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Introduction

The appearance of the sky and its relationship to the atmosphere's properties have, no doubt, always provoked curiosity, with early ideas on explaining its variations available from Aristotle. A defining change in the philosophy of atmospheric studies occurred in the seventeenth century, however, with the beginning of quantitative measurements, and the dawn of the instrumental age. Since then, elaborate devices to monitor and record changes in the elements have continued to develop, providing, along the way, measurements underpinning the instrumental record of past environmental changes, most notably in air temperature. This means that characterising and understanding early meteorological instruments are of much more than solely historical interest, as recovering past measurements, whilst recognising their limitations, can also have immediate geophysical relevance.

An important meteorological example is the reconstruction of past temperature variations from the miscellaneous thermometer records originally undertaken to satisfy personal curiosity. Ships' logbooks provide another example, in terms of geomagnetic field changes. Beyond the actual data produced in either case, this also provides a reminder that all measurements can have unforeseen applications well beyond their original motivation [1], either through a change of context in which the measurements are evaluated, or because other subsequently important information has unwittingly been included.[i] Such future scope is probably impossible to predict completely, but it can to some extent be allowed for by ensuring a full appreciation of the related measurement science through careful description of the construction, calibration and recording procedures for the instrumentation employed. The possible future legacy implied by taking this historical perspective adds further motivation for rigour in the modern science of atmospheric measurement.

This chapter briefly highlights some of the major historical landmarks in development of instrumentation science for meteorology, and concludes with an overview of the book's material.

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[i] Consider, for example, the paper burn made by sunlight originally devised to determine the daily duration of sunshine. It is now appreciated that this provides a permanent, continuous record of the detailed state of the sky (see Section 9.8.1).

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Companion website: www.wiley.com/go/harrison/meteorologicalinstruments

1.1 The instrumental age

Many of the early atmospheric measuring instruments were developed in Florence, due perhaps in part to the experimental physical science tradition inspired by Galileo, and availability of the necessary craftsmanship. This included early thermometers, such as the thermoscope produced during the late 1500s to determine changes in temperature. Following key instrument advances such as the invention of the barometer by Evangelista Torricelli in 1643 and an awareness of the need for standardisation of thermometers, modern quantitative study of the atmosphere can be considered to date from the mid-seventeenth century.

Early measurement networks followed from the availability of measuring technologies combined with the formation of learned scientific societies, which together provided the means to record and exchange information in a published form. Comparison of measurements required a system of standardisation, such as that achieved through common instrumentation, and in many cases, common exposure. For thermometers, an agreed temperature scale was necessary and the Celsius,[ii] Fahrenheit[iii] or Réaumur[iv] scales all originated in the eighteenth century [2]. The meteorological values were published as tables of readings, in many cases without any further processing, but which were sufficiently complete for analysis to be made later.

1.2 Measurements and the climate record

Early weather records can be found in ‘weather diaries’, which were usually kept by well-educated and well-resourced individuals able to purchase or construct scientific instruments such as barometers and thermometers. In some cases, these diaries contain considerable descriptive and quantitative geophysical data, such as those of temperature and rainfall measurements (Figure 1.1).

Such early data sources are important because of the reference information they provide for the study of climate change, and they therefore remain of scientific value many centuries later. This is particularly true of the disparate thermometer measurements made in southern England from the 1600s, which, although made originally by individuals in an uncoordinated way, now provide an important climate data resource. The temperature readings were cross-checked and compiled[v] in the 1950s, drawing on knowledge of the different instruments used and understanding of their exposures [4]. This important synthesis generated a long series of temperature data for an area conveniently described as ‘Central England’, amounting to an approximately triangular region bounded by Bristol, Manchester and London.

[ii] Anders Celsius (1701–1744), professor of Astronomy at Uppsala, proposed his temperature scale in 1742. It originally used the melting and boiling points of ice and water as fixed points, reversed from the modern use, giving temperatures of 100 and 0 for freezing and boiling points respectively.

[iii] Daniel Fahrenheit (1686–1736) used the extremes of temperatures then available, producing a scale in 1724 with the melting point of ice at 32°F and the boiling point of water at 212°F. A Fahrenheit temperature F can be converted to a (modern) Celsius temperature C by $C = (5/9)(F-32)$.

[iv] Réaumur (Réné Antoine Ferchault) (1683–1757) used a scale with 0, the melting point of ice, and 80 the boiling point of diluted alcohol (78.3°C).

[v] This was compiled by the climatologist Gordon Manley (1902–1980) and first published (covering 1698 to 1952) in 1953. An updated and extended version (for 1659 to 1973) was published in 1974.

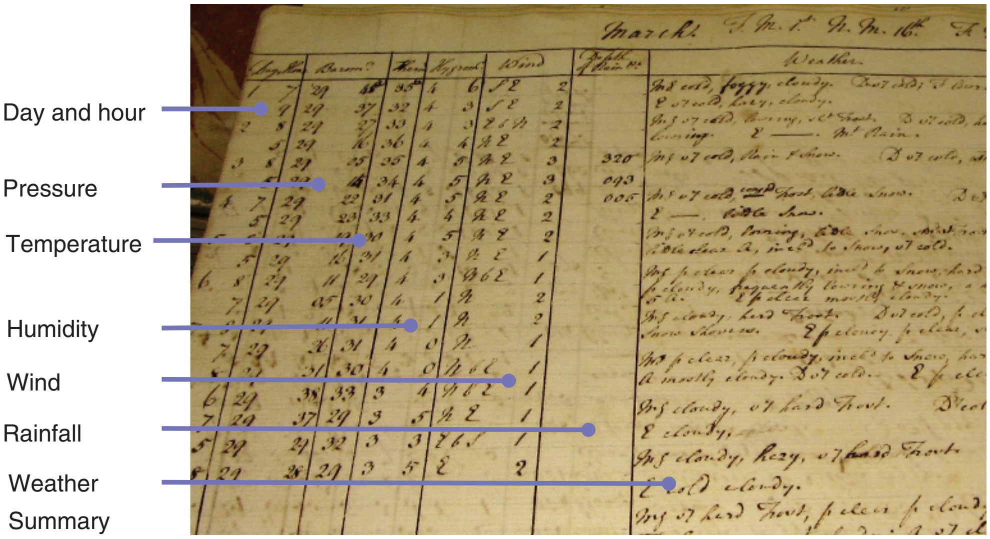

Figure 1.1 Example page from a weather diary (kept by an apothecary and surgeon, Thomas Hughes at Stroud, Gloucestershire, between 1771 and 1813), in which daily measurements of air pressure, temperature, humidity, rainfall and weather were recorded. As well as quantitative weather information, this particular diary includes other geophysical information, such as timings of earthquakes and even occurrence of the aurora borealis, an indirect measure of solar activity [3]. (Reproduced from Reference 3 with permission of The Met Office.)

The Central England measurements form the longest *continuous* set of monthly instrumental atmospheric temperatures available anywhere in the world, beginning in January 1659. (Daily values are also available, beginning in 1772; see Reference 5.) Figure 1.2 shows minimum, maximum and mean annual temperatures of the monthly Central England Temperature (CET) series.

1.3 Clouds and rainfall

In the nineteenth century, classification, quantification and taxonomy became an important aspect of many sciences, particularly in the life sciences and geology, so it was natural for similar approaches to be extended to meteorology. The classification of clouds[vi] was one early aspect, and the compilation of rainfall data also helped further develop the quantitative basis for environmental description. Major developments in meteorology continued in the mid-nineteenth century, following the foundation of the Meteorological Society in 1850, and the establishment of the early Met Office in 1854 under Admiral Fitzroy.[vii] The British Association for the Advancement of Science convened a Rainfall Committee, with G.J. Symons as secretary.

[vi] Luke Howard (1772–1864) established a classification system for clouds in 1802 (see Richard Hamblyn's *The Invention of Clouds*, published by Picador).

[vii] This is thoroughly discussed in *History of the Meteorological Office* by Malcolm Walker, published by Cambridge University Press.

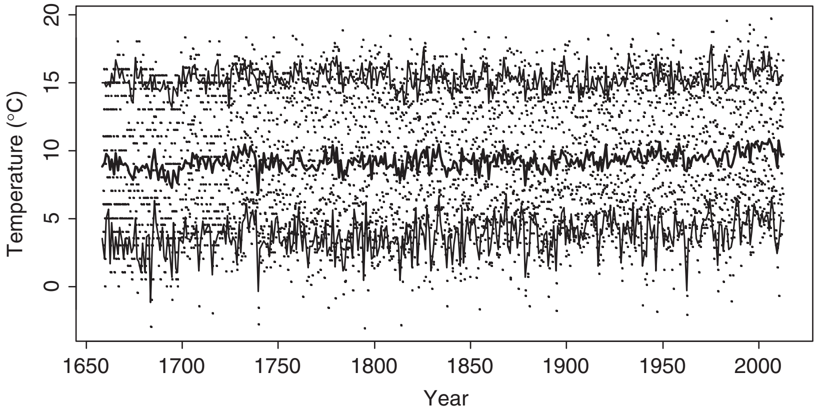

Figure 1.2 Monthly temperatures of ‘Central England’, originally constructed from historical thermometer records by Manley, and continued using updated modern measurements by the Hadley Centre of the UK Met Office [5]. The thick central line shows the annual mean temperature, with the upper and lower lines the mean values for summer (June–July–August) and winter (December–January–February) respectively (the degraded resolution of the early thermometers is also evident). (Reproduced from Reference 5 with permission of The Met Office.)

Compilation of historical rainfall data for the United Kingdom was a herculean undertaking, but, following adverts in many local newspapers leading to thousands of replies, Symons [6] did conclude in 1866 that ‘there are not now very many records in private hands of which copies are not already obtained and classified.’ The legacy of this work is the series of annual volumes of *Symons British Rainfall*. Further, a continuous series of monthly data [7] for England and Wales Precipitation (EWP) exists from 1766 (see figure 1.3).

1.4 Standardisation of air temperature measurements

Standardised exposure for air temperature measurements began in the nineteenth century [8], when meteorological instruments were becoming increasingly available

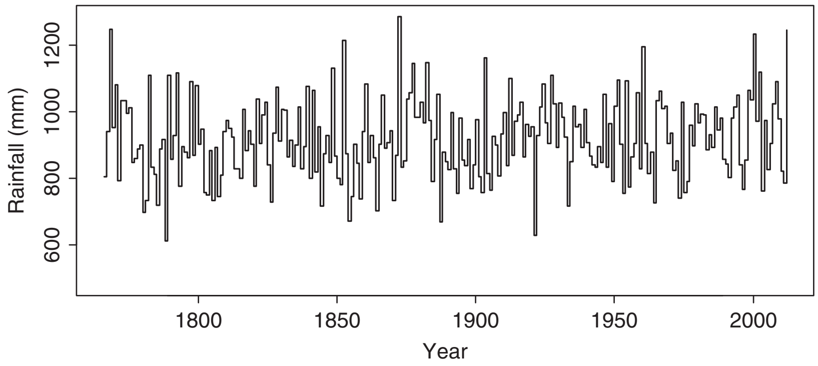

Figure 1.3 Annual rainfall for England and Wales. (Reproduced with permission of The Met Office.)

commercially.[viii] Early (1841) exposure of thermometers for air temperature measurement was through use of a Glaisher stand,[ix] a simple shading board which was rotated manually to prevent direct solar radiation reaching the thermometer [9]. The Glaisher stand's effectiveness depended on the diligence of the observer required to turn the stand after each reading. If the interval between readings became too long, direct sunlight could still reach the thermometer. The practical difficulty in manually turning the shade board yet retaining good ventilation was solved by Thomas Stevenson[x] in 1863, in the form of a double-louvered wooden box painted gloss white. This gave protection to thermometers from solar radiation in all directions, and ensured long wave radiation exchange was with the interior of the screen. The use of a double-louver increased the length of the air path through the screen, which brought the interior of the screen material closer to air temperature than alternatives of simple slits or mesh. In its original form, the Stevenson screen was a wooden box 15 inches high, 14.5 inches long and 7.5 inches wide. It had a solid roof with integral ventilator, and the thermometers were mounted horizontally 4 feet above the ground.

Many minor variants on the Stevenson screen were made. The Scottish physicist John Aitken investigated screen properties [10], noting much later [11] that nothing had been done to mitigate the effects of thermal inertia of Stevenson screens. Assessments of the Stevenson screen and the Glaisher stand were undertaken between 1868 and 1926 at a variety of locations [12] including a sustained 40 years of comparison at Camden Square [13]. The Glaisher stand thermometer was shown to read warmer in the summer months, by a maximum of 3.3°C. Many refinements were made to the Stevenson style screens from the original design, including a double roof and staggered boards across the base to exclude reflected radiation [14, 15], but it has remained largely unchanged since 1884. It was recommended for use by the Meteorological Society in 1873. (Properties of Stevenson screens are discussed in Chapter 5.)

1.5 Upper air measurements

The very first upper air measurements provided fundamental information on the atmosphere's structure. Kites were used for early soundings, such as for carrying thermometers aloft in 1749, and famously employed by Benjamin Franklin for thunderstorm studies in 1752. Manned ascents began with the hot air balloon of Montgolfier (1783), but lighter than air balloons provided suitable measurement platforms to obtain the atmospheric temperature profile to altitudes of several kilometres, notably by Gay-Lussac (1804). Instrumented balloons were later developed as an alternative exploratory tool, with which fundamental discoveries of atmospheric structure were made. For example, after over 200 instrument ascents by day and night, Leon Teisserenc de Bort in 1902 reported a temperature discontinuity at about 11 km, dividing the atmosphere into layers, identifying the troposphere and stratosphere.

[viii] For a survey of nineteenth century instruments, see: *A Treatise on Meteorological Instruments*, Negretti and Zambra, London, 1864, or Middleton's History of the Meteorological Instruments (Johns Hopkins press, 1969).

[ix] The Glaisher stand was originally designed by Sir George Airy (1801–1892), Astronomer Royal, for use at Greenwich Observatory.

[x] Thomas Stevenson (1818–87) was a civil engineer known for the design of many Scottish lighthouses, and father of the writer Robert Louis Stevenson.

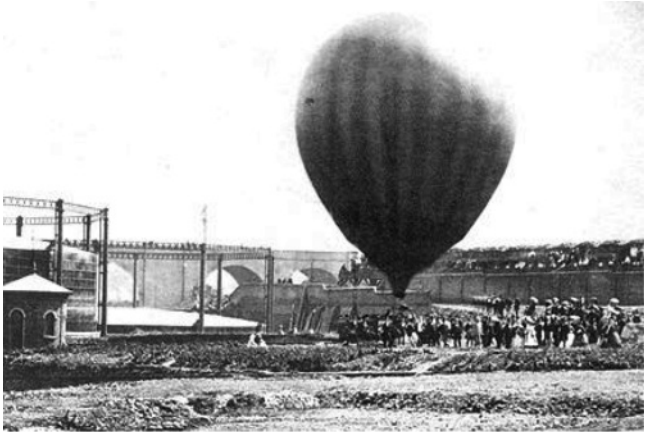

Figure 1.4 The launch of the balloon *Mammoth*, carrying Coxwell and Glaisher, from Stafford Road gasworks, Wolverhampton, probably on 18 August 1862. (Reproduced with permission of John Wiley & Sons.)

1.5.1 Manned balloon ascents

At their earliest stage, manned ascents were voyages of discovery not without risk, indeed presenting mortal danger to those involved. Only a few scientific ascents [16] were made in the early years of the nineteenth century, but a surge of research flights occurred in the United Kingdom from about 1850, including a famous ascent of James Glaisher[xi] and Henry Coxwell from Wolverhampton. This particular flight probably reached about 7 km, although the aeronauts became unconscious and were unable to read their barometer. They were lucky to survive. There are good records of some of these balloon ascents (see Figure 1.4) and accounts of these flights provide not only quantitative information about the atmospheric conditions above the surface, but also insights into the difficulties faced by the aeronauts:

> *The weather on the day (Aug. 18, 1862) of the third ascent was favourable, and there was but little wind. All the instruments were fixed before leaving the earth. A height of more than 4 miles was attained, and the balloon remained in the air about two hours. When at its highest point there were no clouds between the balloon and the earth, and the streets of Birmingham were distinctly visible. The descent was effected at Solihull, 7 miles from Birmingham. On the earth the temperature of the air was 67.8°F, and that of the dew-point 54.6°F; and they steadily decreased to 39.5°F and 22.2°F respectively at 11,500 feet. The balloon was then made to descend to the height of about 3000 feet, when both increased to 56.0°F and 47.5°F respectively. On throwing out ballast the balloon rose again, and the temperature declined pretty steadily to 24.0°F, and that of the dew-point to −10.0°F at the height of 23,000 feet. During this ascent Mr Glaisher's hands became quite blue, and he experienced a qualmish sensation in the brain and stomach, resembling the approach of sea-sickness; but no further inconvenience, besides such as resulted from the cold and the difficulty of breathing, was experienced. This feeling of sickness never occurred again to Mr Glaisher in any subsequent ascent. (Encyclopaedia Britannica, 1902)*

[xi] James Glaisher (1809–1903) was a scientific assistant (and later Superintendent) at Greenwich Observatory, and one of the founders of the Meteorological Society in 1850 (subsequently the Royal Meteorological Society).

Table 1.1 Some significant early scientific balloon ascents in Europe (modified from Reference 17)

Investigator	Launch details	Height (m)	Met data		Other measured quantities or remarks
			Temperature	Humidity	
Robertson and Lhoest	1803 (18 July) Hamburg	7000			Atmospheric electricity
Gay-Lussac and Biot	1804 (24 August; 16 September), Paris	7015	√		Geomagnetism
Barral and Bixio	1850 (29 June; 27 July)	7050	√		
Coxwell and Glaisher	1862 (18 August), Wolverhampton	6900	√	√	
Tuma	1892, 1894 (22 September); 7 flights 1894 to 1898, Salzburg	3000	√	√	Atmospheric electricity
Le Cadet	1893 (1 and 9 August), Meudon-Valhermay, Paris	2520			Atmospheric electricity
Börnstein	1893, Berlin				Atmospheric electricity
Hess	1912 (7 August), Aussig	5350			Discovery of cosmic rays

Some early balloon explorations in the nineteenth century are summarised in Table 1.1, which show a steady increase in use of this measuring platform into the early twentieth century.

1.5.2 *Self-reporting upper air instruments*

Kite-carried instruments continued to be used for research at the end of the nineteenth century and into the early twentieth century, such as by Napier Shaw and W.H. Dines [18]. These carried early recording instruments, or *meteorographs*, which were highly technically innovative. In special configurations and at suitable sites, kite systems could reach up to 7 km [19]. The meteorograph developed by Dines recorded data mechanically by making indelible marks on a metal plate, plotting temperature and humidity against pressure. Later devices employing a rotating drum for recording data were carried on aircraft in the 1920s [20], around which time the use of kites for 'scientific aeronautics' largely ceased (see also Section 8.5), as aircraft platforms became more available. The use of related mechanical recording devices for atmospheric measurements on aircraft was pioneered by G.M.B. Dobson,[xii] and first implemented on military flights from Upavon in Wiltshire during 1916 [21].

The development of small shortwave radio transmitters permitted the information obtained to be sent instantaneously to a distant observer by radio telemetry, leading to the *radiometeograph*. Demonstration of this technology in the late 1920s

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[xii] Gordon Miller Bourne Dobson (1889–1976) was an atmospheric and experimental physicist who became a professor at Oxford in 1945, and after whom a unit of ozone amount is named.

was led by P. Idrac and R. Bureau [22, 23], who showed short wave radio transmitters and a pulse-based method could signal measured temperature and pressure values, although the first radiosonde providing data to a meteorological service was launched by P. Molchanov from Pavlovsk on January 30 1930. Improvements in radio systems, data transfer and batteries led to commercial designs of radiosonde becoming available from about 1936 [24] (see also Section 11.1.)

1.6 Scope and structure

This book is intended to provide background and introductory material on instrumentation science as applied and required for meteorological measurements. It is not, however, in any sense a guide to observing practices or conventions, which are considered more thoroughly elsewhere.[xiii] Rather it considers aspects of instrument and measurement theory (Chapter 2), the electronics required for signal conditioning (Chapter 3) and digital data acquisition and logging (Chapter 4). A range of common instruments and sensors are explored (Chapters 5–10). In Chapter 11, the preceding material is drawn on to describe the combination of sensors, signal processing and data transfer required for radiosonde measurements, and Chapter 12 gives examples of some of the processing techniques used for analysing environmental data. The two brief appendices provide further information, and, in Appendix A, a summary of how a paper on new developments in instrumentation can be written is given.

[xiii] See, for example, *The Weather Observer's Handbook* by Stephen Burt (Cambridge University Press).