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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).