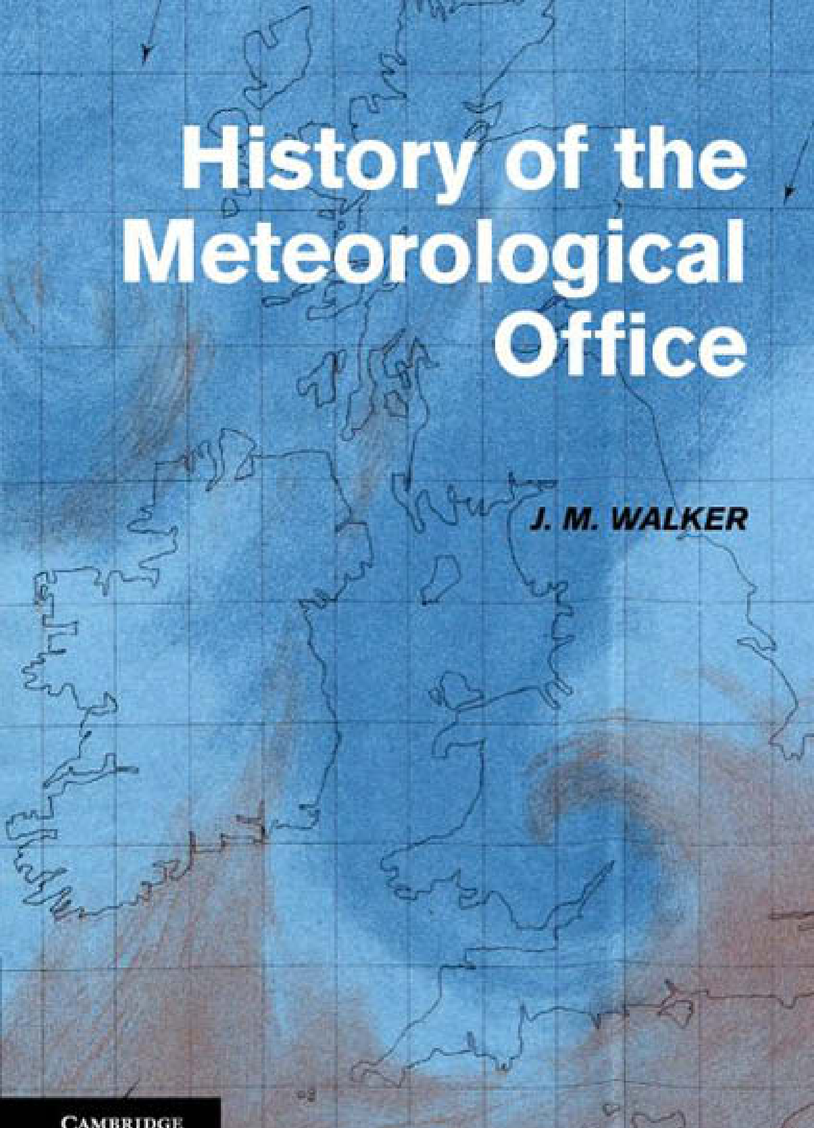

History of the Meteorological Office

J. M. WALKER

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HISTORY OF THE METEOROLOGICAL OFFICE

Malcolm Walker tells the story of the UK's national meteorological service – now known simply as the Met Office – from its formation in 1854 with a staff of four and a budget of a few thousand pounds, to its present position as a scientific and technological institution of national and international importance with a staff of nearly 2000 and a turnover of nearly 200 million pounds per year. The Met Office has long been at the forefront of research into atmospheric science and technology and is second to none in providing weather services to the general public and a wide range of customers around the world. The history of the Met Office is therefore largely a history of the development of international weather prediction research in general.

Formed as the Meteorological Department of the Board of Trade with a specifically maritime purpose, the Met Office is now an Executive Agency and Trading Fund responsible to the UK government's Department for Business, Innovation and Skills and serves not only the shipping industry but also many other groups of users. It is at the forefront of pure and applied research in meteorology and related sciences and, moreover, cooperates and interacts with the international meteorological community at administrative, operational and research levels. In addition to being a premier forecasting bureau, it is at the forefront of the modelling of climate change in the modern era.

This volume will be of great interest to meteorologists, atmospheric scientists and historians of science, as well as amateur meteorologists and anyone interested generally in weather prediction.

MALCOLM WALKER was an academic at Cardiff University from 1967 to 1998, first as a Lecturer, then, from 1983, as Senior Lecturer and, from 1996, as Deputy Head of the Department of Maritime Studies and International Transport. He was Education Resources Manager of the Royal Meteorological Society from 1998 to 2007. He is a Fellow of the Royal Meteorological Society and a Member of the American Meteorological Society. He co-authored *The Ocean-Atmosphere System* (1977), with A.H. Perry. He chaired the Royal Meteorological Society's History Group from 1989 to 1999 and again from 2007 to the present. He was awarded the Group's Jehuda Neumann Memorial Prize in 2001 and the Royal Meteorological Society's Outstanding Service Award in 2007. Since 1980 he has had a strong scholarly interest in the history of ideas in meteorology and physical oceanography and the people behind these ideas. He has published numerous articles and lectured many times on this subject.

HISTORY OF THE METEOROLOGICAL OFFICE

MALCOLM WALKER

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Foreword

LORD HUNT OF CHESTERTON, FRS

The Met Office is a well-respected and familiar British institution, whose weather forecasts people hear every day. News about its activities and advice are discussed at length in the media and in Parliament. It was founded in 1854 and still goes strong. Queen Victoria had personal weather forecasts from Admiral FitzRoy, the first director, for her three-mile voyage across the Solent to the Isle of Wight. It is not an exaggeration to say that the Office has played an important part in the history of the United Kingdom and of many other countries over this period, in both peace and war. Although it is an institution based on the application of science and technology, its outstanding staff have in fact originated some of the key developments of meteorological science and technology, a tradition that continues today.

This book had its origins in the PhD of the late Dr Jim Burton, a forecaster in the Leeds Weather Centre, who was encouraged by Sir John Houghton, then Director-General of the Met Office. His predecessor, Sir John Mason, helped the project. The necessary financial ingenuity to arrange funding for research into the history of the Office was provided by Martyn Bittlestone, our finance director, when the Office became a Trading Fund in 1996. The Chief Scientist, Professor Julia Slingo, has helped recently with her insights into developments up to 2010. I am very grateful to Malcolm Walker, formerly of Cardiff University, for accepting the invitation not only to write the book but also to listen tactfully to all the inputs from meteorologists and commentators on the text. Stan Cornford's detailed study in 1994 of the Met Office involvement in the D-Day forecast was also a significant contribution.

I was introduced to the familiar names of the shipping forecast areas (Wight, Dover, Thames, etc.) by my grandfather, who liked to sail dinghies in very rough weather, and to the scientific approach to meteorology by my great uncle L F Richardson, who originated numerical weather prediction when he was in the Met Office between 1913 and 1920.

When I was Chief Executive at the Office, I found it instructive to read how FitzRoy was able to push through his scientifically controversial ideas while at the same time dealing with his political masters. His extraordinary personality was vividly portrayed in the play on FitzRoy and Darwin by Juliet Lacey, which the Royal Society funded in 1997. Napier Shaw, who like other directors came straight from a university position, had a longer and happier time; he demonstrated how the Met Office should always make best use of science and technology and adapt its services to changes in society and politics. He emphasized the importance of involving outside experts and 'stakeholders' in these developments and in the international responsibilities of the Met Office.

This book does not hide the many arguments within the Met Office about scientific and technical questions, but, unlike some other technical agencies of government, the Office has been quite open about these disagreements and then decisive about implementing the best practical method that emerged from the discussions, as with numerical weather prediction using computers (where scepticism continued for more than thirty years), satellites, weather radar, automatic weather stations (a surprisingly controversial technology) and now the Internet. However, it has often been commented that the Office has not been successful in stimulating new businesses in the UK to produce and market these inventions. But that was not an objective given to it by government.

Government agencies and even meteorological offices come and go, and sometimes get moved between different parts of government, as for example with the U.S. weather service. This existential aspect of the Met Office continues to be discussed regularly in the media and in Whitehall. After the UK joined the European Economic Community in 1973, the question asked by officials, anxious to save money, was whether the time had come to merge the UK Met Office with those of other countries or even in a European Met Office. Although a very successful European Centre was established in Reading for Medium-Range Weather Forecasts, Ministers have continued to support a strong national Met Office in order for the UK to have strategic independence. But they also supported progressively closer collaboration in various European initiatives.

After starting in the Board of Trade, the Met Office had a period of being run by a committee of governmental and nongovernmental bodies which included the Royal Society. This was too cumbersome for the new applications of meteorology in modern warfare, so, under Winston Churchill's influence, it was transferred after the First World War to the Air Ministry and merged with the meteorological services of the Army and Royal Air Force and in part with that of the Royal Navy in 1919. Endorsed by subsequent inquiries, notably that of Lord Brabazon in 1955, the Met Office remained there satisfactorily for more than ninety years, while also increasing its collaboration with most other government departments.[1] It has been largely funded by the government through various financial arrangements, culminating in 1996 in its

[1] The Met Office was transferred to the UK government's Department for Business, Innovation and Skills on 18 July 2011.

becoming a 'Trading Fund', which means that it now negotiates financial and service delivery contracts with about thirty government departments and agencies. Its history suggests that a major reason for its survival is that, even as its structure in government has changed, it has been able to provide up-to-date services needed by government, commerce and the public, through its great success in being one of the world's leading services in the effective and economical use of new science and technology.

Other countries still have two or more weather services, typically for civil aviation and defence, which clearly adds to their costs and does not seem to improve their service. Along with the various changed arrangements, the Met Office's buildings and their locations keep changing. From a single office in 1854, receiving data and delivering warnings by the new technology of telegraph, it kept expanding to more than 6000 staff and many hundreds of offices and observing stations worldwide in the Second World War. It is now down to a little under 2000, with a custom-built headquarters at Exeter and fewer than twenty other installations from the Falkland Islands to Cyprus to the Shetland Islands. This reduced network is sufficient as communications have changed from the electric telegraph in the 1850s to the Internet in the 1990s; also, these developments enabled the range of services and advice, both civil and military, to expand continually.

Met Offices are always under scrutiny, but they generally survive. There is one instance of closure when the director of an early meteorological service in France, the famous scientist J B Lamarck, was dismissed on Napoleon's orders in 1810 – an unfortunate overture to his difficulties in the Russian winter of 1812. In the UK, both Houses of Parliament have regularly inquired about and debated the doings of the Met Office, which are well covered in this book. The long speech by the back-bench Lord Wrottesley in 1853, in which he explained why British shipping needed a Met Office to be able to compete with the United States, was followed by the Office's founding in 1854. The book also covers in some detail the debates that led to the forced cessation of forecasting for the public for thirteen years from 1866, because of its alleged inaccuracy. But storm warnings were accurate enough to reduce the number of shipwrecks, which led to Parliamentary complaints that these forecasts were having a damaging effect on the ship salvage businesses of Cornwall and Devon. We have the same story today from some advocates who argue that forecasts of climate change are damaging business and should be ignored or even suppressed.

However, Parliamentary debate has also prompted technical developments, such as when long-range forecasts were initiated after the very cold winter of 1962–1963 and when Prime Minister Ted Heath in 1973 asserted the need to understand global climatic variations, in particular El Niño, in order to understand variations in the prices of food. Parliament has also monitored the Met Office's work on controversial environmental problems, from London smog, acid rain over Scotland and Scandinavia, the ozone hole and the spread of foot-and-mouth disease to the oil fires of the Gulf War. All recent Prime Ministers have actively promoted research on analysing and predicting climate change by the Hadley Centre, a branch of the Met Office whose leading scientists shared in the award of the Nobel Prize for Peace in 2007 along with other distinguished climate scientists around the world. When Mrs Thatcher was Prime Minister, she devoted most of her speech at the United Nations in 1989 to this subject and made a great impact at the Met Office when she opened the Hadley Centre at Bracknell in 1990.

International collaboration, which has been an essential element of every aspect of the Met Office's work, has been very effective and economical because of the UK's active involvement and financial support of the World Meteorological Organization (WMO), a United Nations agency, which grew out of the International Meteorological Organization set up by directors of Met Offices in 1879. Despite different national policies and political tensions between countries, exchanges of data, weather forecasts and warnings about natural hazards have progressively improved. The passing of 'Resolution 40' brought the agreements up to date at the 1995 WMO Congress, but these arrangements still need extending and also applying to the urgent hydrological problems of warning about floods and droughts, for which the Met Office is also responsible at WMO.

This book reveals how the science of meteorology and its applications has developed over the past 150 years and how it has led to new concepts and techniques. Sometimes developments arose from new technologies and from responses to new user requirements, which have often arisen quite suddenly, such as the recent problem in 2010 of improving the forecasts of how volcanic ash is dispersed in order to advise aircraft where they can fly safely after volcanic eruptions. Some of the innovations of meteorology have had wide ramifications in the worlds of science and technology, notably in the communication of very complex and uncertain information.

It is worth recalling that the Met Office's provision of forecasts and estimations of their accuracy in the 1860s predated the statistical theory and methods that developed later in the century – part of the reason for FitzRoy's problems. L F Richardson had to invent approximate methods for solving the basic equations of fluid flow, starting with uncertain and incomplete measurements in order that forecasts could be made systematically by calculation. Later, Neumann, Lorenz, Charney and others in the United States after the Second World War discovered how to simplify and compute the equations, making use of the new electronic computers, and then proposed a new approach for analysing the chaotic nature of the predicted weather patterns. The computational methods they developed later became the basis of much modern aeronautical design and environmental modelling. Central bankers and economists have finally learnt from meteorology, after about twenty years, how to present the uncertainty of their financial forecasts with multiple curves spreading out into the future.

This history is memorable for its many stories – about great individuals and great team work, some personal tragedies, extraordinary bravery and incredible perseverance – accounts of which, even now, cannot be told in much detail, such as the secret observers of weather data in war zones and the use of the data in breaking codes and forecasting. The best story of all and the greatest achievement of the Met Office came in June 1944, when Group Captain Stagg provided the right twenty-four-hour forecast of moderate winds and low cloud to General Eisenhower for the perilous crossing of the English Channel by the Allied invasion forces. The forecasting office at Dunstable led by C K M Douglas and assisted by the Norwegian Sverre Petterssen collaborated with teams from the United States and Canada in providing the first 'multi-centre' forecast. There is an interesting postscript. Since 2000, with modern technology and scientific understanding, this collaborative approach is now operational, but now the diplomatic role of Stagg has been taken over by connections between sophisticated computer programs – which of course have their problems too.

I am sure readers will enjoy this history, and I hope that when you listen to your next forecast on the radio or TV you will understand a bit better about what the people do who make it possible.

Julian Hunt

Additional Commentary

DR DAVID N AXFORD, CENG, FIET, CMET(RET), FRMETS

It has been an honour to have provided some small help to Malcolm Walker in the production of this important book, which records the history of the Meteorological Office from its gestation as a mainly data-gathering and -analysing institute through its important role forecasting the weather in the Second World War to its present position, where it is enjoined to act as a semi-commercial enterprise within the boundaries set by the Government. The time and effort in researching and summarizing the essence from the multitude of papers drawn together in this book is much to the credit of the author.

Julian Hunt has provided an excellent overview of the book in his Foreword, and I would not wish to repeat his words. Instead I would like to emphasize the contributions to the international status of the UK in the science of meteorology during the second half of the twentieth century by the three Director-Generals (DGs) that I had the pleasure to serve under during my years in the Office from 1958 to 1989.

These were the 'golden years' to my mind, during which forecasting practice progressed from a science based on intuition (and the plotting of sparse data on a map with two ink pens [one blue-black, one red], drawing up the map and making a guess, based on experience, of the way the atmosphere would change over the next twenty-four hours) to a truly physics-based profession with observations from satellites as well as the land and oceans being analysed by super-computers and the analysis being forecast forward using classical physics-based numerical weather prediction programmes. Nowadays the main job of the human forecaster is to interpret the computer output and to add local knowledge where necessary while packaging the output appropriately for the customer.

When I first joined the Office in 1958, Sir Graham Sutton (DG from 1953 to 1965) was in charge. As recorded in this book, he brought together the various branches of the Office which had been scattered in and around London to a new centre in Bracknell, Berkshire, while also focusing on changing the organizational structure of the Office to bring it into line with the new post-war requirements. Following the end of the Second World War, meteorological technology, automation and, from the 1950s, the application of electronic computers made rapid progress, and Sir Graham kept the Office focused on a goal of being at the scientific forefront of meteorology.

Under Sir John Mason (DG from 1965 to 1983) the Meteorological Office became internationally recognized as a Centre of Excellence within which staff were active both in providing weather services to the public, the military and the aviation industry, and in conducting front-edge pure and applied research in meteorological science. All staff were encouraged to achieve their potential through regular review and forward planning by the Directorate. High-achieving scientists of international renown were recruited to ensure that fundamental research was carried out in parallel with the development of new and improved operational services. Sir John Mason himself was a leading light on the international stage, too, ensuring that UK meteorologists were fully involved in the first globally supported scientific experiments such as the Global Atmospheric Research Programme (GARP), GARP Atlantic Tropical Experiment (GATE) and others.

Sir John Houghton (DG from 1983 to 1991) continued the work of his predecessor, in particular in the field of satellite meteorology and, later, in the science related to climate forecasting. There was a growing unease amongst international scientists concerning the likelihood of future climate change. In this respect, his role within the international community of national meteorological services at the World Meteorological Organization in Geneva was seminal. He became the first chairman of the Scientific Working Group of the Intergovernmental Panel on Climate Change (IPCC). I was honoured to be present at a lunch that he hosted in Geneva during which he promoted the setting up of the internationally backed Global Climate Observing System (GCOS) which has been an essential component in the scientific understanding of the Earth's climate, and, at a national UK level, he steered through the establishment of the Hadley Centre, which is now internationally recognized as one of the leading centres of expertise in the understanding of climate and climate change.

Looking to the future, it is to be hoped that the UK Meteorological Office maintains its 'centre of excellence' position amongst the world's meteorological services. The pure scientific research conducted during the second half of the twentieth century in areas such as satellite technology, atmospheric chemistry, climate modelling, cloud physics and many other fields has borne serendipitous fruit so that the Office has been well placed to offer the best advice available to the politicians grappling with the new twenty-first-century environmental problems of air pollution, ozone depletion and climate change. May it continue to hold this position of pre-eminence in the future.

David N Axford
Stanford in the Vale

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Malcolm Walker

Abbreviations

AA	The United Kingdom's Automobile Association
AP1134	The official report on the work of the Meteorological Office during the Second World War
BBC	British Broadcasting Corporation
BIS	Department for Business, Innovation and Skills
British Association	British Association for the Advancement of Science
BRO	British Rainfall Organization
CAA	Civil Aviation Authority
CEGB	Central Electricity Generating Board
CFO	Central Forecasting Office
CMet	Chartered Meteorologist
COMESA	Committee on Meteorological Effects of Stratospheric Aircraft
COST	The EEC's scheme for Cooperation in Science and Technology
Defra	Department for Environment, Food and Rural Affairs
DERA	Defence Evaluation and Research Agency
DETR	Department of the Environment, Transport and the Regions
DSIR	Department of Scientific and Industrial Research
ECMWF	European Centre for Medium Range Weather Forecasts
ECOMET	The Economic Interest Grouping of the National Meteorological Services of the European Economic Area
EEC	European Economic Community
ESSA	Environmental Science Services Administration
EUMETSAT	The European Organization for the Exploitation of Meteorological Satellites
FGGE	First GARP Global Experiment
FRONTIERS	Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite
GARP	Global Atmospheric Research Programme
GATE	GARP Atlantic Tropical Experiment
ICSU	International Council of Scientific Unions

IGY	International Geophysical Year
IIOE	International Indian Ocean Expedition
IMC	International Meteorological Committee
IMD	India Meteorological Department
IMO	International Meteorological Organization
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
IQSY	International Quiet Sun Year
JASIN	Royal Society Joint Air-Sea Interaction Project
JCMM	Joint Centre for Mesoscale Meteorology
MMU	Mobile Meteorological Unit
MoD	Ministry of Defence
MOLARS	Meteorological Office Library Accessions and Retrieval System
MOSS	Meteorological Office Observing System for Ships
MOWOS	Meteorological Office Weather Observing System
MRC	Meteorological Research Committee
MRF	Meteorological Research Flight
NERC	Natural Environment Research Council
NIO	National Institute of Oceanography
NPL	National Physical Laboratory
NWP	Numerical Weather Prediction
Office	(when used with capital O): Meteorological Office
PMO	Port Meteorological Officer
PWD	Petroleum Warfare Department
RAF	Royal Air Force
RAFVR	RAF Volunteer Reserve
RE	Royal Engineers
RFC	Royal Flying Corps
THUM	Temperature and humidity (in the context of upper-air data obtained by aircraft ascents)
TIROS	Television Infra-Red Observation Satellite
TV	Television
UK	United Kingdom
UM	Unified Model
UN	United Nations
WMO	World Meteorological Organization
WWW	World Weather Watch

1

Seeds Are Sown

One afternoon in February 1854, an announcement was made in the House of Commons. A new government department was to be formed, to collect and digest meteorological observations made on board merchant and Royal Navy ships. Six months later, the Meteorological Office was born.

When the Office took its first tentative steps, it had a staff of four and a budget of a few thousand pounds per year. Since then, Britain's national meteorological service has experienced several major changes in control and organization and is now an Executive Agency and Trading Fund responsible to the United Kingdom (UK) government's Department for Business, Innovation and Skills, with a staff of nearly two thousand and a turnover of nearly 200 hundred million pounds per year. It is a scientific and technological institution of national and international importance, serving not only the shipping industry but also many other groups of users, including the general public. It is also at the forefront of fundamental pure and applied research in meteorology and related sciences and, moreover, cooperates and interacts with the international meteorological community at administrative, operational and research levels. What were the origins of this institution? How did it come to be founded?

The simple answer is that its foundation was an outcome of an international conference held in 1853, but this answer begs a number of questions. Why was the conference held, and why then? Who organized it, and why them? Had there been attempts to form a body resembling a national meteorological institution in the UK before 1854? Did any institutions of this kind exist abroad already? Was the foundation of the Office solely the result of a conference? It is appropriate to review not only the origins of the Office as an institution but also the scientific context. Without an awareness of this context and the preceding discoveries and inventions, neither the Office's foundation nor its work in its formative years can be fully understood.

Meteorology in Ancient Times

Long before the 1850s, there were meteorologists, persons who study the processes and phenomena of the atmosphere. The ancient Greeks gave us the word *meteorology*, from μετέωρος (lofty or raised up), and λογος (discourse). Aristotle (*c*. 384–322 BC) used it in his *Meteorologica*, the earliest known treatise on atmospheric phenomena, and stated that it had been used by his predecessors. Who actually coined the word is not, however, known. Who first tried to understand the ways of the atmosphere is not known either, but there has probably never been a time when people took no notice of the weather.

Our earliest ancestors left no records, so nothing is known of their meteorological knowledge and understanding. The earliest records came with the dawn of civilization, in the form of texts and symbols written on walls or papyrus and inscriptions made on clay tablets. From these we know that the ancient Babylonians attached great significance to clouds, winds, storms and thunder, though many of their observations served more as omens of political and economic events than as signs of weather to come. Most ancients considered meteorology a branch of astronomy, and the Babylonians founded astro-meteorology, a pseudo-science concerned with the alleged influences of celestial phenomena such as comets and planetary conjunctions on weather and climate.[1]

The ancient Greeks were careful observers of nature and devised hypotheses which they tested by means of experiments. Thus their approaches were essentially scientific, though most of their ideas have failed the test of time. An exception is their concept of the hydrological cycle, which was recognized by Anaxagoras of Clazomenai (*c*. 500–*c*. 428 BC) and can hardly be faulted today. Some Greek philosophers turned their attention to weather forecasting. We know from a work by Theophrastos of Eresos (*c*. 372–*c*. 288 BC), for example, *De signis tempestatum* (On weather signs), and from a work by Aratos of Soloi (*c*. 315–*c*. 240 BC), *Diosēmeia* (Weather forecasts), that the Greeks relied on weather lore in the form of proverbs, rhymes and rules based on lunar and planetary influences on the atmosphere, the flowering of plants, the behaviour of animals, the appearance of the sky, and so on.

The Greeks appear to have been the first to make and record meteorological observations regularly. By the fifth century BC, they were making them public by means of parapegmata, which were almanacs fixed to columns. The predominance of wind observations suggests that the information was particularly important to seafarers. To ascertain wind direction, a vane may have been used. This device appears to have existed in ancient times in Japan and China and was widely used in Greece by the first

[1] Weather is the state of the atmosphere at any given time and is expressed in terms of temperature, humidity, visibility, wind speed, wind direction, whether or not rain is falling, etc. Climate is the synthesis of the weather at any place and is generally expressed in terms of averages and variability about those averages.

century BC. The Tower of the Winds still stands in Athens today but has lost its vane, a revolving bronze Triton. This structure, built about 40 BC, is properly known as the Horologe of Andronikos Kyrrhestes (after the astronomer who built it) and originally served the triple purpose of sundial, water-clock (clepsydra) and weather-vane.

Several basic elements of a modern meteorological service existed in ancient Greece, albeit in rudimentary or crude form: observations of atmospheric phenomena were made systematically; explanations of these phenomena were sought; forecasts of the weather were attempted; and the effects of the weather on seafarers, farmers and others were matters of concern.

The Dawn of Modern Meteorology

Aristotle's *Meteorologica* did not become available in the West before the late twelfth century, when the first three of its four books were translated into Latin by Gerard of Cremona (1114–1187).[2] The works of Aratos of Soloi were, however, well known to the Romans, as revealed by the *Georgics* of Virgil (70–19 BC), *De rerum natura* by Lucretius (*c*. 95–*c*. 55 BC) and *Naturalis Historia* by Pliny the Elder (AD 23–79). Few works on meteorology appeared in the so-called Dark Ages (the period from the fifth to the tenth centuries AD). Important among them was a compendium of astronomy and meteorology called *De natura rerum*, published by Isidore of Seville in around 620. Important, too, was the first work on meteorology written by an Englishman, the Venerable Bede's own *De natura rerum*. Written in the early eighth century, it drew heavily on Isidore's work and the writings of the classical writers, notably Pliny the Elder.

After the time of Bede, particularly in the period from 1100 to 1300, a considerable number of encyclopædias containing meteorology were published, and many of them were translated into vernaculars, some of them into English. It is evident from these compendia that the science of ancient Greece continued to dominate meteorological thought, especially that expounded in *Meteorologica*, but the tenets of Greek science were eventually questioned.

In around 1270, Roger Bacon (*c*. 1214–1292) wrote a commentary on *Meteorologica* in which he cast doubt on Aristotelian theories. At the time, this was tantamount to blasphemy. Nevertheless, criticisms of Greek science mounted until, in the seventeenth century, the science of the ancients was rejected. Astrological methods of weather forecasting, which had been practised since the days of the Babylonians and had flourished during the Middle Ages, were also questioned increasingly until, again in the seventeenth century, they too were rejected by most scholars. There continued to

[2] He translated them from the Arabic of the Moslems. Books I–III of *Meteorologica* are concerned mainly with meteorology but also cover aspects of astronomy, geography, geology and seismology. Book IV deals mainly with chemistry and may be the work of Straton of Lampsacus (died 270 BC), rather than Aristotle. *Meteorologica* has been translated into English by H D P Lee (Loeb Classical Library, 1987, 433 pp.).

be adherents of these methods, however, and in the early years of the Meteorological Office, astro-meteorology became an issue for a while, when its leading practitioners challenged the official approach to weather forecasting (see Chapter 2).[3]

The earliest extant journal of the weather was kept by an English meteorologist and clergyman, William Merle (dates of birth and death unknown), who maintained a systematic written record of the weather from January 1337 to January 1344. A century later, the practice of keeping weather diaries was encouraged by the spread of mass printing, for it brought about an increase in the use of calendars and almanacs, in the margins of which weather notes were often made. Merle's and other early weather diaries have proved useful to modern students of climatic change, but their usefulness is limited by the lack of instrumental measurements.

Other than rainfall, the only weather variable ascertained instrumentally before the late Middle Ages was wind direction. Without measurements, a fully quantitative scientific approach to the study of the atmosphere cannot be achieved, however diligent observers of the weather might be. The sixteenth and seventeenth centuries saw not only the rejection of Aristotelian theories but also, especially in Germany, France, Italy and England, the dawn of modern approaches to science, including the invention of the three most basic instruments in meteorology: the hygrometer, thermometer and barometer.

The credit for inventing an instrument capable of measuring the amount of water vapour in the atmosphere is generally accorded to Nicholas de Cusa (1401–1464), who used a balance and quantity of wool to show that the weight of hygroscopic material increases as the amount of moisture in the air increases and decreases as the air becomes drier. Soon afterwards, around 1485, Leonardo da Vinci (1452–1519) described a balance hygrometer which was similar but relied on cotton rather than wool.

An apparatus which demonstrated that air expands when heated and contracts when cooled was described by Philo of Byzantium in his work *De ingeniis spiritualibus* (On pressure engines), published in the second or third century BC. Hero of Alexandria utilized this property of air in the first century AD in his device for opening temple doors, but neither he nor Philo appears to have realized that it could be applied to measure heat. This step was not taken until the 1590s, when a thermometer which relied on the expansion and contraction of air was constructed by Galileo Galilei (1564–1642), who was familiar with the works of Philo and Hero. Galileo used his thermometers to compare the temperatures of different places and to investigate diurnal and seasonal variations of temperature. He recorded temperatures in degrees,

[3] Whether or not the Meteorological Office should ever have become involved in weather forecasting may be a moot point. In the December 1989 issue of *Weather* (Vol. 44, p. 478), Jackie Hoskins quoted from *The Pelican Social History of Britain: 16th-century England* by Joyce Youings, where (on p. 36) it is stated that "an Act of Parliament of 1541 included in its prohibition of all manner of sorcery the forecasting of the weather". Mrs Hoskins wondered if this act had ever been repealed!

but the method he used for graduating the stems of his thermometers is not known. The scales that are commonly used today came later. That of Gabriel Fahrenheit (1686–1736) was published in 1724, and the centigrade scale of Anders Celsius (1701–1744) was published in 1742.

A student of Galileo, Evangelista Torricelli (1608–1647), invented the mercurial barometer. In 1643, assisted by one of his pupils, Vincenzo Viviani (1622–1703), he sealed one end of a glass tube, filled the tube with mercury and inverted it with the open end in a dish of mercury. Finding that the height of the mercury column was less than the length of the tube, he reasoned that the space above the column was occupied by a vacuum and therefore that the weight of the column was balanced by the weight of the atmosphere. He later noticed that the height of the column varied over time and concluded that variations in the pressure exerted by the atmosphere accompanied changes in the weather. In France, Blaise Pascal (1623–1662) repeated Torricelli's experiment with different liquids (one of them red wine!) and verified a prediction of Torricelli: that the pressure of the atmosphere decreases with altitude. On 19 September 1648, he found that the atmospheric pressure near the summit of the Puy de Dôme (1464 m) was about 10% less than it was at the foot of the mountain.[4]

The first network of meteorological stations was set up in 1654. Directed by a Jesuit named Antinori, who was secretary to the patron of the project, Grand Duke Ferdinand II of Tuscany, the network comprised stations at Florence, Vallombrosa, Cutigliano, Bologna, Parma, Milan, Warsaw, Innsbruck, Osnabrück and Paris. Observations were made at specific times of day and written down in special tables called 'formulae'. The network was closely associated with the Accademia del Cimento of Florence, the world's first formal scientific institution, and ceased to function in 1667, when the Academy was disbanded. Founded in 1657 by the Grand Duke and his brother, Prince Leopold, the Academy was devoted to experiment and was much involved in the development of barometers and spirit-in-glass thermometers, many of which were used at stations of the network. Viviani was a member.

Whereas the Accademia del Cimento was a private institution dependent on patronage, the Royal Society of London was established as a corporate body, though also with royal patronage. Founded in 1660 for the pursuit of experimental natural philosophy, it is the longest extant academy. It has influenced the development of meteorology in many ways over the three and a half centuries of its existence and has played an important role in the history of the Meteorological Office, as we will see later.

Of the early members of the Royal Society, two in particular made fundamental contributions to meteorology: Robert Boyle (1627–1691) and his assistant, Robert

[4] In honour of Pascal, the unit of pressure in the Système International (SI) is called the pascal (Pa), 1 Pa being a pressure of one newton per square metre. For convenience, the units commonly used in modern meteorology are the hectopascal (hPa) and the millibar (1 mb = 1 hPa = 100 Pa).

Hooke (1635–1703). Together, they developed barometers, thermometers and thermometric scales, and together they investigated the use of the barometer in weather forecasting. In addition, Hooke measured wind strength with a primitive anemometer which relied on the movement of a swinging plate over a scale. Some say that the anemometer was invented by him, though a wind-measuring instrument which employed a swinging plate had been described two centuries earlier by Leon Battista Alberti (1404–1472) in his treatise *On the Pleasures of Mathematics*, published in around 1450.

The habit of making weather observations regularly and systematically was encouraged by the Royal Society, and as early as 1663 Hooke presented to the Society his paper titled 'A method for making a history of the weather', in which he set out precisely what should be included in a weather observation and how, using standard instruments, observations should be made. He stated that he wished "there were divers in several parts of the World, but especially in distant parts of this Kingdom, that would undertake this work, and that such would agree upon a common way somewhat after this manner, that as neer as could be, the same method and words might be made use of". Thus he showed himself aware of not only the need for uniform procedures in the making of weather observations but also the potential value of comparing meteorological observations made simultaneously at different places. His words were apparently heeded, for the practice of making meteorological observations regularly and systematically spread in the ensuing decades, with networks of meteorological stations established in various European countries, notably France and Germany.

The need for uniform procedures in the meteorological observing practices of seafarers was not highlighted until the nineteenth century, when it was an important factor in the foundation of the Meteorological Office.

The Origins and Growth of Marine Meteorology

Seafarers of ancient Greece ventured beyond the Pillars of Hercules (the mountains on either side of the Strait of Gibraltar), and the Romans also travelled far and wide. Indeed, *The Periplus of the Erythraean Sea*, written in the first century AD, provides documentary evidence that Graeco-Roman sailors maintained trade links between the Middle East and India and also understood monsoon winds sufficiently well to sail by direct routes between the Red Sea and India.

By the eighth century, Arabs were trading regularly between the Persian Gulf and China. By the middle of the sixteenth century, they had accumulated a wealth of knowledge of the winds and weather over the Indian Ocean and adjacent lands. This is shown by two works on navigation: *The Book of Useful Instructions and Principles of the Science of the Sea*, written by Omani pilot Ahmad Ibn Majid in the second half of the fifteenth century, and *The Ocean*, written by Turkish admiral Sidi Ali Celebi between 1554 and 1557. Both authors discussed winds, weather, ocean currents and the state of the sea, and both provided specific advice on sailing seasons, defining them in terms of the dates when monsoonal wind reversals and associated changes in the weather normally took place. The Arabs also considered the causes of the phenomena they observed. Indeed, the earliest correct explanation of land and sea breezes can be found in Majid's work.

The Portuguese explorers of the Indian Ocean drew upon the nautical expertise of the Arabs, including their knowledge of winds, weather and sea conditions. No such expertise was available to Columbus when he set out across the Atlantic Ocean in 1492. Nevertheless, he had by then been a seafarer for many years and undoubtedly possessed considerable knowledge of the winds, weather and currents of the North Atlantic. His understanding of atmospheric behaviour was shown in 1502, when, off Haiti, he made use of local weather signs to predict successfully the advance of a hurricane.

By the late seventeenth century, knowledge of marine meteorology had advanced to such an extent that Edmund Halley (1656–1742) was able to produce the first substantial contribution to meteorology since the days of Aristotle. It was published in 1686 in the *Philosophical Transactions of the Royal Society of London* (henceforth abbreviated to *Philosophical Transactions*) and bore the title 'An Historical Account of the 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'. He deduced correctly that thermal contrasts between land and sea are fundamental in the shaping of atmospheric circulation patterns on the scale of trade winds and monsoons, but in attributing the westward course of trade winds to the effect of the sun shifting westward over the ocean, his intuition failed him. It remained for George Hadley (1685–1768) to propose, in a paper published in the *Philosophical Transactions* in 1735, that the westward course is due to the influence of Earth's rotation on air currents flowing towards the equator.

Halley made full use of mariners' observations. So, too, did William Dampier (1652–1715) when compiling his *Discourse of Winds, Breezes, Storms, Tides and Currents*, published in 1699. This work drew on the observations not only of others, but also his own, made on three voyages around the world. In it, Dampier pointed out the resemblance between the patterns of prevailing winds and ocean currents of the globe and suggested that winds drive currents. Thus another concept which had endured since the time of Aristotle was challenged: that the waters of the sea flow from high latitudes, where the evaporation rate is low, to the tropics, where the rate is much greater and sea level therefore lower. Dampier's *Discourse* contained vivid and accurate descriptions of weather phenomena and remained the standard work on marine meteorology for more than a century. He encouraged seafarers to make meteorological observations systematically, and among those who did were the master mariners of the East India Company, though there is no evidence that he was in any way responsible for their doing so.

No one knows who first took meteorological instruments to sea. The marine barometer was, however, invented by Robert Hooke, who in 1667 presented to the Royal Society a paper which contained a discussion of the difficulties caused by the motions of vessels at sea and offered a solution, namely, the introduction of a capillary bore in the barometer tube to dampen oscillations of mercury. Who first took a thermometer to sea is also not known, but as early as 1663 Hooke took part in oceanographic experiments carried out in the Thames Estuary. These included the measurement of temperature at depths of one foot and sixteen fathoms.

The Emergence of Organized Meteorology

During the eighteenth century, the foundations for the meteorological advances of later centuries continued to be laid. Meteorological instruments were invented and improved, the Royal Society continued to take an interest in meteorology, the number of individuals making regular weather observations increased, knowledge of weather systems expanded, meteorology became progressively more organized, and advances in the physics and mathematics which underlie today's numerical models of the atmosphere were made.

In the latter half of the seventeenth century, Gottfried Leibniz (1646–1716) and Sir Isaac Newton (1642–1727) discovered the calculus (independently), and Newton made pioneering contributions to mechanics and other aspects of theoretical physics. Among those who built on their work were Daniel Bernoulli (1700–1782), Leonhard Euler (1707–1783) and Jean d'Alembert (1717–1783). Others who built on it were Joseph Lagrange (1736–1813), who revolutionized analytical mechanics and the theory of equations, and Pierre Laplace (1749–1827), who produced a mathematical expression known as 'Laplace's equation' which has proved invaluable in various fields of physics, particularly hydrodynamics. In turn, these advances paved the way for the fundamental contributions to understanding of fluid flow made in the nineteenth century by Augustin Cauchy (1789–1857) and George Green (1793–1841).

The need for systematization and standardization in meteorological observing practices continued to be stressed throughout the eighteenth century, and attempts to create international networks of weather observers continued to be made. From 1717 to 1727, for example, Johann Kanold (1679–1729) compiled and published observations from Germany and several places abroad (including London) in a quarterly journal, *Breslauer Sammlung*. At the same time, Secretary of the Royal Society James Jurin (1684–1750) attempted to build on the lead given by Hooke in the 1660s by publishing, in 1723, in the Society's *Philosophical Transactions*, 'An Invitation for Making Meteorological Observations', in which he stated that "changes in the weather, especially when great or sudden, have much influence on the health of mankind". He therefore considered it necessary to observe the weather and "discover the causes of these changes". He recommended that, "for the sake of comparison, all observations be made at the same hour of the day" and appealed to "such persons as may be pleased to make the observations" to send copies of them to the Royal Society that "they may be compared with the diary kept in London" and "comparisons and influences" published in the *Philosophical Transactions*.

From 1724 onward, observers in Britain, North America, India and many parts of Europe duly sent their journals to the Royal Society, and the observations they contained were discussed in the *Philosophical Transactions*. Though the supply of such journals dwindled to almost nothing by 1735, the idea of making weather observations at standard times with standard instruments had taken root and so, too, had an essential element of climatology, the need to compare and contrast observations made at different places. However, successful implementation of the recommended practices depended very much on the enthusiasm of individuals such as Hooke, Kanold and Jurin or the support of bodies such as the Accademia del Cimento and the Royal Society. As yet, there were no state meteorological services.

One who responded to Jurin's appeal was an American, Isaac Greenwood (1702–1745), who pressed for an extension of Jurin's idea of a worldwide network of meteorological stations. In 1728, he urged the Royal Society to extract information about winds and weather from the logbooks of ships and encourage mariners to observe the weather systematically. If this information were compiled in tabular form for the different oceans, he argued, there would be benefits for both meteorology and marine navigation. More than a century was to elapse before this proposal became reality.

An idea similar to Jurin's was put forward in 1744 by Roger Pickering (1718–1755) in a paper in the *Philosophical Transactions* titled 'A Scheme of a Diary of the Weather, Together with Draughts and Descriptions of Machines Subservient Thereunto'. Like previous schemes for making, compiling and analysing weather observations, however, Pickering's bore little fruit. It depended so much, like other schemes, on the enthusiasm of individuals or scientific societies, and most of these societies promoted all branches of science, not just meteorology. The Royal Society was no exception, though it did show more interest in meteorology than most societies. Indeed, in 1725, it supplied barometers and thermometers to observers at its own expense.

On 9 December 1773, the Council of the Royal Society approved a scheme drawn up by Henry Cavendish for (as it was put in the minutes) "regulating the manner of making daily meteorological observations by the Clerks of the Society". Thereafter, from 1774 onwards, observations of "barometer, thermometer, rain-gage (*sic*), wind-gage (*sic*), and hygrometer" were made regularly by the Society until the close of 1843, when responsibility for making them was transferred to the Royal Observatory at Greenwich. The observations were published in the *Philosophical Transactions*.

The reliability of the meteorological records was questioned in the 1820s, as we will see later in this chapter. The Académie des Sciences de Paris was also greatly interested in meteorology, and Père Louis Cotte (1740–1815) published his celebrated *Traité de Météorologie* under the auspices of this academy in 1774.

Before 1780, when Elector Palatine Karl Theodor of Bavaria (1724–1799) founded the Societas Meteorologica Palatina (in Mannheim), there was no society devoted solely to meteorology. However, the political turmoil in France and elsewhere in Europe made the society's survival difficult, and it collapsed in 1795. In its short life, however, it had shown what could be achieved with well-organized and well-equipped observational networks. The observers were equipped with calibrated instruments and detailed instructions, together with special forms on which to record observations, and the instruments were supplied free of charge. The Mannheim Society was a model for the national and international meteorological organizations which were formed more than half a century later. Moreover, the data published in its *Ephemerides* proved to be of considerable value in subsequent studies of weather and climate. At its most extensive, in the late 1780s, the Society's network of observers reached from the Urals across Europe to Greenland and eastern North America but never included anyone from Britain.[5]

In England, meanwhile, in the Old Deer Park at Richmond, Surrey, a short distance from the present-day Kew Gardens, an astronomical observatory had been erected. Originally called 'The King's Observatory at Richmond' and later known as 'Kew Observatory', it had been built for King George III and completed in time for the transit of Venus which occurred on 3 June 1769. Meteorological observations were first made there in 1773 and continued to be made until 1980. During the Royal period, which ended in 1841, observations were made at least once a day and included readings of thermometers, hygrometers, a barometer and a rain gauge. From 1842 to 1980, as we see in later chapters, Kew was one of the principal observatories in the world for the study of meteorology and related branches of physics.

Before the middle of the eighteenth century, no one had attempted to use kites or balloons to study the atmosphere aloft. But in 1749, the Professor of Practical Astronomy in the University of Glasgow, Alexander Wilson (1714–1786), attached thermometers to kites, and in 1752, Benjamin Franklin (1706–1790) carried out his famous, but hazardous, experiment with a kite in a thunderstorm. In later life, Franklin was a balloon enthusiast and was, indeed, present on 27 August 1783, when Jacques Charles (1746–1823) made the first ascent over Paris.

Meteorological observations were first made on a balloon flight on 1 December 1783, when Charles ascended to a height of 3467 metres, also over Paris, taking with

[5] See 'Meteorology in Mannheim: the Palatine Meteorological Society', by David C Cassidy, published in 1985 in *Sudhoffs Archiv* (Vol. 69, pp. 8–25). See also 'Societas Meteorologica Palatina', by Albert Cappel, published in 1980 in *Annalen der Meteorologie* (Vol. 16, pp. 10–27); and 'The Societas Meteorologica Palatina: an eighteenth-century meteorological society', by J A Kington, published in 1974 in *Weather* (Vol. 29, pp. 416–426).

him a thermometer and a barometer, the latter for estimating altitude. The following year, on 30 November 1784, John Jeffries (1745–1819) and Jean-Pierre Blanchard (1750–1809) made the first balloon ascent specifically for meteorological purposes.[6] During the flight, measurements of temperature and pressure were made, clouds were observed and samples of air were taken. The balloon was launched in central London and taken by westerly winds to a point near Dartford, Kent.

In 1796, Alexander von Humboldt (1769–1859) pointed out the need for meteorological observatories not only in different climatic zones but also at different altitudes. He appears to have been the first to realize that climate varies with both latitude and altitude. He also appears to have been the first to plot isotherms and isobars, which are, respectively, lines connecting points having the same temperature and lines connecting points having the same pressure. The isopleths which were drawn on the first published weather charts were, however, lines connecting places with equal departure of pressure from normal. These so-called synoptic charts were constructed by Heinrich Brandes (1777–1834) and drawn for each day of 1783, utilizing data collected by the Palatine Meteorological Society. They were discussed in *Beiträge zur Witterungskunde*, published in Leipzig in 1820. The credit for the idea of comparing meteorological observations made simultaneously at different places is often awarded to Antoine Lavoisier (1743–1794), but Lavoisier himself said the idea was put forward by Jean de Borda (1733–1799).

Early Attempts to Model Weather Systems

Though invaluable immediately in studies of weather systems, such charts could not yet serve any useful purpose in weather forecasting. Without the electric telegraph, which was invented in the 1830s, there was no way of communicating observations to analysts in time for current charts to be drawn. Among those who drew conclusions from the early synoptic charts was Brandes himself, who deduced from inspection of them that storms are barometrical depressions which advance from west to east and move into Europe from the Atlantic. Nevertheless, he was not the first to realize that the weather systems of middle latitudes are mobile.

In North America one evening in October 1743, clouds over Philadelphia prevented Benjamin Franklin from observing a lunar eclipse, but observers in Boston were more fortunate. For them, viewing conditions were good. The weather became cloudy in Boston an hour after the eclipse ended. Franklin realized that the clouds over Philadelphia were associated with a travelling storm that subsequently reached Boston. Thus he gained a place in history as the person who discovered that weather systems are moving formations. Hitherto, the belief had been that weather developed in situ. However, Columbus may have realized in around 1500 that the hurricanes of the

[6] See Crewe, M (1994), 'The first meteorological research flight', *Weather*, Vol. 49, pp. 61–65.

Caribbean are moving formations. If so, then Franklin's contribution may have been the discovery that the depressions of middle latitudes are also moving formations, though this, too, is debatable, because Franklin investigated the depression in question and found that it had once been a hurricane! Whatever the truth of the matter, it is probably safe to say that Franklin was the first to study the movements of weather systems *scientifically*.

An observation as fortuitous as Franklin's was made by William Redfield (1789–1857) on a journey through Connecticut and Massachusetts towards the end of 1821. He noticed that trees blown down by a storm of tropical origin had fallen in a pattern which indicated that the storm had been a vortex rotating counter-clockwise. From an investigation of this storm and a number of hurricanes in the Caribbean, he concluded that the wind directions around storms correspond to the tangents of concentric circles and therefore that the storms are 'progressive whirlwinds' with calm centres. He published his findings in 1831 in the *American Journal of Science and Arts* in a paper titled 'Remarks on the Prevailing Storms of the Atlantic Coast of the North American States'.

His paper was epoch-making. It was the first in a line of scientific contributions which have furthered *understanding* of weather systems, as distinct from *knowledge* of them, and it attracted attention immediately. Indeed, Redfield soon found himself a protagonist in a controversy over his 'Circular Theory'. A prominent American meteorologist, James Pollard Espy (1785–1860), was his chief adversary. According to Redfield, the low barometric pressure at the centre of a storm system was due to "the centrifugal tendency, or action, which pertains to all revolving or rotatory movements". Espy, on the other hand, rejected the concept of rotary motion in a storm system. He stressed the importance of thermal convection and argued that vigorous upward motion at the centre of a system causes air to flow inwards radially from all directions. As is so often the case in controversies, both arguments contained elements of the truth.

Unfortunately, Redfield and Espy did not amalgamate their ideas and, moreover, did not take into account the influence of Earth's rotation, by which a moving body is deflected to the right in the northern hemisphere, left in the southern. This influence had been recognized qualitatively since the days of Hadley and is now called the 'Coriolis Effect', after the French mathematician Gaspard Gustave de Coriolis (1792–1843), who expressed it analytically in 1835.

Another who disagreed with Redfield was Henry Piddington (1797–1858). He too rejected the idea of winds blowing parallel to isobars, saying that his analyses of observations recorded in the logbooks of ships indicated that wind patterns in storms over the Arabian Sea and Bay of Bengal represented a combination of circular and centripetal movements of air. In recognition of this, he coined the term *cyclone*, first using it in print in 1848 in the first edition of *The Sailor's Horn-Book for the Law of Storms*. The term stems from the Greek κύκλωμα, meaning 'coil of a snake', and is a possible allusion to Cyclops, the one-eyed giant of Greek mythology who forged thunderbolts for Zeus.[7] A tropical cyclone possesses an eye.

In the opinion of Heinrich Wilhelm Dove (1803–1879), who had studied meteorology under Brandes, the storm systems of the tropics were essentially symmetrical, and he pointed out, furthermore, that air circulates around their centres clockwise in the southern hemisphere, counter-clockwise in the northern. He did not agree, however, that the weather systems of temperate latitudes were also symmetrical. In his opinion, they appeared to contain two opposing air currents, one warm and moist, the other cold and dry. This was clear from his examinations of the charts of Brandes and was also his personal experience and the experience of seafarers. As he explained in *Ueber das Gesetz der Stürme*, published in 1841, the depressions of middle latitudes result from the continual conflict between two currents of air, "of which one flows from the pole to the equator, the other from the equator to the pole".

A similar view was held by an English master mariner, George Jinman (1829–1884), who argued in his *Winds and Their Courses; or a Practical Exposition of the Laws Which Govern the Movements of Hurricanes and Gales* (first published in 1859) that the weather systems of temperate latitudes were "governed by far different laws from those of the hurricane or typhoon". In the temperate zone of the North Atlantic, he considered, Redfield's circular theory and Piddington's rules were "not only wrong but dangerously misleading". He had concluded that "there never was such a thing as a really circular gale". The model of extratropical weather systems that he put forward contained two distinct currents of air flowing in opposite directions and crossing each other along lines of confluence. His daily life, he said, gave him an opportunity to test "by practical experience *at sea* the laws which closet philosophers were elaborating *on shore*"!

Progress through Organized Science

By the early nineteenth century, meteorological observations were being made in many parts of the world, but scientific progress was slow. Developments in meteorology still depended largely on the enthusiasm of individuals. With the exception of the Palatine Meteorological Society, societies that were devoted solely to meteorology had still not been formed. In general, the literary and philosophical societies that were formed in the capital cities and major provincial towns of Europe, Asia and North America in the eighteenth century and early part of the nineteenth displayed no more interest in meteorology than the learned societies that went before them. An exception was the American Philosophical Society, proposed and established by Benjamin Franklin in 1743.

[7] Nowadays, 'cyclone' is used as a generic name for both the hurricanes of the tropics and the depressions of middle and high latitudes.

Another exception was the Manchester Literary and Philosophical Society, which was formed in 1781 and numbered among its most active members the chemist and physicist John Dalton (1766–1844). He joined in 1794 and remained a member for the rest of his life, reading before the Society in those fifty years 116 papers, many of them on meteorological topics. Though best known for his work on atomic theory, he is considered by some to have been first and foremost a meteorologist. His meteorological work inspired many, not only in Britain but also abroad. For example, Espy declared that Dalton's researches on the physics of atmospheric water vapour had made a remarkable impression on him.

Luke Howard (1772–1864) was also a chemist and meteorologist. He made many substantial contributions to meteorology but is best remembered for his essay 'On the Modifications of Clouds, and on the Principles of Their Production, Suspension, and Destruction', published in 1803 by the Askesian Society. In this, he defined and described cloud types and noted that clouds have characteristic forms, for which he proposed "a methodical nomenclature" based on Latin terms that remain familiar today, namely *cirrus* (curl), *cumulus* (heap), *stratus* (layer) and *nimbus* (rainy cloud). His was the first practical cloud classification, and it forms the basis of modern classifications of clouds, including that still used by the Meteorological Office.[8]

Howard was among those who attended a meeting held at the London Coffee House on 15 October 1823. At the meeting, Britain's first meteorological society was formed, and Howard was elected a Council Member. It was called the Meteorological Society of London and flourished for seven months, after which, despite the initial enthusiasm and activity, it languished until 1836, when it was revived, only to fail again in 1843. The aspirations of the newly formed society were eminently scientific, for in early 1824, a committee set up by the Council recommended that "immediate measures be taken to procure correct registers of comparable observations from different parts of Great Britain and its colonies, as well as from other parts of the world, with instruments graduated to the common scales". "To effectuate this purpose with advantage", they considered it "absolutely necessary that the Meteorological Society of London should set the example of the requisite precision by establishing a Meteorological Observatory in the metropolis, or its vicinity".

These recommendations were, in fact, implemented in due course, as we see later, but, alas, not by the society, for it did not remain active long enough to play any significant role. When the society was revived, its objectives were not as clearly defined as in 1824, and in the early 1840s, indeed, the astro-meteorological tendencies

[8] The first known cloud classification was that suggested by the French naturalist Jean Baptiste Lamarck (1744–1829), who proposed (in 1802, in Volume 3 of his yearbook *Annuaire Météorologique*) three levels of cloud and five types of cloud ('hazy clouds', 'massed clouds', 'dappled clouds', 'broomlike clouds' and 'grouped clouds'). Though Howard's classification was adopted as the foundation of the modern classification of clouds, Lamarck's tripartite division of the atmosphere is still used today, but in modified form. His yearbooks were published annually from 1800 to 1810 and then discontinued after an unnecessarily public and brutal tirade from Napoleon in which Lamarck was told by the Emperor he should confine his attention to natural history.

of some leading members lowered the society's credibility among the establishment scientists of the day.[9]

Another who served on the Council of the Meteorological Society in 1823–1824 was John Frederic Daniell (1790–1845), inventor of the cell and hygrometer which bear his name and author of *Meteorological Essays and Observations*, published in 1823. In the Preface to this work, he mentioned that his enthusiasm for meteorology had resulted from his friendship with the geophysicist Edward Sabine (1788–1883), who was to become a greatly influential figure in meteorology. Sabine was for many years involved in the running of Kew Observatory, and his roles in the foundation and subsequent development of the Meteorological Office were central, as we will see in Chapters 2 and 3. Moreover, he figured prominently in the formation of meteorological services in Canada and India and the establishment of observatories at Toronto, Hobart, St Helena, Cape of Good Hope, Mauritius and Hong Kong.

Daniell criticized the Royal Society's meteorological work, noting that both Dalton and Howard had "recorded their dissatisfaction" over the state of the society's instruments and the unreliability of the society's meteorological records. His dissatisfaction was but part of a more general concern over the decline of science in Britain which became more insistent through the 1820s and helped bring about both the reform of the Royal Society in the 1830s and 1840s and the formation of the British Association for the Advancement of Science in 1831.[10]

At the British Association's Second Meeting, in 1832, a substantial and highly critical *Report upon the Recent Progress and Present State of Meteorology* was presented by James David Forbes (1809–1868), who later became Professor of Natural Philosophy in the University of Edinburgh. In it, he discussed meteorological instruments and focused on what he considered the unsatisfactory state of meteorology, not just in Britain but all over the world. He did not mince his words.

> Meteorological instruments have been for the most part treated like toys, and much time and labour have been lost in making and recording observations utterly useless for any scientific purpose.

He "lamented" that the life of the Palatine Meteorological Society had been so short and commented that the observational system operated by that Society had been "a model of a scheme of combined exertion which the savants of the nineteenth century would do well to imitate". At the Association's Tenth Meeting, in 1840, he presented a *Supplementary Report on Meteorology*. This was as critical as the report he presented in 1832 and almost twice as long. It concluded with suggestions "for the advancement of meteorological science".

9 For the story of this meteorological society and the entirely separate Meteorological Society of London that existed from 1848 to 1850, see 'The Meteorological Societies of London', by J M Walker, published in 1993 in *Weather* (Vol. 48, pp. 364–372).

10 Hereafter in this book, 'British Association for the Advancement of Science' is abbreviated to 'British Association'.

First, he suggested, well-equipped "public observatories" should be established, "to furnish standards of comparison, to establish the laws of phænomena and to fix *secular*, or normal data". Second, he suggested, "private individuals, fond of science", might set up their own meteorological stations to supplement his envisaged network of public observatories. Finally, he proposed, observations should be made by travellers. At no point did he press for the establishment of a government body responsible for co-ordinating meteorological work, even though moves to set up national meteorological institutes had already been made in a number of countries.

The case for establishing such a body in the UK was first made in 1847, by William Radcliff Birt (1804–1881), who had been employed by Sir John Herschel (1792–1871) from 1839 to 1843 on the reduction, tabulation and graphical representation of barometric data. This work had led Herschel to conclude, as he put it in a letter to Birt dated 28 July 1843, that the atmosphere might be considered "a vehicle for wavelike movements which may embrace in their single swell & fall a whole quadrant of a globe".

To further their investigations of atmospheric waves, Herschel and Birt received generous financial support from the British Association. Despite this, Birt came to believe that even greater support for research on the waves from government sources and scientific bodies was needed, not least to help overcome the chronic lack of data which hampered his investigations. In 1847, in letters to a number of influential figures, among them Sabine, he proposed that meteorological observations, especially measurements of barometric pressure, should be made by officers aboard Royal Navy ships in various parts of the world. Through greater understanding of atmospheric waves, he argued, the weather systems of the tropics and middle latitudes would be better understood. The main beneficiaries would be, in his opinion, the naval, merchant and military services, directors of observatories and members of learned societies. Observations would be standardized, regularly deposited in a central meteorological office and arranged under the superintendence of a keeper.

Herschel agreed. To him, there should be a central government office, with a scientific meteorologist as its director and a number of salaried assistants who carried out calculations, provided, as he put it in a letter to Birt in August 1847, the nation could afford it and provision was made for the regular publication of results. Dr John Lee (1783–1866), a patron of astronomy and meteorology, thought the nation ought to be able to afford the proposed meteorological office and suggested, in a letter to Birt in August 1847, that "if one million [pounds] of the annual expenditure of £20,831,077 now spent on the Army, Navy and Ordnance were spent on the Arts and Sciences the public would readily approve of the appropriation of the funds"!

Birt wrote to the President of the Royal Society in October 1847 to seek support for his ideas and published several papers on atmospheric waves in the *Philosophical Magazine* in the period 1846 to 1850. However, his work was largely ignored by the scientists of the day, even though one so distinguished and influential as Sir John

Herschel supported him. His applications to the Royal Society in 1850 and 1851 for grants to help him continue his investigations of atmospheric waves were turned down, and he became progressively more isolated from the scientific community. Eventually, he himself recognized empirical and conceptual difficulties and took care to make little of atmospheric waves in his last meteorological work, his *Handbook of the Law of Storms; Being a Digest of the Principal Facts of Revolving Storms. For the Use of Commanders in Her Majesty's Navy and the Mercantile Marine* (published in 1853).

Given that Herschel's idea of atmospheric waves and Birt's development of it could have led to the foundation of a meteorological office seven years before one was actually founded, it is a curious quirk of history that the most scathing criticism of the idea came from the first Director of the Office, who stated, in 1863, in his *Weather Book*, that "what are commonly called 'atmospheric waves' are delusive". And it is ironic that seafarers were to have assisted Birt's research on atmospheric waves by making observations and would have been among the main beneficiaries of his work, given that the Office came into being to serve the needs of seafarers and also enlisted seafarers as meteorological observers!

Networks of Observers Develop

Observations made by seafarers are not made at fixed locations. To overcome this difficulty, the idea was put forward that the ocean surface be divided into squares for the correlation of data and identification of oceanic areas. These have long been called 'Marsden squares', after William Marsden, who was Secretary of the British Admiralty from 1804 to 1807. They were first used early in the nineteenth century for showing on a chart the distribution of meteorological data over the oceans and are still used by marine climatologists today.[11] It is not clear, however, who actually conceived the idea of using squares. The credit may belong to Isaac Greenwood, who was mentioned earlier in this chapter. In his paper in the *Philosophical Transactions* in 1728, he proposed a method of tabulating data by using squares of latitude and longitude.[12]

The first systematic attempt to collect and analyse the meteorological observations of seafarers was made in 1831 by Captain Alexander Becher (1796–1865) of the British Hydrographic Office, and he used Marsden squares. However, the work had to cease almost immediately for lack of funds and other resources. So, too, did attempts

[11] Marsden squares are each 10° latitude by 10° longitude on a Mercator chart and every square is sub-divided into 100 squares which are each 1° latitude by 1° longitude. The Marsden Squares are numbered systematically, and each sub-square bears a number from 00 to 99. Thus position on the ocean can easily be ascertained to the nearest degree.

[12] See Agnew, D C (2004), 'Robert FitzRoy and the myth of the 'Marsden square': transatlantic rivalries in early marine meteorology', *Notes and Records of the Royal Society of London*, Vol. 58, pp. 21–46.

by others, but a successful system eventually came into being in the United States as a result of an unfortunate accident.

On 17 October 1839, whilst travelling through Ohio, an American naval officer, Matthew Fontaine Maury (1806–1873), was thrown from an overloaded stagecoach when it overturned and was injured so severely that his seagoing career was ended abruptly. In July 1842, on being recalled to duty, he was employed in Washington, first as Superintendent of the U.S. Navy's Depot of Charts and Instruments and subsequently, from October 1844, as Superintendent of the U.S. Naval Observatory (later Naval Observatory and Hydrographical Office).

For much of his time, he extracted from the logbooks of ships information about winds, weather and currents, which he compiled for use by mariners. The fruits of his labour were published in 1847 in the first sheet of his *Wind and Current Charts*, the primary means by which he disseminated to mariners the information he had accumulated. He also prepared special charts and forms on which American naval officers and merchant seamen were asked to record observations (in addition to those recorded in their logbooks). Most were keen to do so, and from the information thus obtained, he was able to revise the charts he had already produced and publish, in 1851, *Explanations and Sailing Directions to Accompany the Wind and Current Charts*. His work led to safer and faster voyages than hitherto. However, he was not satisfied with these contributions to practical navigation. He wanted to establish an international system.

In Britain in the 1840s, meanwhile, James Glaisher (1809–1903) had established a network of reliable meteorological observers, among them Samuel Charles Whitbread (1796–1879) of Cardington, Bedfordshire. Glaisher and Whitbread were two of the ten gentlemen who assembled in the Library of Hartwell House, near Aylesbury, Buckinghamshire, on 3 April 1850, "to form a society the objects of which should be the advancement and extension of meteorological science by determining the laws of climate and of meteorological phenomena in general". The gentlemen called this society 'The British Meteorological Society' and appointed Whitbread its President. Thus he became the first to preside over the body which is known today as the Royal Meteorological Society. He and his gardeners made meteorological observations for many years, and in January 1873 he presented a set of observations to the Meteorological Office. Titled *Fluctuations of Barometer Cardington Observatory, January 1st 1846 to December 31st 1870*, they are held today in the Office's Archive at Exeter, Devon.[13]

Glaisher was Superintendent of the Magnetic and Meteorological Department of the Royal Observatory at Greenwich, responsible for administration of the Department

[13] The National Meteorological Library and Archive at Exeter and the Office's archives in Edinburgh and Belfast are the principal repositories of the UK's meteorological treasures, among them weather diaries, logbooks of ships and early photographs. Committee minutes and other records of the Royal Meteorological Society are in the National Meteorological Archive at Exeter.

and for organizing observations and investigations. He was appointed in 1840 and held the post until 1874, when he resigned. He was Britain's first full-time government-appointed meteorologist.

In 1848, he was commissioned by the proprietors of the *Daily News* to organize the collection of weather reports by electric telegraph for publication in their newspaper. This action was prompted by the rainy and inclement weather which had prevailed throughout that summer and caused concern as the harvest approached. Publication of weather observations, it was considered, would help dispel or allay the fears of the general public and provide practical information for agriculturalists, especially during the period when harvesting was taking place. Accordingly, from 31 August to 30 October 1848, a table showing the "State of the wind and weather" was published daily in the newspaper.

Britain's first telegraphic Daily Weather Report contained observations made at 9 a.m. the previous morning by a network of twenty-nine railway stationmasters (twenty-seven in England, two in Scotland) and was made possible by cooperation between the railway companies and the rapidly expanding Electric Telegraph Company. Such was public and official approval of the weather reports that publication was resumed on 14 June 1849. That day, reports from only thirteen stations were published, but the network rapidly expanded until reports were published from about fifty stations, some in Ireland. From the observations, Glaisher daily drew weather maps. From 8 August to 11 October 1851, he published them by lithography at the Great Exhibition, selling them to the public at a penny each.

The Outcome of a Conference

The year 1851 was also notable for the appearance of the earliest periodical devoted to meteorology, the weekly *Wind and Weather Journal*, which was published in London and first appeared on 8 July 1851. However, the meteorological developments in 1851 of greatest importance in the history of the Meteorological Office were the schemes proposed by William Reid (1791–1858), a British army officer. He had worked with Redfield on the characteristics of tropical cyclones and published, in 1838, a classic book titled *An Attempt to Develop the Law of Storms by Means of Facts, Arranged According to Place and Time; and Hence to Point Out a Cause for the Variable Winds, With a View to Practical Use in Navigation*.

In the 1840s, Reid persuaded the British Colonial Office to set up meteorological stations in the colonies. Then, in 1851, his persuasiveness was rewarded yet again, when his former commanding officer, Sir John Fox Burgoyne (1782–1871), authorized the establishment of a network of observing stations worldwide. Responsibility for making observations systematically and routinely at foreign stations was given to officers of the Royal Engineers stationed overseas, with overall control of the network given to Henry James (1803–1877) of the Royal Engineers. Reid's persuasiveness did not end there, for in the autumn of 1851, encouraged by Reid, Burgoyne approached the government of the United States via diplomatic channels to suggest expansion of the British network through American collaboration.

In Washington, DC, the recipient of the letter from the British government was Secretary of State Daniel Webster, who wrote to the Secretary of the Navy, William Graham, on 14 November 1851, to ascertain the extent to which the U.S. Navy would be prepared to cooperate with the British. Graham passed the letter to Maury via Maury's superior and, in reply, Maury proposed that a meteorological conference be held. Its purpose would be to review meteorological observing practices, its objective to reach agreement on standard procedures.

Maury pointed out that the greater part of the globe is covered by ocean and argued that no general system of meteorological observations could be considered complete unless it embraced the sea as well as the land. He suggested an amendment to the British proposition:

> That England, France, Russia and other nations be invited to cooperate with their ships by causing them to keep an abstract log according to a form to be agreed upon and that authority be given to confer with the most distinguished navigators and meteorologists both at home and abroad, for the purpose of devising, adopting and establishing a universal system of meteorological observations for the sea as well as for the land.

The American government replied to the British government on 6 December 1851, proposing that a conference be held to consider meteorological observing practices on land and at sea. Four days later, Graham gave Maury authority to organize it, after which Maury wrote to a great many diplomats and government officials at home and abroad and to a number of distinguished foreign scientists, among them Glaisher (in his capacity as Secretary of the British Meteorological Society). He suggested the conference be held in Paris, mainly because he was keen that Dominique Arago (1786–1853) should attend. Arago was ailing and not expected to be well enough to travel to another venue.

The replies Maury received were generally favourable, with Humboldt, a close friend of Arago, particularly enthusiastic. The British, too, supported the idea of a conference, except that Sabine opposed inclusion of land meteorology in the conference plans. The Royal Society, to which the response of the American government had been passed for comment and advice, accepted Sabine's objections and strongly recommended to the British government that a conference on marine meteorology be held. The main reason why the Society felt that land meteorology should not be included was that achievement of uniform observing practices in the many countries where meteorological observations were already made was considered too ambitious. Achieving uniformity in marine observing practices was a different matter.

In early 1853, the American government accepted the response of the British and issued invitations to "a conference limited to adopting a universal system for observations at sea". When by the third week of April the British government had failed to respond, Lord Wrottesley took action. A senior Fellow of the Royal Society, Chairman of the Parliamentary Committee of the British Association and a close friend of Burgoyne, he was keenly interested in Maury's *Wind and Current Charts* and convinced of the merit of the proposal for a universal system of meteorological observations at sea. On 26 April 1853, he made a long speech in the House of Lords in which he reviewed Maury's achievements, explained the proposal in great detail, emphasized the potential commercial advantages for British shipping, and urged the British Government to send delegates to the conference.

But still a response from the government did not materialize, so the Americans decided to proceed notwithstanding. In June 1853, they issued invitations to a conference to be held in Brussels, rather than Paris. The reason for the change of venue is not clear, but the poor state of Arago's health may have been a critical factor. He died on 2 October 1853. Whatever the reason, Brussels was an important meteorological centre, where Adolphe Quetelet (1796–1874) was Director of the Royal Observatory and Perpetual Secretary of L'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique.

There were two British delegates, and they were forbidden by the government to make any commitments to spending! Both were Fellows of the Royal Society: Henry James, an expert on land meteorology, and the Arctic explorer Frederick William Beechey (1796–1856), a Captain in the Royal Navy and the professional member of the Marine Department of the Board of Trade. There were twelve delegates in all, representing ten nations, namely, Belgium, Denmark, France, Great Britain, The Netherlands, Norway, Portugal, Russia, Sweden and the United States.[14] Of the twelve, only James and Quetelet were not naval officers. The conference met daily from 23 August to 8 September 1853 and reached agreement on a code of observational practice at sea, including the use of a standard meteorological register for recording observations. The interval between observations was soon changed from two to four hours, but the scheme to which the delegates agreed has otherwise not been modified significantly to this day.

Beechey duly reported to the British government after the conference. At first, there was no response, probably because of ministerial preoccupation with events leading up to the Crimean War. Eventually, however, on 6 February 1854, the First Lord of the Admiralty, Sir James Graham, announced in the House of Commons that a new government department was to be formed, its responsibilities being to collect and digest the meteorological observations already made on board merchant and Royal Navy ships, to increase the number of ships from which observations were

[14] In addition to Maury, Quetelet, James and Beechey, the delegates were: Victor Lahure of the Belgian Navy; P Rothe of the Danish Navy; A Delamarche of the French Imperial Navy; Marin H Jansen of the Dutch Navy; Nils Ihlen of the Norwegian Navy; J de Mattos Corrêa of the Portuguese Navy; Alexis Gorkovenko of the Russian Imperial Navy; and Carl Anton Petersson of the Swedish Navy.

obtained, to ensure that observations were made every four hours, and to communicate observations after reduction to Captain Maury.[15]

The original intention was that funds for the new department would be included in the Navy estimates, but, in the event, funds were included in the Board of Trade vote.[16] After the Board's President, Edward Cardwell, submitted the vote to the House of Commons, on 30 June 1854, there was a short debate in which John Ball, the Member for Carlow, "anticipated that in a few years, notwithstanding the variable climate of this country, we might know in this metropolis the condition of the weather 24 hours beforehand". According to Hansard, the reaction to this optimism was "laughter"!

In the Board of Trade vote, the sum of £3200 was included for the first year of the new department's work, plus an additional £1000 for meteorological services to the Admiralty. Regarding who should direct the new department, the government consulted the Royal Society, the outcome being that Captain Robert FitzRoy of the Royal Navy was chosen. He took up his duties on 1 August 1854.

[15] Meanwhile, the Royal Netherlands Meteorological Institute had already been set up. Based in Utrecht, with Christoph Buys Ballot (1817–1890) as its director, it had been founded on 31 January 1854. Its foundation was an outcome of the Brussels conference, and the Institute soon began to publish marine meteorological maps, the first of them in 1856. The first national meteorological institute was that set up in Belgium in 1826. It was based at the Brussels Royal Observatory and directed by Quetelet until 1874. The other institutes which existed before 1854 were those in Russia, Prussia and Austria. Respectively, they were set up at St Petersburg in 1840 (directed by A T Kupffer until 1865), Berlin in 1847 (directed by Dove from 1849 to 1879) and Vienna in 1851 (directed by K Kreil until 1863).

[16] In British usage, a 'vote' is a sum of money granted by a majority of votes, in this case in the House of Commons.