METEOROLOGY

An Introductory Treatise

BY

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PREFACE

There are many classes of the community to whom the weather conditions are of the utmost importance. The aviator, the farmer, the sailor, and even the holiday-maker are all interested in the state of the weather, though in very different ways. The study of the weather from one man's point of view is therefore a very different thing to a study of it from another's point of view. But though the subject may be developed along different lines by different sections of the community, yet the principles underlying it are in all cases the same.

The present book has been written with the view of indicating these principles, putting them in their simplest form, and avoiding, as far as possible, the use of mathematical language. In this way the student who has only an elementary training in mathematics will be able to follow the reasoning.

Also, as the book is intended to serve as an elementary text-book, I have endeavoured to avoid developing any one part at the expense of another. Any chapter might quite easily be expanded into a book in itself, but in so doing the object for which the book is written would be lost sight of.

Meteorology, like many other sciences, is developing very rapidly at the present day, and in a book of this type it is impossible to embody all the latest developments. The discovery of the conditions within the upper atmosphere or stratosphere has influenced the development of modern meteorology to a very great extent. Throughout the book, therefore, the stratosphere and its influence have been kept before the reader.

PLAN OF THE BOOK

The book may be very conveniently divided into three main sections, together with the final chapter wherein application has been made of the conclusions arrived at in the preceding chapters. Section one, consisting of three chapters, forms the introductory part. Herein are found a short historical sketch of the subject, and methods of attacking and solving certain meteorological problems. Likewise the atmosphere, that gaseous envelope in which all meteorological phenomena take place, is dealt with briefly, while a short chapter is devoted to the study of solar radiation.

The next five chapters constitute section two, and deal with the subject-matter of meteorology itself. In treating of temperature I have employed the gas scale throughout, indicating at the same time the relation between it and the other scales. By this means all negative values are got rid of. Also all problems involving the alteration of temperature through the expansion or the compression of a gas must be treated on this scale, and therefore the plan of recording all temperatures on the absolute or gas scale gets rid of the necessity of conversion. Further, this scale is the only scale on which there is a definitely fixed temperature, namely, the absolute zero of temperature.

Pressure is a force, and therefore should be expressed in units of force. The dyne, the absolute unit of force in the C.G.S. system, is, however, extremely small, and consequently in meteorology the unit employed is 1000 dynes or a "millibar". The Standard Atmosphere is 1,000,000 dynes per square centimetre or 1000 millibars, and is called a "bar". Until comparatively recently, however, all pressures were expressed in terms of the length of a column of mercury. But during the last few years the Daily Weather Reports issued by the Meteorological Office, London, have shown the pressures expressed in millibars. Therefore it is essential that everyone who wishes to make use of these reports should understand what a millibar (mb.) is. Hence throughout the book all pressure-values have been expressed in millibars.

Chapter VIII has been devoted to a study of the upper atmosphere. This chapter might with advantage be read before the section in Chapter VII which treats of the origin of cyclones of mean latitudes. Much of the material in this chapter I owe to the writings of Mr. W. H. Dines, F.R.S., and Captain C. J. P. Cave, to both of whom I wish to express my indebtedness.

The third section is devoted to a short study of the electrical, optical, and acoustical phenomena occurring in the atmosphere.

These phenomena, though not pertaining directly to meteorology, yet are closely allied to the subject. They are often of great assistance in indicating the temperature distribution in the atmosphere, and thereby help greatly in the matter of weather forecasting.

In the last chapter I have endeavoured to show how, by using the conclusions arrived at in the preceding chapters, one may develop a reasonable method of weather forecasting. Also I have attempted to indicate how any individual with the aid of a barometer, a barograph, a wind-vane, and thermometers may, by careful observation, forecast over short periods and for limited areas with considerable accuracy.

A brief survey of the factors that determine climate is to be found in the concluding sections. The various climatic divisions of the globe are considered, while the climate of the British Isles is dealt with a little more in detail.

ACKNOWLEDGMENTS

Figs. 14, 19, 30, 60, 60a, 74, 80, 81, 82, have been reproduced by the permission of the Controller of H.M. Stationery Office from publications of the Meteorological Office.

I have to thank the Meteorological Committee for the loan of blocks for figs. 61, 62, 72, 73, 75, 76, and 78.

For the coloured drawings, the cloud photographs, with the exception of those taken above the clouds, for many of the photographs of instruments, and also for the line drawings of many of the figures including those representing the barometers and anemometers, I am indebted to Mr. G. A. Clarke, F.R.P.S., of the Aberdeen Observatory. I owe the photographs reproduced on Plate VIII to Captain Cave and to Captain C. M. K. Douglas, R.A.F., respectively. The photographs of lightning flashes reproduced on Plate XVII (*a* and *b*) are due to H. H. Cowan, Esq., London, while I am indebted to my publishers for the blocks for figs. 27, 54, 67, 68, and for Plates IX and XVII (*c*). Wherever figures have been adapted from other publications acknowledgment has been made either in the text or on the figure.

I desire to express my thanks to Sir Napier Shaw, F.R.S., late Director of the Meteorological Office, for permission to photograph or make drawings from the various instruments in the Aberdeen

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Not only do I owe many of the photographs and drawings reproduced in the book to Mr. G. A. Clarke of King's College Observatory, but I obtained much valuable information from his almost unique experience in the observation of many meteorological phenomena.

Captain Cave I have to thank for reading the proof-sheets, and for adding many helpful suggestions while the book was passing through the press.

I take the present opportunity of thanking the publishers for the great care they have taken in the production of the work.

A. E. M. GEDDES.

ABERDEEN, 1920.

NOTE

In the present reprint I have taken the opportunity of making a few slight alterations, and have added a paragraph on the Polar Front method of analysing weather charts.

A. E. M. G.

August, 1930.

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METEOROLOGY

CHAPTER I

Introduction

A.—HISTORICAL

Early Evidences.—From the earliest times the phenomena taking place in the atmosphere have occupied the attention of man. The changes in the state of the atmosphere were watched, and there arose in consequence a sort of weather lore. In some of the oldest books of the Bible, especially in the book of Job, one can see that this weather lore had even then taken definite form, and some of the information given there is even after the lapse of three thousand years found to be perfectly sound.

First Definition of Wind.—In the writings of Homer and Hesiod there is also to be found much weather lore. The first series of regular observations we owe probably to the Greeks, for as early as the fifth century B.C. almanacs, known as parapegmata (Gr. παραπή γματα), were fixed on public columns, giving mainly wind directions. During the same century the first scientific designation was given to the wind by Anaximander of Ionia, who defined the wind as "a flowing of the air", which definition holds to the present day. At Athens was built the Tower of the Winds, octagonal in shape, with its various faces looking towards N.E., E., S.E., S., S.W., W., N.W. and N. respectively. At the top of each face was carved a figure, which may probably be considered as representative of the wind blowing from the direction towards which it looked; e.g. on the northern face the figure was clad in warm winter clothing, and his cheeks were distended as he blew lustily through a trumpet. Such a figure may therefore be regarded as symbolical of the cold, strong northerly winds. This tower, however, was built inside the city in the market-place, and contained a water clock. Further, it is recorded that in order to obtain wind directions, observations were made outside the city on open ground. Consequently this tower was probably used rather as a time-piece than as a station for the observation of wind and weather, and the builder simply carved these symbolical figures on the faces by way of decoration.

Greek Influences.—Since the Greeks were in the habit of making regular observations of the wind, it is rather striking that no word for wind-vane has come down either from them or from the Romans. To the Greeks, however, we owe the word Meteorology, as it is derived from *τα μετέωρα*, meaning "the things above". This at first included the study of comets and meteors, and no clear conception of the atmosphere was formed by the ancient Greek philosophers. They formed various theories about atmospheric phenomena, but during the time of Socrates meteorology had fallen greatly into disrepute.

Aristotle.—A century later came Aristotle, one of the greatest geniuses the world has ever seen. His treatise on the winds is the oldest in existence. Hellmann in his lecture before the Royal Meteorological Society, March, 1908, "The Dawn of Meteorology", says that Aristotle's most distinguished successors, Theophrastus and Posidonius, added but little to it. All European textbooks issued from Aristotle's time until the end of the seventeenth century are exclusively based on his writings. His conception of the atmosphere was, however, rather strange when viewed in the light of modern developments. The atmosphere he considered divided into three regions: (1) The region in which plants and animals live, immovable like the earth on which it rests; (2) an intermediate region intensely cold; and (3) a third region contiguous to the region of fire or the heavens, and partaking of the diurnal motion of the latter. Comets and meteors were regarded as exhalations or vapours ascending from the earth and becoming heated and incandescent on reaching this region. When observations were wanting in support of any particular theory, their place was filled by imagination.

Hellmann[1] also points out that, in the third century B.C., Philo of Byzantium and Hero of Alexandria describe a primitive kind of

[1] *Quar. Jour. Roy. Met. Soc.*, Vol. XXXIV.

thermoscope. A treatise by Hero on pneumatics was in the last quarter of the sixteenth century translated into Italian and Latin, and was studied by Galileo, Porta, and Drebbel, giving to all the idea of constructing a thermoscope.

From the time of Aristotle until the beginning of the seventeenth century little progress was made. During that period no true conception of the motion of the atmosphere as a whole was formed. Probably Posidonius had formed some idea of the height of the atmosphere, but nothing that is of any real value has come down to us from these early times. It is reported that some Arabian geometers during the eleventh century A.D. estimated the probable height of the atmosphere as 92 Km. from observations of the duration of twilight, but not until five centuries later was it re-determined by European astronomers.

Galileo and Torricelli.—Up to, and during the lifetime of Galileo, who was professor of Philosophy and Mathematics at Florence, it was supposed that water rose in a pump because nature abhorred a vacuum. One day, however, some men came to him wishing him to explain to them why they could not raise water by an ordinary pump more than 18 cubits above the surface of the water in the well. He appears to have been puzzled, and gave them as a probable reason that perhaps nature did not abhor a vacuum above that height. This answer, however, did not satisfy Torricelli, who was a pupil of Galileo at the time, and who afterwards succeeded him in the professorship at Florence. Consequently he set himself to work to find out the true solution if possible. After years of labour he was able, by means of his historical experiment, which resulted in the invention of the barometer, to demonstrate that the atmosphere could be weighed, and that it exerted continually a certain pressure. In the last decade of the sixteenth century a crude kind of thermometer was invented. Whether the invention of the thermometer was due to Galileo alone, or to the combined efforts of Galileo and Sanctorius, who was then a pupil of the former, and who afterwards became professor of Medicine in the same university, is uncertain. The invention of these two instruments, the barometer and thermometer, marks the beginning of a new era in meteorology.

THE FIRST PERIOD.—The first period in the development of meteorology may therefore be said to date from very ancient times until about A.D. 1600. During this period certain qualitative observations were made. The observations and methods were crude, and though some useful information was obtained, yet as the observations were nearly all made without instruments, many of them were inaccurate, and were often influenced by superstition, while the explanations were often fantastic and supernatural.

Early Rainfall Records.—During this period the only quantitative observations that have come down to us are those of rainfall. In the first century A.D., records of rainfall were made in Palestine. "The great influence of rainfall on the crops," says Hellmann, "must have been fully appreciated at an early date, and the results of which observations are preserved in the *Mishnah*, a collection of Jewish religious books apart from the Bible."

Another instance of rainfall records taken during this period is given by Dr. Y. Wada[1], director of the Korean Meteorological Observatory. He has shown that rain-gauges were in use in Korea as early as 1442. Both these examples show that the people of those days felt how great a part the amount of rainfall played in determining the yield from the soil.

THE SECOND PERIOD.—With the invention of instruments, the second period of meteorology begins. In addition to the two instruments already mentioned, the first European rain-gauge is said to have been invented by an Italian, Benedetto Castelli, in 1639. At this time, i.e. during the first half of the seventeenth century, meteorology owed much to the labours of the Accademia del Cimento. This group of investigators consisted of nine Florentine scholars, who were nearly all pupils of Galileo, and through their labours considerable progress was made.

In 1653 Ferdinand II, Grand Duke of Tuscany, established several stations throughout northern Italy for the purpose of making careful meteorological observations, and the first attempt to establish an international meteorological system of observations is due to him.

From the beginning of the seventeenth century thermometers had been in use in Italy. From there, Southwell brought to England in the year 1650, a thermometer of the Florentine type, the first seen in this country. Soon after this, various instruments, such as thermometers, barometers, rain-gauges, and wind-vanes were in use, and even dew collectors. Progress continued to be rapid, and Boyle, who had made duplicates of the thermometer

[1] *Quar. Jour. Roy. Met. Soc.*, Jan., 1911.

brought by Southwell, published in 1662 the law governing the compressibility of air, or of any gas, a law which has come to be known as Boyle's Law.

Halley.—In this period another great step was made when Halley published, in 1686, in the *Philosophical Transactions*, his celebrated memoir, entitled "An historical account of Trade Winds and Monsoons observable in the seas between and near the Tropicks, with an attempt to assign the phisical cause of the said winds". Alexander the Great is said to have brought back to Greece, after his invasion of India, information concerning the monsoons. Aristotle has described them, and they had been observed by the Arabs. In his book on the navigation of the Indian Ocean, published in 1554, Sidi-Ali gave the time of their commencement at about fifty different places. Towards the end of the sixteenth century Christopher Columbus, on his voyage of discovery of America, encountered the winds which later came to be known as the Trade Winds. Thus, though many of the prevailing winds came to be known before Halley's time, no real attempt at an explanation of them was given until the publication of his famous memoir, in which he pointed out that these winds were primarily due to the difference of temperature between the equator and the poles, and to the excessive heating and cooling of the land as compared with the sea.

Hadley.—The next step in this direction was made by Hadley when, in 1735, in the *Philosophical Transactions*, he demonstrated the effect of the rotation of the earth on the direction of the Trade Winds. He took account of winds blowing in a north and south direction only, however, and thus, though the germs of the explanation were given in Hadley's paper, yet it was not until much later that the full explanation was arrived at. In this direction but little progress was made further until about the beginning of the nineteenth century.

Early Investigations of the Upper Atmosphere.—In 1749 Wilson of Glasgow succeeded in raising thermometers into the air by means of a kite. This is the first record of any meteorological observations having been made above the surface of the earth. Thereafter occasional use was made of kites and balloons to carry thermometers, barometers, and hygrometers to determine the conditions in the upper air, but no systematic investigation was undertaken until near the end of the last century. Franklin, in 1752, made use of a kite in his famous experiment on electricity in thunderstorms, and his methods were adopted by others.

The second period in the history of meteorology, which may be said to close towards the end of the eighteenth century, is marked, therefore, by the invention of a large number of instruments and an ever-increasing number of observations. As is to be expected, with the invention of instruments the accuracy in the observation of the atmospheric phenomena increased considerably.

THE THIRD PERIOD.—This was a period which sought to furnish logical explanations of the phenomena which had been observed during the second period. In the seventeenth century Halley, and Hadley in the eighteenth, had each endeavoured to give an explanation of the circulation of the atmosphere.

Dove.—During the early part of the nineteenth century, Dove, a German meteorologist, endeavoured to give a fuller explanation of the wind system, both as regards the major and minor circulations. According to Dove there were two major circulations on each hemisphere, one between the thermal equator and the tropics, the other between the tropics and the pole. The storms of temperate zones were, according to him, due to the continual strife between the warm moist south-west wind coming from the tropics and the cold dry north-east wind coming from the pole.

Maury.—In America, Maury arrived at conclusions analogous to those of Dove. In his idea of the general circulation there was this difference, however, viz. that he regarded the circulation as being confined not to one hemisphere, but considered that the air passed from one hemisphere to the other, thus giving a continual oscillation of air from pole to pole.

Redfield.—These ideas dominated the scientific world for a considerable time, but at the present day they have no supporters among meteorologists. While Dove in Europe was engaged with the problem of the origin of cyclones, Redfield took up the same problem in America. Whenever a storm took place in the Antilles or on the Atlantic coasts of North America, he procured all the observations made during the storm both on land and on sea, and plotted these on a chart. He arrived at the following conclusion, viz. that "the cyclone is constituted by a considerable mass of air endowed with a rapid movement of rotation in the direction opposite to the hands of a watch, but having at the centre a calm region".

Piddington.—The study of storms in the western Atlantic by Redfield was pursued farther by Reid. He was able to confirm Redfield's results. Under his influence the study of storms in the Indian Ocean was undertaken, and the work was entrusted to Piddington in 1838. The latter published a large number of memoirs, and finally collected his results into the book, *Sailors' Horn-Book for the Laws of Storms in all parts of the World.* He insisted that the wind round the centre of a storm has an inclination inwards, and that the air moves in consequence in spirals towards the centre.

During this same period we have the study of monsoons by Keller and Thom, and at the same time Meldrum, in Mauritius, was engaged in the study of cyclones in the Indian Ocean.

Brandes.—While the question of the origin and behaviour of cyclones was being actively pursued in this period, there belongs to it also the introduction of synoptic charts. In Germany, H. W. Brandes published in 1820 *Contributions to Meteorology* (*Beiträge zur Witterungskunde*, Leipzig, 1820); and, in 1826, *Physical dissertation on the rapid variations of the pressure of the air* (*Dissertatio physica de repentinis variationibus in pressione atmosphaerae observatis*; *Theses*, Leipzig, 1826). The first contained a study of the weather over Europe on each day of the year 1783, the observations having been published in the *Mannheimer Ephemeridien.* In his researches he made use of synoptic charts, being the first to do so, but unfortunately he did not publish specimens of these charts. As a result of his work he arrived at certain important conclusions, as we shall see later. Redfield in his work also made use of synoptic charts, but as Brandes had already published his first book in 1820, whereas Redfield's work dates from 1821, the honour rests with Brandes of being the first to use synoptic charts.

Espy.—Two other Americans contributed largely to the advancement of meteorology in the first half of the nineteenth century, viz. J. P. Espy and E. Loomis. The former organized and directed the meteorological stations in Pennsylvania, and in 1843 he was made Chief of the Meteorological Bureau of the War Department of the United States. Thus he began the organization of the meteorological service of the United States, a service which has become one of the biggest in the world. The results of Espy's work may be summarized briefly thus: