines from bottom: Delete 8-26 at extreme right.

Index page 10, second column, 7 lines from bottom: Read 6-46, 6-59, 8-26 instead of 6-46, 6-59.

Index page 14, first column, 3 lines from bottom: Immediately below the word "Theory" insert the word "Units" before the number 1-7.

Index page 14, first column, last line: Delete entire line - Units ..... 12.App.1.3.1-5.

Index page 17, first column, 4 lines from bottom: Read Evaluation of T_v for various levels ..... 7-45,.

Index page 20, first column, 3 lines from top: Read 7-2, 7-18+ instead of 7-2, 7-184.

Index page 23, first column, 4 and 5 lines from top: Delete Station pressure derived from altimeter setting (continued)

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FOREWORD

The ideas which led to the development of the mercury barometer began historically with the curiosity of Galileo regarding the causes for the failure of a suction pump to raise water in a tube higher than about 27–33 feet with the best vacuum obtainable during his time (1564–1642). Although he reasoned that the tensile strength of the water determined the limiting height to which the column of liquid of given density could be sustained under a vacuum, he was not completely satisfied with the sufficiency of this explanation of the phenomenon; he was disinclined, also, to accept the speculation common to many philosophers of that era that nature's abhorrence of a vacuum supported the column. The speculatons of Galileo on this subject, published in 1638, gave impetus to the performance of a crucial experiment about 1640–41 in Rome. Here, G. Berti and his collaborators constructed an ingenious design of what amounted to a water barometer. Shortly after Galileo's death, the quest was taken up by his pupil, Torricelli. The latter reasoned that we live submerged at the bottom of an ocean of air and that the known weight of the air causes the atmosphere to press down upon the free surface of the liquid, therefore impelling it up into the tube at the top of which there is a vacuum. He pointed out that since the vacuum at the top of the tube had no weight it could not press down on the surface of the liquid within the tube, and hence it could not resist the force due to the weight of the atmosphere, acting to raise the fluid. Torricelli came to the logical conclusion that the liquid must rise in the tube until its weight comes to equalize the weight of the air pressing down on the same area of the free surface of the liquid exposed to the atmosphere. A beautiful test of the deduction was obtained by Torricelli's famous experiment of 1643 in which he immersed the open end of a full tube of mercury into a dish of this metallic liquid and observed that it was supported to a height of about 30 inches, which is approximately 1/14th the height of a column of water raised under a vacuum pump at the same time. Since the density of mercury is about 13.595 times as great as that of water, the experiment proved that the weights of the columns of the two dissimilar liquids were the same, suggesting that they were sustained by a common pressure (namely, atmospheric). The Torricellian tube thus became the first barometer, creating a landmark in the history of science. See fig. 12.2.1.3.

Since 1643 there have been many developments in the field of barometry, covering such matters as the determination of heights in the atmosphere by means of barometric observations; the measurement of pressure changes associated with various systems such as HIGHS, LOWS, tornadoes, etc.; and the representation of the pressure field over extensive areas of the globe for purposes of synoptic weather analysis. Thus, barometry may be categorized under several headings, such as those listed above, and is concerned not only with the subject of the barometer as an instrument used for the measurement of atmospheric pressure but also with these other important aspects. Unfortunately, the broad scope of the field together with certain inherent complexities have led to the employment of diverse practices in regard to the various phases over a period of years, with a resultant lack of consistency.

On these grounds an imperative need has arisen for the establishment of standardized procedures to be used in connection with pressure observations, reduction of pressure, altimetry, and other aspects of the subject. In the light of that requirement, the preparation of this manual was undertaken. We are happy to express appreciation for the work of Louis P. Harrison, U.S. Weather Bureau, whose deep interest in the subject has led to significant advances, and who is the one primarily responsible for completion of the task of writing the Manual of Barometry.

August 1, 1963

Chief, U.S. Weather Bureau

PREFACE

It is the purpose of this manual to provide instructions to those concerned with various operational practices relating to *barometry*, and to present scientific and technical information pertinent to the subject regarded in a rather broad sense. As a matter of choice it is considered that *altimetry* may be properly regarded as falling within the province of this work. On these grounds the manual serves not only the meteorologist and the laboratory technician, but also those persons concerned with the various aviation and scientific aspects of the subject, together with the interested citizen.

Chapter 1, section 1.1, explains the scope of "barometry" as considered for the purposes of this publication. Briefly, the subject may be subdivided into parts for individual treatment as indicated by the following list:

(a) Measurement of atmospheric pressure by means of a barometric instrument, which involves the proper calibration, standardization, correction, reading, and maintenance of the device.

(b) Reduction of pressure from one level to another by means of the hypsometric equation (see Appendix 7.1) in order to obtain data of such comparable character as to permit their being studied on a synoptic basis. Note: The reduction of pressure to sea level with reference to stations on land is a case in point, involving suitable assumptions regarding the non-existent vertical distributions of temperature and humidity in the fictitious "air column" which hypothetically extends downward from the station to sea level.

(c) Hypsometry; that is, the computation of the difference in height between two levels pertaining to neighboring points of given atmospheric pressure, under the assumption that the height difference is related to the logarithm of the pressure ratio by virtue of the hypsometric equation, subject to the proviso that the vertical distributions of temperature and humidity are either observed or assumed.

(d) Altimetry; that is, the determination of altitudes or heights, usually with respect to sea level, by means of an altimeter, particularly of the type employed in aviation; and the investigation of the accuracy of the altimetry system in its various aspects, together with a consideration of the problems that stem from uses of the system in air navigation for purposes of landing, vertical separation of aircraft, and terrain clearance.

(e) Representation and analysis of the pressure field over the earth's surface by means of special parameters involving systems based on functions, potential or otherwise, designed to enable one to ascertain the distribution of pressure and its horizontal gradient, or more precisely the horizontal gradient of the local isobaric surface nearest the ground, depending upon the topography and the pertinent observed meteorological quantities. (It may be noted that the latter gradient is related to the geostrophic wind in a mathematical sense.)

(f) Investigation of the effects of irregular terrain and nonstatic atmospheric conditions on the distribution of pressure and its variations with time over the surface; for example, the effects on the pressure of such phenomena as air drainage, wind, and accelerated atmospheric motions in mountainous regions.

Owing to the need for this manual it was decided to publish it in two volumes at different times. Volume I consists of Chapters 1–8, inclusive, together with Chapters 12, 13 and 14. Volume II which is to be issued later will consist of Chapters 9, 10 and 11, plus certain additions to the appendices which comprise Chapter 12; also the complete index for both volumes.

In order to facilitate the finding of material the work is organized in chapters and sections, numbered according to a decimal system of classification. The pagination of

each chapter is separate; such that a bold face number is used to indicate the chapter, while the page number within the chapter is given by the number which comes immediately after the dash that follows the bold face number. This system has the great added advantage that it permits adding new material to future editions without the need for disturbing the numbering in earlier pages or in other chapters which do not require revision or addition.

As a rule the introductory paragraphs of sections (usually numbered to end with .0) outline the scope of the succeeding related sections, and therefore they serve the useful purpose of providing a sort of directory to help the reader find the material in those sections relevant to the subject under consideration.

From a scrutiny of the table of contents, it may be seen that the manual is organized on the following basis:

(A) *Chapter 1* is introductory, and is concerned mostly with matters of definition, the running of levels to determine the elevation (height above sea level) of barometric instruments, and the computation of the geopotential of the station. A detailed explanation of geopotential is presented in Appendix 1.3.1 (see Chapter 12).

(B) *Chapter 2* is concerned with various kinds of barometers and related equipment, considered mostly from an instrumental point of view. It presents general discussions relating to the various errors to which these instruments are subject, and tells how to read and install a barometer. The Annex of Chapter 2 contains a good deal of information of a special technical nature, such as cleaning of barometers, maintenance, packing and shipping of the instruments, etc.

(C) *Chapters 3, 4 and 5* deal with corrections of certain definite categories. Thus, one has *Chapter 3* on the gravity correction for mercury barometers; *Chapter 4* on the so-called "removal correction" for difference in height between instrument and station elevations, also on the so-called "residual correction" for any residual instrument error which is determined after a barometer is in use at a station; and *Chapter 5* on the temperature correction for mercury barometers.

(D) *Chapter 6* gives instructions relating to the calibration and standardization of barometric instruments, usually on the basis of comparative readings between the given instrument and a standard barometer or other device that serves as an intermediate standard.

(E) *Chapter 7* presents information mainly in regard to the special techniques of reduction of pressure to sea level as used in the United States, and provides instructions to permit one to compute pertinent reduction factors for field stations.

(F) *Chapter 8* deals with various problems relating to altimetry.

(G) *Chapters 9, 10, and 11* which are to appear in Volume II, will be categorized as follows: *Chapter 9* on "Reduction to Constant Pressure Surfaces, and Hypsometry"; *Chapter 10* on "Special Potential or Other Functions Representing the Earth's Pressure Field"; and *Chapter 11* on "Atmospheric Pressure as Affected by Accelerations, Nonstatic Conditions, and Terrain."

(H) *Chapter 12* is composed of a series of appendices which provide scientific and technical information relevant to the matters dealt with in the main body of the manual. By separating these items from the main body, interruption of the principal trend of thought in the text is obviated; however, in many cases, one may find it useful or necessary to refer to the special material contained in the appendices.

(I) *Chapter 13* consists of nothing but a collection of samples of all forms referred to in the text in connection with data entries pertinent to the various aspects of the subject.

(J) *Chapter 14* is a compilation of tables specifically useful for the purpose of obtaining certain corrections which must be applied to some barometric instruments, and other tables giving data specifically necessary for the objective of permitting one to compute different factors which may be involved in one or more phases of the subject, such as the reduction of pressure to sea level.

While all tables involving computational data are assembled in Chapter 14, the numbering of tables is designed to show the chapter and section numbers in which first use of the tables is made. For example, Tables 5.2.1 and 5.2.2 are two tables used in connection with instructions in section 5.2 (that is, the second full section of Chapter 5).

Similar systems of numbering of figures and appendices are employed. However, since all of the appendices are collected in Chapter 12, the numbering in the latter shows both the chapter and the appendix.

In some instances it has been found desirable to supplement the information embodied in a particular chapter with an annex. When these are given, they will always be found at the end of the chapter to which they relate.

The present manual supersedes the pamphlet, now out of print, by C. F. Marvin, entitled "Barometers and the Measurement of Atmospheric Pressure" (Weather Bureau Circular F), which went through seven editions, from its inception until its last printing in 1941. An inestimable debt is owed to that publication.

With reference to the technique of reduction of pressure to sea level used in the United States, it is worthy of special mention that the method of reduction developed by F. H. Bigelow about the year 1900 forms the underlying basis of the reduction procedure covered by the instructions in Chapter 7, although some of the precise details of the technique have been modified since that time for the sake of simplicity or gain in efficiency of operations. A monument to Bigelow's work in the field of reduction technique still remains in the form of his book, long out of print and now virtually a rarity, entitled "Report on the Barometry of the United States, Canada, and the West Indies," Volume II—Report of the Chief of the Weather Bureau, 1900–1901, Washington, D. C.

An effort has been made to embody in this manual the most recent decisions and recommendations of the World Meteorological Organizat' ¬ 'WMO) pertaining to various matters relevant to barometry. In this connection, the following items may be mentioned: (a) Appendix 1.4.1 which cites the complete text of the "International Barometer Conventions" as adopted by the WMO in 1953; (b) information in Chapter 3 relating to procedures recommended by the WMO for the calculation and determination of local gravity under various conditions; and (c) the Annex to Chapter 6 on "International Comparison of Barometers" adopted by the WMO in 1953.

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CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

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CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

CHAPTER 2 INSTRUMENTS FOR DETERMINING ATMOSPHERIC PRESSURE; THEIR INSTALLATION AND CHARACTERISTICS (Cont'd.)

CHAPTER 3 GRAVITY CORRECTION FOR MERCURY BAROMETERS

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CHAPTER 6 STANDARDIZATION AND COMPARISON OF BAROMETERS (Cont'd.)

CHAPTER 6 STANDARDIZATION AND COMPARISON OF BAROMETERS (Cont'd.)

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CHAPTER 7 REDUCTION OF PRESSURE TO SEA LEVEL, AND OTHER LEVELS (Cont'd.)

CHAPTER 7 REDUCTION OF PRESSURE TO SEA LEVEL, AND OTHER LEVELS (Cont'd.)

CHAPTER 8 ALTIMETRY