# 1 Why measure the weather?

Of all the physical sciences, meteorology depends more than any other on frequent, accurate and worldwide measurements. Every day, millions of weather measurements are made by thousands of people across the globe, on land, over the oceans, in the upper air and from space, providing the raw data essential to supercomputer-based weather forecasting models that are vital to modern economies. Meteorology (and its statistical cousin, climatology) is one of the few sciences where both amateurs and professionals make significant contributions.

'Measuring the weather' is undertaken for many different reasons: as well as input to weather and climate forecasts, it is a vital part of aviation safety, critical in detecting and quantifying climate change, keeping tabs on typhoons and hurricanes, monitoring the ebb and flow of pollutants and arctic ice, and hundreds of other applications of enormous benefit to society. Weather records are made in every country and region in the world – from the hottest deserts to the coldest polar regions, from densely populated city centres to the most remote mountaintops. There is even a permanent automatic weather station at 8,000 metres above sea level just below the summit of Mt Everest (**Figure 1.1**), whose observations are updated to the Internet hourly.

For many, professionals and amateurs alike, measuring the weather is also an absorbing long-term interest, guaranteed to deliver something different every day of every year. Well-kept records by individuals and organizations alike assist in the scientific analysis of all types of weather phenomena, and can become a permanent part of a nation's weather record.

## About this book

This book has been written with four main audiences in mind:

- Weather enthusiasts and amateur meteorologists
- Professional users, including local authorities and other statutory bodies
- Schools, colleges and universities
- Weather-dependent outdoor activity professions and organizations.

The aim of this book is to provide useful and practical guidance on most aspects of weather observing, with emphasis on observations using instruments. Particular attention is paid to the selection and use of modern electronic instruments and 'automatic weather stations' (AWSs), while not forgetting the long and interesting history of 'traditional' instruments.

Figure 1.1. Installing the world's highest weather station at 8000 m above sea level on the south col of Mt Everest, May 2011. The summit is 8850 m. Observations are updated hourly on the web – http://share-everest.it/SHAREEverest2011MeteoData/SouthCol/sensorSouthCol.html (Photograph courtesy of the Ev-K2-CNR Committee archive)

## Weather enthusiasts and amateur meteorologists

For individuals who are new to the fascinating science of measuring the weather, this book is intended to help guide your choice of what may be your first item or items of weather-measuring equipment. It explains the important things to look out for, what can be measured within particular budgets, how best to site your instruments, and how to start collecting and sharing data. Whether your site and equipment is basic and sheltered, or extensive and well exposed, this book provides help to improve the quality and comparability of your observations to attain, or even surpass, the standards established by the World Meteorological Organization (WMO).

For those who already have experience of weather observing and who perhaps are looking to add an AWS to complement their existing 'traditional' instrumentation, or who already own a basic AWS and are looking to upgrade to a more capable system, this book provides assistance and suggestions on choosing and siting appropriate equipment. It is also a practical day-to-day observing reference handbook to help get the most out of your instruments and your interest.

### Professional users

There are many ‘professional’ users who need reliable and accurate weather information, for one or more sites, whose needs can be served by a properly sited AWS. Typical users include local or state authorities managing road maintenance (including winter gritting or snow clearance), landfill management, environmental monitoring as part of civil engineering projects, and airport weather systems. For professional users requiring environmental records, perhaps as part of new statutory requirements, this handbook provides independent guidance on choice of systems, siting of sensors, and suggestions on data collection and handling processes. The information gathered needs to be both manageable and relevant, while meeting the appropriate standards of measurement and exposure. It also includes advice on how to document the site and instruments in use (and any changes over time), to minimize possible future downstream technical or legal challenges relating to the data obtained.

### Schools, colleges and universities

The installation of automated weather-monitoring equipment offers the chance to include weather observations at all levels within the educational curriculum, from early schooldays to post-doctoral levels. Weather measurements are often made more relevant and interesting to the student by virtue of the readings being made at the school or college site, particularly where both real-time and long-term archived records are available for study purposes. From junior school to university, the observations can be used immediately (especially so in an interesting spell of weather, such as a heatwave or flood event) or in a variety of curricular activities such as numeracy, IT, telecommunications, severe weather awareness training and alarms, office software packages (particularly spreadsheets), statistics and website design, in addition to conventional geography, science and mathematics courses [1]. This book provides assistance on choosing and siting suitable systems and making best use of the data collected.

Many of those who have gone on to study meteorology further and who become professional meteorologists picked up the ‘weather observing’ bug at school (including the author). The importance of encouraging curious young minds to observe and take an active and enquiring interest in their physical environment, and its changes on a day-to-day basis, cannot be underestimated.

### Weather-dependent outdoor activity professions and organizations

Many organizations or clubs need site-specific weather information; for example, yacht clubs, gliding clubs, private aviation airfields, as well as windsurfers and microlight pilots. In some cases, particularly microlight and gliding clubs, members may live a considerable distance from the main club operations and value the opportunity to be able to view live weather conditions at the site on a club website before making a decision whether to travel to the club that day. Farmers and other professions largely at the mercy of the weather also need accurate and timely weather information, perhaps from more than one site within a local area. Many such organizations or businesses may not have previously considered their own weather station or monitoring network as being affordable. Today, respectable quality weather data in real time is available from inexpensive, easily maintained and robust systems. Modern electronic weather stations connected to the Internet can provide local or distant-reading output facilities quickly, cheaply and reliably; this book outlines what is available and where to site the instruments for best results.

## Topics covered

Current 'traditional' weather instruments – largely non-digital – and their development are also covered in this handbook. They still have a very important part to play, not just in providing continuity with existing and historical records, but because they are likely to remain the reference or benchmark system for at least the next decade or two. For those seeking to automate an existing manual climatological station, suggestions are provided on how to minimize the discontinuity of record that often occurs when new observing systems are brought into use, although in all cases the network administrator (such as NOAA in the United States or the Met Office in the United Kingdom) should also be consulted at the earliest opportunity.

This book covers a wide range of weather station systems, sensors and associated technology, from $100 (U.S.) to upwards of $1,500 (at 2012 pricing). It does not cover homemade instruments or remote-reading sensors without any means of logging (such as wireless temperature and humidity displays), nor does it cover in detail professional systems costing many thousands of dollars (for which more specific pre-sales advice should be sought from the manufacturer). It covers land- and surface-based systems only. Sensors and logging equipment for aircraft or buoys have very different characteristics and are not covered in this book.

### Geographical coverage

This book covers equipment, standards and measurement methods as set out by the World Meteorological Organization (WMO), based in Geneva, Switzerland [2]. The details of some measurements and methods differ slightly from country to country, and where applicable this book provides specifics relevant particularly within the United States, the United Kingdom and the Republic of Ireland. The majority of the book is also relevant outside these geographies, but readers in other regions should check the availability of products and the detail of country-specific equipment, specifications and siting recommendations with their national meteorological service prior to implementation [3].

**Abbreviations, references, footnotes and further reading**

Abbreviations and technical terms are kept to a minimum: where used, they are defined at first use and indexed. The most frequently used abbreviations are listed at the front of the book for easy reference. References and suggestions for further reading are included for readers who may wish to delve further into these topics. Specific references are indicated within the text by a number within square brackets, thus [9]. References and further reading are listed in numerical order at the end of each chapter. Footnotes are indicated by symbols thus * † with the appropriate text appearing at the foot of the page on which the footnote appears.

A number of sample and template spreadsheets are available online at www.cambridge.org/9781107662285 and at www.measuringtheweather.com. These are referenced at the appropriate point in the text and are available for free download. They can then be customized to your specific requirements.

**Units**

Meteorology is necessarily an international science and consistent units are required for information exchange and understanding. In this book WMO recommendations for units are used in preference, with bracketed alternatives where necessary; for instance, wind speeds can be expressed in metres per second (m/s), knots (kn) or miles per hour (mph), depending upon the requirement. Conversions between the different units involved are given in **Appendix 3**.

## Automatic weather stations

In this book an automatic weather station (AWS) is defined as any system which creates and archives a digital (computer-readable) record of one or more weather 'elements', such as air temperature, precipitation, sunshine, wind speed or other parameters.

In its simplest form, an AWS can be a single sensor integrated with a small, inexpensive electronic data recorder (a 'datalogger' or simply 'logger'). Loggers that can record only one input signal, or 'channel', are therefore 'single-channel loggers'; those that can handle two or more are 'multi-channel'. Most such systems can be left exposed as a whole unit including the logger, perhaps for several months in a remote location, before the recorded data are retrieved. The most advanced AWSs (**Figure 1.2**) are completely automated remote multi-element single-site observing systems, requiring only the minimum of human attention and maintenance, self-powered by a solar cell array or wind turbine and communicating observations at regular intervals over a telecommunications system to a collecting centre. Telecommunications may be direct to satellite in the most remote areas.

Most of the world's meteorological services are moving towards such devices as replacements for costly human observers. But even with today's most sophisticated technology and sensors, human observers are still required for many weather observing tasks; for example, AWSs are still very poor at telling the difference between rain and wet snow, nor can they report shallow fog just starting to form across the low-lying parts of an airfield or see distant lightning flashes on the horizon which warn of an approaching thunderstorm. Human weather observers will continue to be required for a long while to come!

## The makers of the observations

Fascination with the changes in day-to-day weather is nothing new, although weather records were by necessity purely descriptive until the invention of meteorological instruments in the 17th century [4]. Probably the oldest known weather diary in the Western world is that of Englishman William Merle, who kept notes on the weather in Oxford and in north Lincolnshire from 1337 to 1344 [5]. In North America, the earliest surviving systematic weather records are those made by John Campanius Holm, a Lutheran minister originally from Sweden, who made observations at Fort

Figure 1.2. The U.S. National Weather Service Automated Surface Observing System (ASOS) sensor package located at Pocatello, Idaho (42° 55’ N, 112° 34’ W, 1356 m above MSL, WMO station no. 72578), October 2011. From left to right, the instruments shown are – heated tipping-bucket raingauge within wind shield: aspirated temperature and humidity sensors: present weather sensor: 10 m wind mast with heated ultrasonic wind sensor: data collection panel (big box): laser ceilometers: freezing precipitation sensor (little tilted box), and finally the visibility sensor. (Photograph by Gary Wicklund)

Christina in New Sweden (near present-day Wilmington, Delaware) in 1644–5. (Today, the annual National Oceanic and Atmospheric Administration NOAA John Campanius Holm Award is given for outstanding accomplishments in the field of cooperative meteorological observations.)

During the Renaissance, the invention of instruments to measure the temperature and pressure of the atmosphere, and later other elements, made it possible to track the changes in weather conditions more accurately, and more consistently, between different observers and locations. Galileo invented the air thermoscope around 1600; Santorio added a scale to make it a thermometer in 1612. The first liquid-in-glass thermometer (in a form we would recognize today) was invented by Ferdinand II, the Grand Duke of Tuscany, in 1646, while Evangelista Torricelli invented the mercury barometer in 1644.

Surprisingly perhaps, what we would now call multi-element automatic weather stations began to appear very early in the history of weather instruments. Sir Christopher Wren (1632–1723) is best known today as the architect of London’s St Paul’s Cathedral, but in his early career he was a noted astronomer [6], a founding member of the Royal Society in London [7] in 1660, and a prolific instrument designer. Together with Robert Hooke (1635–1703) he designed and built many weather instruments, including Hooke's sophisticated mechanical 'weather clock' in the 1670s [8] (see Box, *Wren and Hooke: a fertile partnership*). The earliest surviving rainfall records in the British Isles were made by Richard Towneley at Towneley Hall near Burnley, Lancashire, in northern England from January 1677 [9]; the raingauge used was based upon Wren's design. It was Wren who first described the tipping-bucket form of raingauge, modern varieties of which are still in use at tens of thousands of locations across the globe today (see Chapter 6).

**Wren and Hooke: a fertile partnership**

Wren's long friendship and professional collaboration with Robert Hooke spawned many designs for instruments to 'measure the weather'. Wren is acknowledged as the inventor – around 1662/3 [10] – of the tipping-bucket mechanism for measuring rainfall, the principle of which is still used in today's instruments. Hooke was a polymath with a superb ability for translating ideas into practical working devices [11], and he built many weather instruments, as the following extract from the Royal Society Journal Book (JBO/6), dated 5 December 1678, shows:

"Mr Hook[e] produced a part of his new weather Clock which he had been preparing which was to keep an Account of all the Changes of weather which should happen, namely the Quarters and points in which the wind should blow 2ly the strength of the Wind in that Quarter. 3ly The heat and cold of the Air. 4ly The Gravity and Levity of the Air. 5ly the Dryness and moisture of the Air. 6ly The Quantity of Rain that should fall. 7ly The Quantity of Snow or Hail that shall fall in the winter. 8ly the times of the shining of the Sun. This he was desired to proceed with all to finish he hoped to doe within a month or six weeks."

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As materials and methods evolved, meteorological instruments became more practical, robust, reliable and cheaper, and thus were used more widely, carried to the New World on the ships of the European superpowers of the day. The once-ubiquitous Six's maximum-minimum thermometer was invented by James Six in 1782, and although they ceased to be used for accurate climate recording more than 100 years ago, these instruments can still be found today in many a gardener's greenhouse (**Figure 1.3**). In the early 19th century one of the first amateur meteorologists, apothecary Luke Howard of London, more popularly known as 'the inventor of clouds', [12] owned a magnificent – and very expensive – 'clock-barometer', or mercury barograph [13]. Records from this instrument survive today; a very similar instrument, made for Great Britain's George III in 1763–5 by Alexander Cumming (c. 1732–1814), remains in the Royal Collection [14].

Weather instruments benefited from the enormous technological and manufacturing advances made between the late 18th and late 19th centuries. Many of today's instruments date from this period (see timescale in **Figure 1.4**) [15] including the Stevenson screen (see Box, *The lighthouse Stevensons*). A meteorological observer from the late 19th century would today have little difficulty in making a weather observation at many of today's standard climatological stations in North America or in the United Kingdom and Ireland. Many of these instruments are being rapidly

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More Information



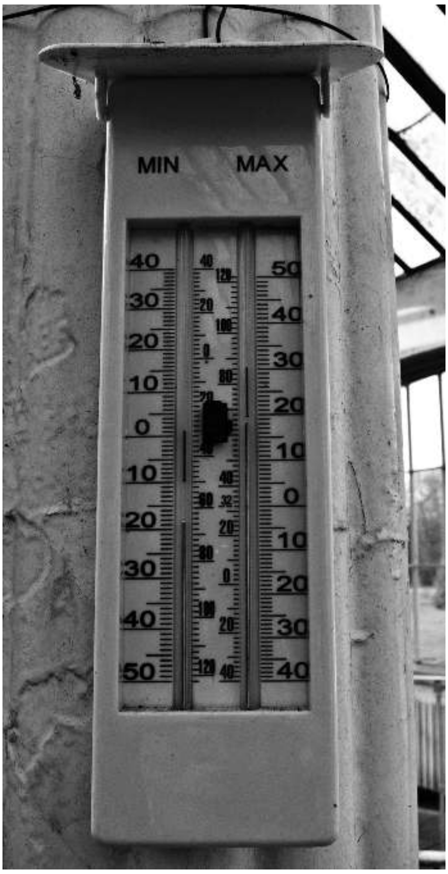


Figure 1.3. A Six's maximum-minimum thermometer; this in the Temperate House at Kew Gardens in west London. (Photograph by the author)

superseded by newer electronic equipment, the subject of later chapters, and our Victorian-era observer will have much greater difficulty in making sense of the instruments in a few years time.

Recording meteorological instruments continued to be developed and improved during the 18th and 19th centuries, but while many ingenious designs were invented, almost all relied upon mechanical components and thus were, to a greater or lesser degree, subject to friction, often hugely expensive (many were made to order or in very small numbers), and difficult to maintain in good working order when exposed to the elements. For these reasons few were made – and even fewer have survived, even in museums.

**The lighthouse Stevensons**

Thomas Stevenson (1818–87) was a marine engineer; a member of the famous Stevenson engineering dynasty which built most of Scotland's lighthouses [16]; and the father of Robert Louis Stevenson (1850–94), author of *Treasure Island* (1881), *Kidnapped* (1886) and *The Strange Case of Dr Jekyll and Mr Hyde* (1886).

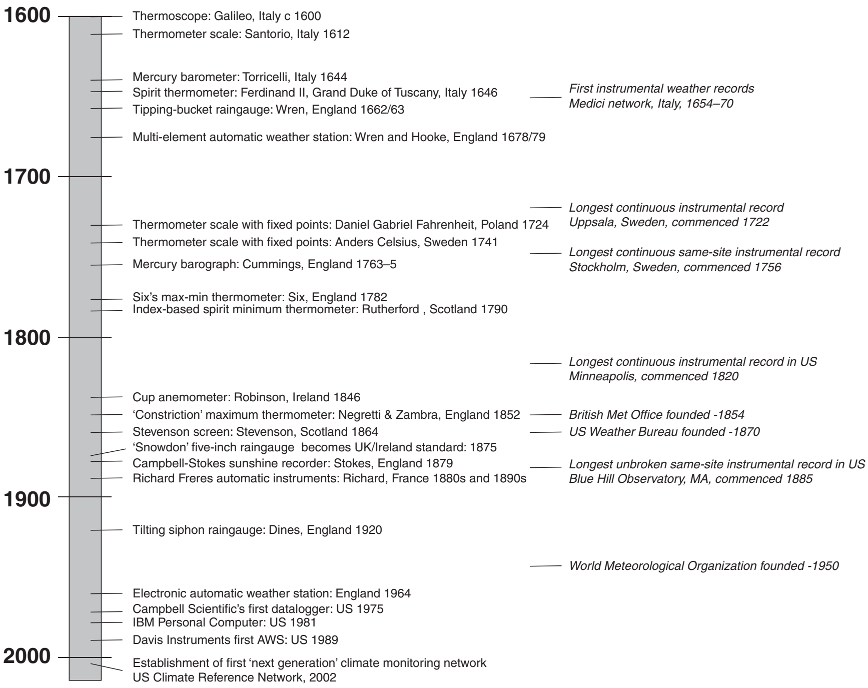


Figure 1.4. Four hundred year timeline showing key dates in the development of meteorological instruments and weather recording. For sources see references in the text.

In a brief note in the *Journal of the Scottish Meteorological Society* in 1866 [17] he described the form of thermometer shelter which still bears his name – a white-painted double-louvred box which protected the thermometers inside from rainfall, sunshine and infrared radiation from Earth and sky. At the time there were dozens of proposed designs for thermometer screens, some of which had been in use for a decade or more [4]. It was only a series of painstaking trials undertaken by the Reverend Charles Griffith at Strathfield Turgiss rectory in Hampshire, England, in the late 1860s and early 1870s comparing air temperatures measured in Stevenson's screen with other models (**Figure 1.5a**), that eventually led to its adoption (with minor amendments to the original design) as the preferred method for taking air temperature measurements by the Royal Meteorological Society in 1884 [18]. The de facto British standard spread rapidly to the rest of Britain's empire and then to the rest of the world (**Figure 1.5b**) as the enclosure was simple, easy to make locally, robust and gave good protection from the tropics to the poles. The basic principles – a white, louvred, roofed enclosure – remain common to many thousands of thermometer screens in daily use throughout the world today (**Figure 1.6**).

The end of the 19th century saw the advent of relatively inexpensive, mass-produced single-element mechanical recording instruments using clock-driven paper charts, such as the barograph and thermograph (**Figure 1.7**), and later various

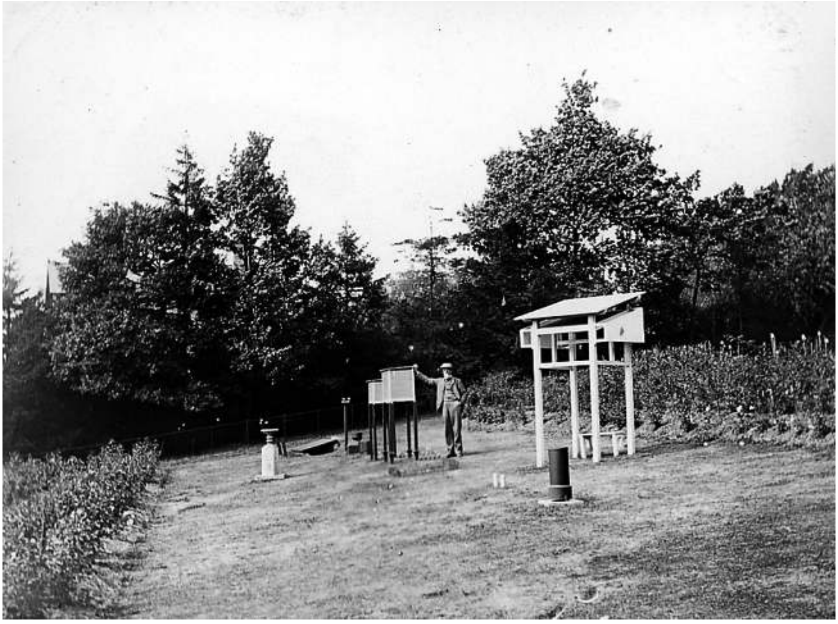


Figure 1.5. Early models of thermometer screen.

(a) This photograph was taken at Berkhamsted, Hertfordshire, England, on 29 July 1896, and shows two Stevenson screens (centre of picture) adjacent to a much larger modified Glaisher stand (an earlier and more open pattern of thermometer screen). The observer is Edward Mawley. (© Royal Meteorological Society)

(b) Cotton Region Shelter (see Chapter 5) and young observer at U.S. Weather Bureau observing site at Granger, Utah, c. 1930. (Courtesy NOAA/Department of Commerce National Weather Service Collection wea00903)