MANUAL OF METEOROLOGY

MANUAL OF METEOROLOGY

VOLUME IV

METEOROLOGICAL CALCULUS: PRESSURE AND WIND

(A REVISED EDITION OF PART IV, 1919)

BY

SIR NAPIER SHAW, LL.D., Sc.D., F.R.S.

Late Professor of Meteorology in the Imperial College of Science and Technology and Reader in Meteorology in the University of London; Honorary Fellow of Emmanuel College, Cambridge; sometime Director of the Meteorological Office, London, and President of the International Meteorological Committee

WITH THE ASSISTANCE OF

ELAINE AUSTIN, M.A.

of the Meteorological Office formerly of Newnham College, Cambridge

CAMBRIDGE
AT THE UNIVERSITY PRESS
MCMXLII

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781107475496

First edition 1919
Second edition 1931
First published 1931
Reprinted 1942
First paperback edition 2014

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-47549-6 Paperback

PREFACE TO VOLUME IV

THE volume now presented is a revised edition of Part IV which was issued in advance in 1919. There are besides two chapters introductory to the theory of motion under balanced forces which had been adopted in Part IV as the basis of the relation between pressure and wind, and two chapters supplementary, summing up the position with regard to the theory of the general circulation of the atmosphere and its local disturbances. Here we need only account for the limitations of the work now ended.

Its purpose was to give the reader an idea of the general problem of the meteorology of the globe and of the material and methods which are available for its solution.

More narrowly stated the problem is to provide a rational quantitative explanation of the sequence of the phenomena of weather in any locality—its first stage to trace the phenomena to their natural causes and identify the physical and dynamical processes by which the sequence is controlled.

In *Nature* the account which has been given of the physical processes of weather in Vol. III has been called discursive, and with at least equal justice the epithet may be applied to the account of the dynamical processes in this last volume; and there is no reason for resentment on that account. Fifty years ago similar remarks were often made about Maxwell's *Theory of Heat*, "an extraordinary text-book," the perusal of which may even now be recommended to students of meteorology as a good resolution for every New Year, though neither author nor editor nor publisher (up to 1891) had found himself able to make an index to it. Nature is herself very discursive in the demands which she makes upon her various sciences for providing the sequence of our weather. The book does not aspire to be regarded as an abstract even of meteorological literature, still less of dynamical or physical. It adheres as strenuously as circumstances permit to the idea of weather as a manifestation of the transformations of energy taking place in the atmosphere. Anything which helps the comprehension of the actual structure and processes as affecting the transformation of energy would be helpful to the book; but the accretions around different sections of the subject, instrumental,

observational, methodical, theoretical or literary, even if the point of attachment is physical or dynamical, are deliberately left for the reader's enjoyment of private excursions with occasional finger-posts to remind him of their existence.

Discursiveness is shown not merely in the sections of the subjects treated but also in the mode of treatment itself. Results have been quoted without exhibiting the algebraical reasoning employed in the original papers. Algebra has powerful attractions for its familiars; but it is not everybody's hobby. We shall have satisfied our aspiration if those who seek can find. There is no part of the subject in which a knowledgeable friend is not welcome. Our own obligation to D. Brunt on that score alone is always in mind.

The plan of the complete work as modified by the experience gained in its construction stands as follows:

Vol. I, 1926, Meteorology in History leading up to modern instruments and methods of investigation.

Vol. II, 1928, Comparative Meteorology setting out the accumulated data in maps, diagrams and tables.

Vol. III, 1930, The Physical Processes of Weather with examples of their application.

Vol. IV, 1931, Meteorological Calculus for expressing the relation of pressure and wind.

A general summary of the contents has been added to exhibit the manner in which the material has been arranged.

Additional acknowledgments for the material of this volume are indicated in the Table of Contents, p. xiii, and List of Illustrations, p. xvii. We can only reiterate our grateful thanks to the Meteorological Committee of the Air Ministry and to the Director of the Meteorological Office for their continued support, to Mr R. G. K. Lempfert, C.B.E., Mr D. Brunt and Commander L. G. Garbett, R.N., for assistance with the proofs, to the Cambridge University Printer and his staff of compositors and readers for the form in which the work is presented.

Since Part IV was written originally with the needs of aviation in view the attention of the world's meteorologists has been concentrated upon that part of the general subject, and the information available in 1919 will seem very small compared with what has been published since that date. But still it provides material for the portals of the subject, and though perhaps perspective makes the

portals of 1919 seem insignificant compared with the masses of material now available for those who look through them, the alignment may be useful in the development of the structure.

The body of the volume, chapters numbered III to X in place of I to XI, remains devoted to the study of the kinematics of the atmospheric structure and is here reprinted with necessary alterations and a few additions. The two new chapters at the beginning introduce the classical methods of dealing with the dynamical aspects of the problem of atmospheric motion and incidentally illustrate the importance of the idea of stratification by entropy. The other two at the end summarise the view attained when the situations expressed in the three previous volumes, historical, geographical and physical, are taken into account.

No general solution of the dynamical problem of the atmospheric circulation is offered but some suggestions of a connected system are afforded in the final summary by harmonies in the correlation of some well-recognised parts.

In some respects the attitude adopted is one for which it would be difficult to find approval in the meteorological canon. The following statements are designed to express the more pertinent innovations.

1. Records of horizontal wind by pressure-tube anemometers are put forward as a concise statement of the dynamical problem of the atmosphere and a guide to the order of consideration of the elements of structure as set out in chapters III to X.

2. In the free air, motion is the controlling dynamic feature of the circulation. Pressure-gradient, stabilised by the persistence of horizontal motion on the rotating earth, appears as a static index of the motion. It is not regarded as a source of energy apart from that indicated by horizontal differences of entropy.

3. The balance of horizontal wind, pressure-gradient and centrifugal force is disturbed by turbulence due to rigidity and friction at the surface and also by convection which operates wherever there is a difference of entropy between masses of air in juxtaposition, most notably at points along the "polar front."

4. Convection is regarded as the effect of gravity redressing in any horizontal surface differences of entropy that may be developed by conduction of heat to or from the ground, by the emission or absorption of radiation or by the condensation or evaporation of water.

5. Apart from the disturbing effects of conduction and turbulence at the surface and of local convection, the relation of horizontal wind to pressure-gradient, which was and still is the fundamental principle of the volume, is further developed and confirmed; but motion has taken the place of pressure as the "independent variable" in the gradient equation, that is to say the pressure-distribution is regarded as the "banking" required for the maintenance of the air-currents.

6. Motion is derived ultimately from convection with the aid of conservation of momentum, but the derivation is intricate and only partially explored.

7. Since entropy-difference acting through gravity is the cause of convection, it follows that the elements by which the whole drama of the atmosphere is staged are two, viz. entropy-difference and wind-velocity. Entropy-difference is contingent upon the condition of the air in respect of water-vapour.

Entropy (with water-vapour as an accomplice) and air-motion are the joint rulers of the atmosphere; gravity, pressure, the centrifugal force of rotation whether of the earth or of a local mass (and incidentally the author) are their obedient servants.

NAPIER SHAW

31 *March* 1931

PREFACE TO PART IV 1919

WITHIN the past four years urgent questions have been addressed to the Meteorological Office from many quarters about the winds. Some of them refer to the winds at the surface, a subject of immemorial antiquity which has only within the last score of years been subjected to comparatively accurate measurement; and others refer to the winds of the free atmosphere beyond the reach of the highest point upon which an anemometer could be fixed.

The work of the Meteorological Office aided by the contributions of data from various departments of the naval, military and air-services has provided the material for answers to these questions, but the first conclusion derived from the study of the material is that the answers to all the questions cannot be treated separately. They all form part of a description of the structure of the atmosphere, a structure so complicated, even so perverse, as to make the attempt to describe it intelligibly without some guiding principle, or to deal with it piecemeal, hopeless.

We have found a guiding principle of great practical utility in the relation of the wind to the distribution of pressure which can be deduced from the assumption that as a general rule the motion of air in the free atmosphere follows very closely the laws of motion under balanced forces depending on the spin of the earth and the spin in a "small circle" on the earth. And therefore, in order to provide the best available answers to the questions put to us, we have studied the relation of the winds to the distribution of pressure at the surface and in the free atmosphere.

This study has led to setting out what amounts almost to a general meteorological theory. It forms Part IV of this manual and includes within its scope the best answer which we are able to give to the general questions put to us.

Behind it lies the vast accumulation of facts obtained by the industry and perseverance of meteorological observers all over the world which are represented compendiously for practical meteorologists by a series of normal values of meteorological elements of every kind. These are summarised in Part I (Vol. II) as a general survey of the globe and its atmosphere which is based upon the great but unfortunately still incomplete work of Hildebrandsson and Teisserenc de Bort, *Les Bases de la Météorologie dynamique*.

But anyone who takes an intelligent interest in the structure of the atmosphere, whether he regards it in detail or thinks only of its more general features, must have a working knowledge of the physical properties of air, and that is no slight matter. Maxwell's wonderful *Theory of Heat* with all its digressive chapters might have been written for the purpose, for all that it contains is extraordinarily appropriate. Only one additional chapter, on the difficult subject of the thermodynamical properties of moist air, is required.

The physical properties of air form the subject of Part II (Vol. III).

Part III (Vol. IV) contains the formal setting out of the dynamical and thermal principles upon which theoretical meteorology depends, and which find their application in Part IV. It is necessarily technical but again its main outlines are sketched by the hand of a perfect master of the art in Maxwell's *Matter and Motion*.

The whole is preceded by a historical introduction and a statement of the position of the general meteorological problem at the present day (Vol. I); because the history of the study of weather forms a striking example of the interaction of the progress of science and the creation of the instruments which it uses.

Part IV is issued in advance because what is contained therein has not hitherto been presented in a collected form. It represents the progress made chiefly by those who have been associated in the work of the Meteorological Office in the past twenty years. We owe our success to the fortunate circumstances of our meteorological *terrain*.

For the other parts of the subject all meteorologists have the same sources of reference open to them if they care to use them.

Our concern in this work is to present a summary of them in the most handy form for conveying an idea of the information which is available. For the survey of the meteorology of the globe Bartholomew's *Atlas of Meteorology* by Buchan and Herbertson is in itself an admirable compendium.

The special climatological atlases, of Russia by General Rykatchef, of India by Sir John Eliot, of Canada by Sir Frederic Stupart, the great work on the climatology of the United States of America by A. J. Henry and the less complete but still notable work by C. M. Delgado de Carvalho on the Meteorology of the United States of Brazil, invite contributions to the common stock of knowledge on the part of other countries so that the student of meteorology may not continue to be dependent upon the data in their original form, which are only contained in a few of the libraries of any country.

The physical and dynamical principles upon which the processes of weather depend are the common property of all students of physics. If those to whose care the progress of physics is entrusted had taken the physical problems of the atmosphere under their charge as their predecessors did before the advent of the electrical era one half at least of this book might have been more effectively dealt with by other hands.

A work of this kind necessarily depends in very large measure upon illustrations which often represent, in the most succinct manner, results of observations which cannot be transcribed in words or formulae. The original drawings are the only satisfactory evidence for writer or reader because in the gradual development of the science what at one stage of our knowledge appears to be a superfluous accident may become the starting point of a new advance. The author and the Meteorological Committee, at whose instance this work was undertaken, desire here to place on record their acknowledgment to the Controller of H.M. Stationery Office, the Board of Trade, the Ordnance Survey and the Advisory Committee for Aeronautics for permission to use illustrations which have appeared in the publications of H.M. Government.

And similar acknowledgment is due to the Royal Society, the Royal Meteorological Society, the Carnegie Institution of Washington, Professor McAdie of Harvard University and particularly to C. J. P. Cave of Stoner Hill.

Particulars of the extent to which illustrations have been borrowed are set out in the list contained in pp. xvii to xx.

The author desires also to express his thanks to an old friend and colleague, Mr J. B. Peace, Printer to the University of Cambridge, for the care which he has given, in the difficult circumstances of the later stages of a great war, to the arrangement of the book and the form of the illustrations.

NAPIER SHAW

METEOROLOGICAL OFFICE, LONDON
9 *December* 1918

A preliminary issue of a limited number of copies of this part of the work for official use has enabled me to obtain from colleagues and friends some corrections and suggestions which have now been incorporated in the text or added as notes.

N. S.

17 *May* 1919

TABLE OF CONTENTS

VOLUME IV. METEOROLOGICAL CALCULUS: PRESSURE AND WIND

LIST OF ILLUSTRATIONS

NOTE. Many of the diagrams are copied, with modifications in some instances but more generally in the original form, from the publications to which reference is made. Those marked * are from Official Publications of H.M. Government and permission for their reproduction has been obtained from the Controller of H.M. Stationery Office. The mark † indicates original records of the Meteorological Office.

Thanks are also due to the Royal Meteorological Society for fig. 45 and to the Royal Aeronautical Society for fig. 1.

FIGURE NUMBERS

In this revised edition the figures have been re-numbered consecutively throughout the volume in accordance with the practice in the other volumes. In the original edition the figures of each chapter were numbered separately. For the illustrations of the original edition the original figure-number is inserted after the number on the revised plan.

The relation between the current numbers and the original chapter-numbers of Part IV is indicated in the following table:

PART IV fig.	1	2	3	4	5	6	7	8	9	10
	Figure numbers in new volume									
Chap. II	17	18	19	20	.	.	.	.	.	.
,, IV	23	24	25	.	.	.	.	.	.	.
,, V	28	29	30	31	32	33	34	.	.	.
,, VI	35	36	37	38	39	40	41	42	43	44
,, VII	49	50	.	.	.	.	.	.	.	.
,, VIII	22	21	.	.	.	.	.	.	.	.
,, IX	52	51	.	.	.	.	.	.	.	.
,, X	59	60	61	63	64	62	65	66	.	.
,, XI	67	71	72	68	69	70	.	.	.	.

The Frontispiece of Part IV has become fig. 74.