PART I

THE BASICS

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978-1-009-26054-1 — The Weather Observer's Handbook
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Excerpt
More Information

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 people and automated sensors across the globe, on land, over the oceans, in the upper reaches of the atmosphere 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.

Society 'measures the weather' 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 the community. Accurate surface measurements provide essential 'ground truth' to the broad-brush data sweeps of remote sensing capabilities such as satellite and radar. Weather records are made in every country and region in the world – from the hottest deserts to the coldest ice sheets in Antarctica, from densely populated city centres to the most remote mountaintops. The latter category includes a network of six automatic weather stations (AWS) on Mt Everest (**Figure 1.1**), from Phortse at 3810 m (about 640 hPa) and Base Camp at 5315 m (about 530 hPa), to the highest weather station on Earth at Everest's Bishop Rock, 8810 m above mean sea level (about 340 hPa), just below the summit at 8849 m [1,2,3].

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. Records kept by individuals and organisations 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:

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

Figure 1.1 Installing one of the world's highest weather stations, the 'Balcony Station' at 8430 m above sea level on the south col of Mt Everest, just below the summit at 8849 m. (Photograph courtesy of the Ev-K2-CNR Committee archive)

The aim of this book is to provide **useful, independent and practical guidance** on most aspects of weather observing, with emphasis on instrumental observations. Throughout, the information and standards set out in this volume are based upon the authority and guidance of the Geneva-based World Meteorological Organization's (WMO) latest *Guide to Meteorological Instruments and Methods of Observation* publication, otherwise known as the WMO CIMO guide (CIMO being the Commission for Instruments and Methods of Observation) [4]. By necessity in its role as a global reference and being written for a professional, specialised audience, the CIMO guide is very detailed and often highly technical. In contrast, this book is intended as the 'everyday CIMO guide', with content sufficiently detailed for most purposes, but where individual topics can be referenced quickly and easily back to WMO standards and guidelines as necessary. The focus of this new edition is primarily on the selection and use of modern electronic instruments and automatic weather stations (AWS), although sections on the history and use of 'traditional' instruments within the twenty-first-century context have been retained where appropriate.

Professional users

There are many 'professional' users who need reliable and accurate weather information, whether at a single site or from multiple locations, whose needs can be served by one or more properly sited AWS. Typical users include local or state authorities managing road maintenance (including winter gritting or snow clearance), landfill management, airport or airfield weather systems, environmental monitoring as part of civil engineering projects, outdoor field study centres and many more. 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 both the appropriate standards of measurement and exposure and budget restrictions. It also includes advice on how to document the site and instruments in use (and any changes over time), to minimise possible future downstream technical or legal challenges relating to the records made.

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 set out by the World Meteorological Organization.

For those who already have experience of weather observing and who already own a basic AWS and are looking to add additional sensors or upgrade to a more capable system, or those who are considering upgrading an AWS to complement or replace existing 'traditional' instrumentation (particularly 'legacy' mercury thermometers and barometers), 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.

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 archived records can be made easily available. From elementary 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, climate change as considered within the school curriculum, severe weather awareness training and alarms, office software packages (particularly spreadsheets), statistics and website design, in addition to conventional science, geography, and mathematics courses. There are dozens of websites giving examples of the installation and use of school weather stations: this book provides independent 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 became 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 on a day-to-day basis, and the 'bigger picture' of global climate change with its risks and consequences, cannot be underestimated.

Weather-dependent outdoor activity professions and organisations

Many organisations or clubs need site-specific weather information; for example, field study centres, yacht clubs, gliding or parachuting clubs and 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 on 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 organisations or businesses may not have previously considered their own weather station or monitoring network as being cost-effective. 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

Although the main focus of this book is on electronic instruments, current 'traditional' or legacy weather instruments – largely non-digital – and their development are also covered in this handbook. Many of these are being replaced, or indeed have already been, by their digital equivalents. Some still have an important part to play, not least in providing continuity with existing and historical records, but in many countries automated systems now supply the majority of meteorological measurements. This trend has been greatly accelerated by statutory restrictions on the manufacture and sale of mercury-based instruments, such as traditional thermometers and barometers, under UN Environment Programme regulations following the Minamata Convention, signed by 128 countries in 2013 and which came into force in 2020 [5]. Mercury is a powerful toxin, and while (understandably) both legal and WMO advice is to eliminate completely the use of mercury-based instruments, a very few exceptions may be sanctioned at long-period sites where a period of a few years of overlap records are beneficial to assess the consistency and homogeneity of the 'new' instrumentation alongside traditional methods. With such 'replacement' situations becoming more the norm, this book provides suggestions on how best to minimise the discontinuity of record that may happen when such changes are introduced – although in all cases the network administrator (such as NOAA in the United States, the Bureau of Meteorology in Australia 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 (US) to upwards of $2,000 (nominal price guidelines correct at the time of going to press). It does not cover homemade instruments or remote-reading sensors lacking any means of logging (such as wireless temperature and humidity displays), nor does it cover in detail professional systems costing thousands of dollars upwards (for which more specific presales advice should be sought from the manufacturer). It covers land- and surface-based systems only. Sensors and logging equipment for aircraft, drones or buoys have very different characteristics and are outside the scope of this book.

Geographical coverage

As previously stated, this book covers equipment, standards and measurement methods for surface meteorological observations as set out by the World Meteorological Organization (WMO), based in Geneva, Switzerland [4]. 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. Details of, and links to, the world's national weather services are available on the WMO website at https://community.wmo.int/members.

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 towards the end of the book 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]) and are listed in numerical order at the end of the book. 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 referred to within the book are available online at www.measuringtheweather.net. These are referenced to the appropriate point in the text and are available for free download. They can then be customised 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), miles per hour (mph) or kilometres per hour (kph), depending upon the country and requirement. Conversions between different units are given in **Appendix 6**.

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

Figure 1.2 The US National Weather Service Automated Surface Observing System (ASOS) sensor package located at Pocatello, Idaho (42.917°N, 112.567°W, 1356 m above MSL, WMO station no. 72578). From left to right, the instruments shown are – heated tipping-bucket raingauge (TBR) 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. See also www.weather.gov/asos. (Photograph by Gary Wicklund)

'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'), which may simply be a memory chip within a circuit board, device or console. 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 complete package, including the logger within a suitable enclosure, 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 built around a sophisticated (user-)programmable datalogger, 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 via satellite in remote areas.

Most of the world's meteorological services are increasingly adopting such systems to replace costly human observers. But even with today's most sophisticated technology and sensors, human observers are still required for many weather observing tasks; 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 warning 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 mid-seventeenth century [6]. 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 [7, 8]. In North America, the earliest surviving systematic weather records are those made by Rev. John Campanius Holm, a Lutheran minister originally from Sweden, who made observations at Fort Christina in New Sweden (near present-day Wilmington, Delaware) in 1644–45 [9]. (Today, the prestigious 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 recognise 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 automated weather stations began to appear very early in the history of meteorological 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 and mathematician [10,11,12], a founding member of the Royal Society in London in 1660 [13], 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 [14] (see Box, *Wren and Hooke: the first automated weather station, 1678*). 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 [15]; the raingauge used was based upon Wren's 1662/63 design of the tipping-bucket type. Modern varieties of Wren's instrument are used to measure rainfall at hundreds of thousands of locations across the globe today (see Chapter 6*, Measuring precipitation*).

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 [19], and although these instruments ceased to be used for accurate climate recording over 150 years ago, they can still be found today in many a gardener's greenhouse (**Figure 1.3**). In the early nineteenth century one of the first amateur meteorologists, apothecary Luke Howard of London, popularly known as 'the inventor of clouds' [20], owned a magnificent – and very expensive – 'clock-barometer', or mercury barograph [21]. Records from this instrument survive today; a very similar instrument, made for Great Britain's King George III in 1763–65 by Alexander Cumming (c. 1732–1814), remains in the Royal Collection [22].

Wren and Hooke: the first automated weather station, 1678

Christopher 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 [16] – 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 [14, 17, 18], and he built many weather instruments, including what can only have been the first automated weather station, 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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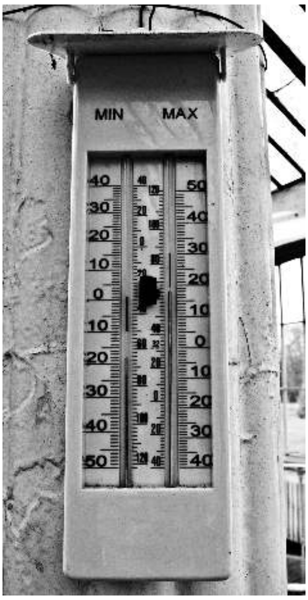

Figure 1.3 A Six's maximum-minimum thermometer; this formerly in the Temperate House at Kew Gardens in west London. (Photograph by the author)

Weather instruments benefited from the enormous technological and manufacturing advances made between the late eighteenth and late nineteenth centuries. Many of today's instruments date from this period (see timescale in **Figure 1.4**) [23] including the Stevenson screen (see Box, *The lighthouse Stevensons*). As late as the first decade of the current century, a meteorological observer from the late nineteenth century would have found little difficulty in making a standard observation in almost any weather station in the world, but as traditional instruments are rapidly superseded by newer electronic equipment, our time-traveller would today find it increasingly difficult even to recognise many instruments.

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.

Recording meteorological instruments continued to be developed and improved during the eighteenth and nineteenth 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. They were also often extremely 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.