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Chapter 1. Measurements at automatic weather stations

1.1 General

## 1.1.1 Definition

An automatic weather station (AWS) is defined as a “meteorological station at which observations are made and transmitted automatically” (WMO, 1992; WMO, 2015).

An AWS is now a standard equipment in a surface meteorological observing station, as the majority of the sensors are connected to an electronic data acquisition system. A surface observing station with an AWS may be fully automatic or part of a mixed system, allowing the addition of visual observations by a human observer. The main functions of an AWS are the conversion of the measurements of meteorological elements into electrical signals through sensors, the processing and the transformation of these signals into meteorological data and the recording and/or the transmission of the resulting information.

Such a combined system of instruments, interfaces and processing and transmission units is usually called an automated weather observing system (AWOS) or automated surface observing system (ASOS). It has become common practice to refer to such a system as an AWS, although it is not a “station” fully in line with the stated definition. Nevertheless, throughout this chapter, an AWS may refer to just such a system. Data loggers are sometimes used as the acquisition equipment of the system and they are considered as a part of an AWS .

## 1.1.2 Purpose

Observing stations without data acquisition system are less and less used. AWSs are used in the majority of the meteorological observing stations and are a key element of the observing system to collect the data measured by the sensors. The mandatory transition from mercury-based sensors to modern alternative will replace human-reading instruments by electronic ones.

Automatic weather stations are also used for increasing the number and reliability of surface observations. They achieve this by:

(a) Allowing an increase of the density in observing networks by providing data from new sites and from sites that are difficult to access and inhospitable;

(b) Supplying, for manned stations, data 24 hours a day;

(c) Increasing the reliability of measurements by using digital measurement techniques;

(d) Ensuring the homogeneity of networks by standardizing the measuring techniques;

(e) Satisfying new observational needs and requirements;

(f) Reducing human errors;

(g) Lowering operational costs by reducing the number of observers;

(h) Measuring and reporting with high frequency and/or continuously;

(I) Compensating for the shortage in the number of observers.

AWS networks decrease (sometimes to zero) the number of observers, but increase the staff needed for the maintenance , inspections, the system and software design and update, the calibration of electronic sensors, etc.

## 1.1.3 Meteorological requirements

The general requirements, types, location and composition, frequency and timing of observations are described in WMO (2015, 2016a).

The performance of today’s electronic is no longer a limitation factor to achieve the accuracy requirements given in Part I, Chapter 1 of the Guide. The measurement uncertainties associated with an AWS are mainly linked to the characteristics of the sensors themselves and their exposure.

The guidance provided in this chapter must be used in conjunction with the chapters on measurements of the various meteorological variables in Part I and, in particular, with the chapters on quality management (Chapter 1), sampling (Chapter 2) and data reduction (Chapter 3) in Part IV.

As for any observation network, the development and installation of AWSs should be the result of a definite, coordinated plan for getting data to users in the format required. To achieve this, negotiations should first be undertaken with the users to draw up a list of all functional requirements for the planned system (RRR process).

The Guide to the Global Observing System (WMO 2013) gives a list of functional specifications for AWS (Appendix III.1, meteorological variables and associated BUFR descriptors to be used), the basic set of variables to be reported by standard AWS for multiple users (Appendix III.2) and AWS metadata (Appendix III.3)

When considering the introduction of new AWS instrument systems, Meteorological Services should:

(a) Introduce into service only those systems that are sufficiently well documented so as to provide adequate knowledge and understanding of their capabilities, characteristics and any algorithms used;[[1]](#footnote-1)

[[2]](#footnote-2)#

(b) Explore fully user requirements and engage users in system design of AWSs;

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(c) Develop detailed guides and documentation on the systems to support all users;

(d) Develop adequate programmes for preventive and corrective maintenance and calibration support of the AWSs and associated sensors;

(e) Consult and cooperate with users, such as aeronautical authorities, throughout the process from AWS design, to implementation, to operational use;

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With respect to the automation of traditional visual observations (present weather, visibility, clouds), Meteorological Services should understand that the observational characteristics of an AWSs’ system are different from the observation capability of a human observer:

- The visibility measurement is representative of the instrument location (unless several visibility meters are installed), while a visual observation may use a 360° field of view, but is limited by the available visual landmarks.

- The cloud cover is usually derived from the measurements of the cloud base height from a ceilometer, combined over a given period of time (10, 30 or 60 minutes), while a human observer has a larger view of the sky, at least during day.

- A present weather sensor is not currently able to identify the full range of present weather codes that a human observer is able to report.

Therefore, the Meteorological Services should improve their definition of requirements with respect to:[[3]](#footnote-3).

(a) Areas of application for which data are no longer required;

(b) Areas of application for which different or new data are needed;

(c) Prioritizing the requirements for data to be provided by AWSs.

[[4]](#footnote-4)

## [[5]](#footnote-5)

Where a proposed automatic station has a role in providing data for climatological records, it is important for the integrity, homogeneity and utility of the climate datasets that the following areas be considered for action[[6]](#footnote-6) :

(a) Ensure overlapping periods of comparable measurements between conventional and new automated instrumentation;

(b) Ensure proper documentation is available on differences between the old and the new site as well as on instrumentation changes (Metadata);[[7]](#footnote-7)

The overlap time[[8]](#footnote-8) is dependent on the different measured variables and on the climate region. In tropical regions and islands, the overlap time could be shorter than in extratropical and mountainous regions. The following general guidelines are suggested for a sufficient operational overlap between existing and new automated systems:

(i) Wind speed and direction: 12 months

(ii) Temperature, humidity, sunshine, evaporation: 24 months

(iii) Precipitation: 60 months

A useful compromise would be an overlap period of 24 months (i.e. two seasonal cycles);

[[9]](#footnote-9)

[[10]](#footnote-10)

[[11]](#footnote-11)

[[12]](#footnote-12)

## 1.1.4 System configuration

An AWS is usually not used as a stand-alone equipment. It is part of a system with three main elements :

(a) The local AWS and the sensors connected to it;

(b) the local modem or interface used to connect the AWS to a telecommunication network;

(c) a central processing system fed by the data transmitted by all the AWS making up the observing network. This central processing system is usually connected to the WIS or to an Automatic Message Switching System linked to the WIS.

Therefore, an AWS cannot be considered independently of this environment (sensors, telecommunication, central system) which influences the role of the AWS, the distribution of the data processing, quality control, etc.

## 1.1.5 Types of automatic weather stations

Automatic weather stations are used to satisfy several needs, ranging from a simple aid-to-the-observer at manned stations to complete replacement of observers at fully automatic stations.

The proceedings of several international conferences on AWS give very valuable information on the state of the art; the implementation of AWS networks; the migration from manual to automated measurements; technical aspects for vommunications and system design; qualitry control and quality assurance ( WMO 2017b).

An off-line AWS, i.e. a station recording data on site without any automatic transmission, is less and less used, because data is not available in real-time and it does not allow a fast detection of possible failure of the equipment. The wide offer of means of telecommunication pushes to recommend the use of real-time AWS, even for climatological data.

Since observing stations can be very expensive, the stations’ facilities can also be used to satisfy the common and specific needs and requirements of several applications, such as synoptic, aeronautical and agricultural meteorology, hydrology and climatology. They may also be used for special purposes, such as nuclear power safety, air and water quality, and road meteorology. Some AWSs are, therefore, multipurpose.

In practice, there exist several categories of AWS, though some equipment are able to cover several of these categories:

* Light AWS for the measurement of precipitation and/or air temperature, as many observing stations may be limited to these 1 or 2 main parameters, both for climatology and real-time use.
* “Basic” AWS for the measurement of “basic” meteorological measurements (typically air temperature, relative humidity, wind, precipitation and sometimes atmospheric pressure).
* “Extended” AWS with the additional measurement of solar radiation, sunshine duration, soil temperatures, evaporation, etc.
* AWS with automation of visual observations: “basic” or “extended” AWS with automatic observation of visibility, cloud base height, present weather. Such stations are commonly named AWOS or ASOS in some countries.

A wide range of low cost AWS including associated sensors can be bought on-the-shelf, mainly used by hobby meteorologists or private companies. More about low-cost AWSs can be found in Annex 1.A. For lowering the price, the sensors are included in the system and no third party sensors are usable. The sensors and the electronics are not designed to be calibrated independently. Therefore the uncertainty of the measurements is greater than that obtained with “professional” equipment, and can hardly be estimated, due to a lack of documentation and no possibility to open the equipment. Such equipment do not yet satisfy the CIMO requirements.

All-in-One AWS are also available, designed by several suppliers of professional meteorological equipment. They include a set of embedded sensors with adapted electronics and software. Price, compactness and ease of installation are the advantages of these all-in-one AWS, usually allowing the measurement of wind (with an ultrasonic sensor), air temperature and relative humidity within an embedded radiation screen, pressure and precipitation (by radar, detection of droplets hits or with a more classical tipping bucket rain gauge at the top of the instrument). The main limitation is the same location for the measurement of wind and other parameters: if exposed at about 2 m, the wind measurement is very sensitive to the surface below; if exposed at 10 m to follow the recommendations concerning the wind measurement, other parameters are also measured at 10 m, which does not comply with the CIMO siting recommendations.

## 1.1.6 Telecommunications

The available means of communications on the sites composing the observing network are a key factor in the design and the specification of an AWS system/network. Many technologies may be considered: Public Switched Telephone Network (PSTN), leased lines, cellular networks, satellite transmissions, optical fibres, access to Internet and use of a Virtual Private Network (VPN) through these supports. The primary technical question before designing an observing network is to identify the available means of telecommunication. It is also important to consider the life cycle of the envisaged telecommunication medium, as rapid changes are possible in terms of coverage, price (generally decreasing), but also in term of sustainability. Therefore, the AWS and network design should allow an easy change of the telecommunication modem or interface, both in terms of physical interface and software.

Information Technology (IT) security has to be considered, especially if Internet is used as an interim media for the transmission of data and system’s dialogue. VPN and other techniques may be used, associated with the framework of Machine to Machine (M2M).

The wide spread of telecommunication media and Internet may allow the application of the concept of IoT (Internet of Things) to individual “intelligent” meteorological sensors, thus eliminating the need for an AWS. This concept is not yet used for meteorological sensors but will be available in the near future. With such connected sensors, the concept of an AWS could partly disappeared on site, all the data acquisition and processing being implemented in the central system.

## 1.1.7 Networking

An AWS usually forms part of a network of meteorological stations, each transmitting processed data to a central network processing system by various data transmission means (see 1.1.6). As the tasks to be executed by this central system are strongly related, and often complementary, to the tasks of the AWSs, the functional and technical requirements of both the central system and the AWSs have to be coordinated.

When planning the installation and operation of a network of AWSs, it is of the utmost importance to consider the various problems associated with maintenance and calibration facilities, their organization and the training and education of technical staff. Network density considerations are beyond the scope of this Guide as they depend on the specific applications. However, the optimum siting and exposure of stations have an important influence on the performance of the stations and must be studied before they are installed.

1.2 system configuration

## 1.2.1 Telecommunication network

1.2.1.1 One-way communication

It is important to identify if the telecommunication media to be used with the AWSs’ network is restricted to a one way (AWS towards the central system) or allows two-ways communications. When limited to one way communication, the AWS cannot know if the data sent have been successfully received. Therefore, it is advisable to format the data messages with control codes allowing the receiver to check the integrity of the message. Correction codes may be also used, to cope with possible few transmission errors. If the volume of the message allows it, it can be a good practice to transmit several times the same observation (in the same message or in consecutive messages) to cope with errors and missed receptions.

1.2.1.2 Two-ways communication

When the telecommunication network allows it, the AWS can receive an acknowledge from the central system for the correct reception of the transmitted messages. This guarantee the transmission of all new data since the last data successfully received by the central system. The quantity of data to transmit can be optimized, without the need of introducing the transmission of redundant data in order to cope with missing messages.

The AWS may also receive commands from the central system, to change its configuration, the transmission intervals, to retransmit old data, etc.

1.2.1.3 Satellite transmission

Many satellite telecommunication systems are available, some of them being able to cover any part of the world.

Aside their main mission of imagery and sounding, nearly all the geostationary meteorological satellites have a Data Collection Service (DCS), a transponder of messages from self-timed Data Collection Platforms (DCP) towards the ground centre for the exploitation of the satellite. A DCP is a one-way transmitter, associated with an antenna oriented towards a geostationary satellite, connected to an AWS. The messages have to be kept short (few hundreds of bytes), because of the low speed transmission of the channel (either 100 bauds for standard, 300, 1200 for high rate, 4800 bauds, depending on the satellite and DCS) and the limited time slot allocated to each station. As the transmission frequency is shared by several DCPs, each DCP must respect its allocated time slot and needs a precise clock, now easily achieved by using a local GPS receiver. An AWS with a DCP typically transmits every hour, at a time slot and a frequency channel allocated by the satellite operator. The majority of the frequency channels are “regional” channels used by each single satellite, but ”international” channels shared by all the geostationary meteorological satellites also exist, to be used by mobile platforms (buoys, ships), which can move seamless from the field of view of one satellite to another one. A major advantage of this Data Collection Service is that DCP channels are available at no cost for meteorological, geophysical and hydrological messages, provided they are also made available through the Global Telecommunication System (GTS) and discoverable in the WMO Information System (WIS). A disadvantage is that a specific transmission terminal (the DCP) is needed, with few manufacturers due to the quite low number of users and that normalized modern telecommunication protocols (IP, FTP, HTTP) are not available at the DCP level.

More and more commercial satellite telecommunication services exist, based either on geostationary telecommunication satellites (such as INMARSAT, THURAYA, VSAT) or on low earth orbit satellites’ constellation (such as ORBCOMM, GLOBALSTAR, IRIDIUM). Aside voice services, the operators offer data transmission services, generally using standard telecommunication protocols (IP based) and allowing M2M services. The needed modem are not specific to meteorological applications, adapted to many data acquisition systems and therefore, available at a quite low price. This allows the design of a system where the AWS and the transmission modem are functionally separated, thus allowing an easy change of the telecommunication modem during the life cycle of the system, to use the services of a new (cheaper) telecommunication operator, for example. Sometimes, the way to use the telecommunication service has to be optimized to minimize the transmission cost, often linked to the quantity of data to be transmitted.

1.2.1.4 Public Switched Telephone Network

A Public Switched Telephone Network is often available in developed countries, in populated area. It may be easily used for data transmission with a modem, allowing two-ways communications with a central system. The connection may use either analogue signals (a modem generates standard modulation frequencies for binary codes) or numeric ones (Integrated Services Digital Network, ISDN). The connection to a central system can be made by several ways:

* A point to point connection, the central system having a modem or a pool of modems on a set of lines. A Remote Access Service may be used, allowing IP based protocols once the connection is established.
* An access of the local AWS to an Internet Service Provider, thus allowing the use of an Internet link to connect to a central system. This eliminates the need for the central system to use a pool of modems. The use of Internet needs to consider security aspects, both on the side of the AWS, but particularly on the side of the central system.

Many countries and telecommunication operators are announcing the end of PSTN (analogic and ISDN). The fixed networks of copper lines should not be abandoned, but will be used for IP based communications, with ADSL connection or other techniques. Nevertheless, ADSL needs to be close enough from a switchboard, so the end of PSTN may reduce the availability of a connection through a fixed lines for isolated locations.

1.2.1.5 Cellular network

Cellular networks are developing more and more, leading to the end of PSTN, often being the primary telecommunication offer in developing countries, the needed infrastructure being much cheaper that a copper base network of fixed lines. There exist several generations of data services, with an increasing flow rate (GPRS, Edge, 3G, 4G, …). Considering the volume of meteorological observational data, a low rate is sufficient and it is better to prefer a better coverage rather than a higher flow rate. Many industrial modems exist, at a low price and now, with a low power consumption, fully compatible with solar panels of a reasonable size. Technical specifications for operation under high and/or low temperature must be considered, since the modems are usually installed in the AWSs cabinet, and therefore subject to local atmospheric conditions.

Standard IP based protocols can be used (TCP, FTP, HTTP, etc.). Operators also propose special services for M2M transmissions, using dedicated VPN for the customer.

1.2.1.6 Remote connection to Internet or VPN

Satellite, PSTN, ISDN, cellular networks can be used for an IP connection to a central system, via Internet or a VPN. Any other Internet connection can also be used, such as optical fibers, WIMAX, TV cable, etc.

1.2.1.7 Others

Leased lines are sometimes used when a permanent connection is needed between the AWS and a dedicated user (for example an aeronautic user, needing one minute data in real time). Nevertheless, the offer of dedicated point to point lines is being replaced (by the operators) by IP based connections, using the available transmission network.

In area not covered by a PSTN or a cellular network, dedicated radio links may be used. But the allocation of a frequency band by the appropriate regulatory authorities may be difficult, due to the competition between radio-frequency bands users.. There exist specific radio bands reserved for data transmission, with a limitation of the power of the radio transmission, thus limiting the distance to few hectometres or kilometres. Such radio transmissions may be interesting to connect a distant sensor to an AWS, for example at an aerodrome.

New technologies of Low Power Wide-Area Network (LPWAN) are emerging. An LPWAN may be used to create a private [wireless sensor network](https://en.wikipedia.org/wiki/Wireless_sensor_network), but may also be a service or infrastructure offered by a third party, allowing the owners of sensors to deploy them in the field without investing in [gateway](https://en.wikipedia.org/wiki/Gateway_(telecommunications)) technology. The volume of data which can be transmitted is limited to few tenths or hundreds of byte, which may be compatible with hourly meteorological observations. The main advantages are a very low power consumption of the transmitters (up to 5 years with a single battery) and a low cost, both in terms of hardware and telecommunication service. Several technologies are competing, such as LoRa and Sigfox.

## 1.2.2 Central processing system

The majority of AWS are connected to a central system, which can be functionally separated in two parts:

* A collecting platform, designed to collect data from the AWS.
* A processing platform, fed in data by one or several collecting platforms. This processing platform is the interface towards the users of the observational data.

The collecting function and the data processing in order to supervise the AWS’ network are typical tasks of a Supervisory Control And Data Acquisition (SCADA) system. SCADA are used in many industrial processes, factories, any location where field devices (sensors) are needed to control and interact with a production process. The problematic of an observing network is not different: field devices (AWS + sensors), communication infrastructure, data collecting and control (of the observing network). Many commercial software used for collecting and monitoring meteorological observations are developed by SCADA editors. And systems developed by hydro-meteorological equipment industry may be specific to their own data acquisition system (AWS) rather than being issued from a multi-purpose SCADA type software, but they have the same functionalities.

1.2.2.1 Collecting platform

A surface observing system is often composed of several AWS networks, covering various needs and often set up during successive periods. Therefore, it is seldom to have a homogeneous set of equipment: different types of AWS, of telecommunication media, of protocols are mixed. Each generation of stations (AWS+modem) is functionally linked to an associated collecting platform. For ease of use, it is possible to consider that each AWS type with a given telecommunication network is associated to a specific collecting platform. In case of multiple ways of telecommunication, a set of collecting platforms may exist. Depending on the software and hardware needed, these collecting platform may be implemented in the same system or separately.

A collecting platform has a connection to the telecommunication network used. When modems have to be used (i.e. for PSTN, ISDN, GSM Data, etc.) a pool of modems is managed. The modems can be physical equipment (one modem = one equipment) or logical equivalents within a physical equipment, such as a Remote Access Server (RAS). When the number of incoming lines is smaller than the number of AWS to be collected, which is generally the case, the system must be designed to share the lines. If the AWS is initiating the connection, it has to follow a ‘telecommunication profile’, including a calling schedule to share the lines with other stations. If the connection is initiated by the collecting platform, the AWSs can be called sequentially by the collecting platform. In any case, the collecting platform should check the operational status of each incoming line, in order to detect problems, such as silent lines, error rate of communications on each line, etc.

More and more, telecommunication networks are used as a gateway to the Local Area Network of the network manager (using Internet or preferably VPN Tunnels through Internet). The advantage in this case is that the collecting platform has no modems to handle, the physical interface to the telecommunication network being managed by the telecommunication operator. Standard IP based protocol can be used, such as FTP transfers, emails, etc.

A collecting platform should monitor the communications with the AWSs’ network, by checking the actual connections compared to the expected ones. Silent AWSs should be identified. Supervision tools should be implemented to offer a global view of the network status (e.g. green dots for AWSs waited and received, red dots for AWSs waited and not received), with detailed information for each station (such as the time stamp of the more recent data received) and each connecting line (if any).

If the telecommunication network allows two-ways communications, the collecting platform is also used to configure the network and individual AWS, in particular in terms of transmission schedule, type of data to be collected, etc.

Security protections should be installed, to avoid unauthorized access to the system. They include use of firewalls, control of the calling IP address or the calling phone number for authentication.

1.2.2.1 Processing platform

Data coming from one or several collecting platforms are sent to a processing platform. The primary function of this platform is obviously to provide the observation data to the end users. But it is also very important to use this platform to support the technical management of a network and to offer a technical supervision of the observing network. Various indicators may be used to help the network manager, such as:

* Percentage of missing values for the whole network, for each station, over a one hour period, over a daily period, …
* Alarms for missing values, for each measured parameter (e.g. air temperature, wind, pressure, …)
* Alarms for doubtful or erroneous values after application of quality control checks
* Voltage of each AWS’s battery and alarms if voltage is too low (the voltage measurement may be not significant when the battery is in charge, e.g. by a solar panel; night measurements or minimum daily value have to be used)
* Presence or absence of the main power (if present in the installation), in order to detect a failure such as the release of a circuit breaker, which could be hidden by a buffering battery.
* When smart sensors are used, they often deliver service parameters, in addition to the desired meteorological variables. These service parameters are useful to detect or anticipate problems with the sensor (such as cleaning needed) and should generate alarms for the maintenance manager.

The typical operational functions of the processing platform are:

* The quality control of the “raw” data. The quality control algorithms may be partly split between the AWS itself and the central system.
* The calculation of meteorological parameters from individual measurements, e.g. the calculation of the dew point from the measured air temperature and the relative humidity. Again, this calculation may be shared between the AWS and the central system.
* When the data processing can be implemented either at the AWS’s level or at the central server’s level, it is recommended to choose a central implementation, where software development and updates are easier to implement. Nevertheless, some data processing by the AWS itself may be needed in case of a local use of the observation (e.g. a local observer or an aerodrome), unless the telecommunication network used is considered compatible and safe enough with a downloading of the local observation, from the central system to the tower control. A local aeronautic usage is a special case which may need local data processing in order to supply the Air Traffic Control with local observation data, through aeronautical local reports.
* The coding of standard messages to feed an Automatic Message Switching System (AMSS), usually the source of data for the meteorological service. Standard messages in a format needed for the distribution on the GTS may also be formatted in the AMSS, if not directly formatted in the central processing platform. For surface observation, alphanumeric messages (SYNOP) are now replaced by self-described codes (Table-Driven Code Forms, TDCF). BUFR templates have been designed for surface observation (WMO 2016b).

## 1.2.3 Sensors

All modern sensors are suited to be used with an AWS. Sensors are described in part I of this guide. Some constraints for their use with an AWS are listed below:

* They have to be robust and with minimal maintenance and cleaning required, as many sites have no local maintenance staff.
* They should be easily interchangeable, with little or no change needed in the AWS configuration and calibration.
* Their connection to an AWS shall be fully documented, in terms of cabling, power supply (range, power consumption with and without heating, warming up time if the power supply is switched on and off to lower the power consumption, etc.), transfer function (relation between the electrical output and the meteorological parameters).

Sensors with an analogue output generally deliver only one information, the meteorological variable measured by the sensor. Sensors with a digital output deliver the meteorological variable measured, but also oftfer additional service parameters, useful to monitor the sensor’ s state and to optimize its maintenance. It is important that the service parameters are also taken into account by the system (AWS + central system).

Radiometers (pyranometers, pyrheliometers, etc.) are a special case. The majority of these sensors are using a thermopile, which output is often directly connected to the AWS. Therefore, the calibration factor of the thermopile has to be applied behind the sensors, either in the AWS itself or in the central system collecting the data. When a radiometer is changed on site (at least for a regular calibration, typically every 1 or 2 years), the associated calibration factor has to be changed accordingly in the system. The experience shows that errors sometimes occur, due to human fault (change of the sensor without updating the calibration factor at the same time). Some models of radiometers include a microprocessor to convert the analogue signals into numeric physical values within the sensor itself; the calibration factor is included in the sensor, updated during its calibration. Such a sensor is fully interchangeable, with no needed update of a calibration factor in the system, which reduces possible human errors.

Wind observation (mean values, gusts) need a high acquisition rate (4 Hz is recommended, see part I, chapter 6) and a calculation of mean values and gusts over larger periods (10 minutes for synoptic use, 2 minutes for local aeronautical use). The calculation can be carried on the AWS itself, but many modern wind sensors have an embedded calculation of the wind parameters. An advantage is the reduction of the data acquisition rate at the level of the AWS, with a typical one minute update of wind data, rather than a 4 Hz data sampling.

It is highly recommended that barometers connected to an AWS have a digital output, to avoid additional uncertainty in the conversion of an analogue signal into pressure. Indeed, using a barometer with an analogue output needs a high quality analogue to numeric converter, to cope with a resolution of at least 0.1 hPa and a measuring range of at least 150 hPa.

It can be chosen to double (or even triple) some sensors, in order to minimize the probability of missing values in case of sensor failure; and/or to introduce measurement redundancy in the system to detect possible sensors’ drift: the difference between two sensors indicates a drift of at least one of them; if three sensors are used, it becomes possible to automatically identify which sensor is drifting and the system may choose to skip its values. This procedure of using multiple sensing elements is sometimes used within the sensor itself: several commercial models of barometers are available with one, two or three cells.

## 1.3 Automatic weather station hardware

Several designs of AWS exist:

* A stand-alone equipment specifically designed for meteorological measurements. Depending on the manufacturer, it is designed to accept a given list of sensors. Therefore, it may be difficult to use or add new sensors that are not supported. But, being designed for meteorological measurements by the meteorological industry, there is good chance that all the needs may be fulfilled and therefore, the restriction for adding new sensors may not be a problem.
* An industrial data-logger, not specific to meteorological measurements. An advantage is a potential higher versatility, with analogue inputs, counters, etc. Also, the cost may be lower than a dedicated equipment. In some cases, where meteorological sensors have stringent characteristics, such as the low output voltage of a radiometer using a thermopile, it may not be suitable. Wind measurement is also a special case, if the data logger must derive wind parameters from 4 Hz samples.
* Some designs split the data acquisition between separate electronic boxes, some of them being associated to one sensor, to digitize its analogue output as close to the sensor as possible. These interface boxes dialog with a central processing unit.
* In some designs, digital or smart sensors and analogue sensors digitized by an electronic interface are directly connected to a laptop Personal Computer (PC) or an industrial PC, installed either indoor or directly in the field. This allows to use the hardware and software of standard microcomputers. Nevertheless cabling and surge protection should not be neglected.
* When a human observer must interact with the AWS, e.g. to enter visual observation, a local PC is usually used, both to locally display the observations and to edit the visual observation. Such a local computer may also deliver the local observation to local users, such as aeronautic users.

The layout of an AWS typically consists of the following:

(a) On a standard observing area (see Part I, Chapter 1, and WMO, 2013), a series of automated sensors sited at the recommended positions and interconnected to one or more data collection units using interfaces, sited for not affecting each other, connected to a central processing unit (CPU) by means of shielded cables, fibre optics, or radio links;

(b) A CPU for sensor data acquisition and conversion into a computer-readable format, proper processing of data by means of a microprocessor-based system in accordance with specified algorithms, the temporary storage of processed data, and their transmission to remote users of meteorological information;

(c) A modem or an interface to the telecommunication network used for the transmission of data towards a central system;

(d) A stabilized power supply providing power to the various parts of the station;

(e) For specific applications, local terminals for the manual entry and editing of data, display devices and printers, or recorders are added to the station.

It is a good practice to design the system on a modular basis in order to adapt it to new sensors, new variables, changes in the telecommunication network, etc. Nevertheless a high level of modularity may increase the cost of the equipment, therefore it is important to anticipate the possible future changes as much as possible, in order to select a good compromise between modularity and a compact and standard design (across the whole network). Due to the short life cycle of many telecommunication networks, it is highly recommended to use an AWS with a modular telecommunication terminal.

For the maintenance of the AWS, the design should facilitate field work for preventive and corrective maintenance (e.g. regular replacement are needed for sensors’ calibration). Again, modularity is a solution or the possibility to easily replace the whole AWS, if it is a stand-alone design. Connectors with a keyed position may be preferable to wires directly connected to a terminal strip.

Built-in test equipment: Vital parts of an AWS often include components whose faulty operation or failure would seriously degrade or render useless the principal output. The inclusion of circuits to monitor automatically these components’ status is an effective means of continuously controlling their performance during operation. Examples are: a power-failure detector which restarts the processor and continues the AWS function after a power failure; a “watchdog” timer to monitor the proper operation of microprocessors; and test circuits for monitoring the operation of station subsystems such as battery voltage and charger operation, aspirators (if temperature and humidity ventilated screens are used), A/D converters, heaters, etc. Status information should be monitored as well, and transferred to the central server unit for automatic quality-control and maintenance purposes.

Guidance on preparing a functional specification for the AWS system is available in Part I of WMO (1997).

[[13]](#footnote-13)

## 1.3.1 Central processing unit

The core of an AWS is its CPU. Its hardware configuration depends on the complexity and magnitude of the functions it has to perform. In general, the main functions of the CPU are data acquisition, data processing, data storage and data transmission.

In the majority of existing AWSs, all of these functions are carried out by one microprocessor-based system installed in a weather-proof enclosure as close as possible to the sensors, or at some local indoor location. If the unit is located near the sensors, on-site processing reduces the amount of data which must be transmitted and enables those data to be presented in a form suitable for direct connection to communication channels. In such cases, however, the CPU is vulnerable to power-supply failure and must be protected against the outdoor environment in which it must operate. If the unit can be located indoors, it can usually be connected to a main supply and operated as if it were located in a normal office environment. However, such a configuration results in an increased number of long signal cables and appropriate signal conditioners.

Depending on local circumstances and requirements, the different functions of the CPU may also be executed by different units. In such cases, each unit has its own microprocessor and relevant software, can be installed at different places in the station, and can communicate with each other through well-established inter-processor data transfer links and procedures. They operate in a dependency relation, the data-processing unit being the independent unit. An example is the installation of one or more data-acquisition units in the field close to the sensors that are connected to the data processing or transmission unit of the CPU by means of one or more telephone lines using digital data transmission. Low power wireless links are also usable, some frequency bands being dedicated to data transmission without a specific authorization procedure, assuming a low power emission. These units can consist of one sensor (for example, an intelligent sensor such as a laser ceilometer), a number of similar sensors (for example, thermometers), or a number of different sensors, such as analogue sensors connected to a data logger in the field.

The data-processing hardware is the heart of the CPU and its main functions are to act as the master control of the input/output of data to, and from, the CPU and to carry out the proper processing of all incoming data by means of the relevant software.

The first AWS were equipped with 8-bit microprocessors and limited memory (32 to 64 kbytes). Systems using 16- or 32-bit microprocessors surrounded by a considerable amount of solid-state memory (at least 1 Mbyte) are now standard. These AWOSs provide more input/output facilities which operate at much higher processing speeds and are capable of performing complex computations. Together with this hardware, sophisticated software is applied which was, some years ago, available only in minicomputer systems. In addition to the random access memories (RAM) for data and sometimes non-volatile programmable read-only memories (PROMs) for program storage, the CPU often uses non-volatile random-access memory (NOVRAM or EEPROM, also known as flash memory): constants can be modified for the system’s configuration; data can be stored safely during power failures; the AWS software itself may be downloaded from a local connection or even from the central system. The volume of today’s available memory is large enough to memorize tenths or hundreds days of observation data.

Real-time clock: The CPU of an AWS needs a 24 h real-time clock powered by a battery, which ensures that the time is kept even during power outages. Ensuring the accuracy of actual AWS clocks requires special attention to guarantee correct read-outs, sample intervals and time stamps. A clock stability better than 1 second over a 24 h period is recommended and achievable. The real-time clock should also be synchronized either with the GPS signals or by a central reference clock, available through the telecommunication network (such as a time server over the internet).

1.3.2 Sensors’ interface

In general, the data-acquisition hardware is composed of:

(a) Signal-conditioning hardware for preventing unwanted external sources of interference from influencing the raw sensor signals, for protecting the CPU electronics, and for adapting signals to make them suitable for further data processing; detailed in the next paragraph.

(b) Data-acquisition electronics with analogue and digital input channels and ports, scanning equipment and data conversion equipment to enter the signals into the CPU memory.

Low-pass filtering: Filters are used to separate desired signals from undesirable signals. Undesirable signals are noise, alternating current line frequency pick-up, radio or television station interference, and signal frequencies above half the sampling frequency. Generally, a low-pass filter is employed to control these unwanted sources of error, excluding that portion of the frequency spectrum where desired signals do not exist. These filters may be realized either by analogue techniques (electronic) or digital filters.

Amplifiers: Analogue sensor signals can vary in amplitude over a wide range. The analogue-to-digital (A/D) converter (ADC), however, requires a high-level signal in order to perform best. In many cases, an amplifier module is used to boost possible low-level signals to the desired amplitude. Amplifier modules are sometimes employed to standardize the voltage output of all sensors to a common voltage, for example 0–5 voltage direct current, in order to use a common high performance ADC.

Resistances: Special modules are used to convert resistances, such as platinum thermometers, into an output voltage signal by providing the necessary output current. .

Data-acquisition function

The data-acquisition function consists of scanning the output of sensors or sensor-conditioning modules at a predetermined rate, and translating the signals into a computer-readable format.

To accommodate the different types of meteorological sensors, the hardware for this function is composed of different types of input/output channels, covering the possible electrical output characteristics of sensors or signal-conditioning modules. The total number of channels of each type depends on the output characteristics of the sensors and is determined by the type of application.

Analogue inputs: The number of analogue channels depends on the basic design of the equipment. In general, a basic configuration can be extended by additional modules that provide more input channels. Analogue input channels are of particular significance as most of the commonly used meteorological sensors, such as temperature, radiometers and humidity sensors, deliver a voltage signal either directly or indirectly through the sensor-conditioning modules.

The data-acquisition tasks are the scanning of the channels and their A/D conversion. A scanner is simply a switch arrangement that allows many analogue input channels to be served by one A/D converter (ADC). Software can control these switches to select any one channel for processing at a given time. In some AWSs’ designs, a separate ADC is used for each channel. The ADC transforms the original analogue information into computer readable data (digital, binary code). The A/D resolution is specified in terms of bits. An A/D resolution of 12 bits corresponds to approximately 0.025%, 14 bits to 0.006%, and 16 bit to 0.0015% of the A/D full range or scale. In the first AWSs generation, offset and gain of amplifiers and A/D converters had to be adjusted by means of potentiometers. Modern electronics use fixed stable and precise reference elements, which allow to avoid any manual adjustments of the electronic chain.

Parallel digital input/output: The total number of individual channels is mostly grouped in blocks of 8 out of 16 bits with extension possibilities. They are used for individual bit or status sensing or for input of sensors with parallel digital output (for example, wind vanes with Gray code output).

Pulses and frequencies: The number of channels is generally limited, because few sensors are delivering such signals . Typical sensors are wind speed sensors and (tipping-bucket) rain gauges. Use is made of low- and high-speed counters accumulating the pulses in CPU memories. The counters should use analogue or digital filters to avoid unwanted pulses, such as electro-magnetic spikes.

Serial digital ports: These are individual asynchronous serial input/output channels for data communication with intelligent sensors. The ports provide conventional inter-device communications over short (RS232, several metres) to long distances (using of a pair of modems or RS422/485, several kilometres). Different sensors or measuring systems are sometimes connected on the same line and input port, each of the sensors being addressed sequentially by means of coded words. Unfortunately, there is no universal standardization of the dialogue protocol with the sensors, except protocols or formats defined by some manufacturers for their own equipment. SDI-12(Serial Digital Interface at 1200 baud) is an asynchronous serial communication protocol for intelligent sensors that monitor environment data, which is supported by some sensors and AWSs.

*Ethernet connection*: Some sensors are quite autonomous and are able to dialogue either with the AWS or even with a central system (Internet of Things) using IP based protocols.

1.3.3 Cable connection and surge protection

Connections: Cables and a mechanical connecting system are necessary for connecting the sensors to the data-acquisition electronics. The cables may be connected directly to the data acquisition system via a terminal strip, with screwed connections or solder connections or self-locking connections. Packing glands are often used to cross the enclosure box of the AWS. Another solution is to use a pair of connectors, with a fixed one on the enclosure box (and connected to the electronics). The advantage is the possibility to easily unlock a sensor and its cable for replacement. The type of connection and the location of possible connectors should be selected to facilitate the field operations, having in mind the expected periodicity of sensor’s replacement (e.g. for regular calibration).

Sensor cables: Electrical signals from the sensors entering a data-acquisition system might include unwanted noise. Whether this noise is troublesome depends upon the signal-to-noise ratio and the specific application. Digital signals are relatively immune to noise because of their discrete (and high-level) nature. In contrast, analogue signals are directly influenced by relatively low-level disturbances. The major noise transfer mechanisms include capacitive and inductive coupling. A method of reducing errors due to capacitive coupling is to employ shielded cables. The additional use of a pair of wires that are entwined is effective in reducing electromagnetic coupling.

Surge protection: When an AWS could be subject to unintentional high-voltage inputs, the installation of a protection mechanism is indispensable to avoid possible destruction of the equipment. High-voltage input can be induced from magnetic fields, static electricity and, especially, from lightning. Protection modules against surge should be easily replaceable. They are often a one shot protection, therefore their status should be easily testable, the best solution being a visual mark of their status. A basic rule for good surge protection is to insure an equipotential bonding of the different electrical masses of the system, including the shield of the cables. Ground connections should be kept as short as possible, in order to facilitate the path of high voltage spikes through these ground connections rather than through the electronics. The ground of the AWS and its peripherals (including sensors) must be connected to the ground network of the site (if available). If not available, a local grounding electrode and associated buried grounding network must be installed, in order to offer the best path to current surges.

Digital isolation: Electrical modules are used to acquire digital input signals while breaking the galvanic connection between the signal source and the measuring equipment. The modules (modems) not only isolate, but also convert the inputs into standard voltage levels that can be read by the data-acquisition equipment. The galvanic isolation allows to avoid the use of copper lines to realize the equipotential bonding between distant points (copper cables and trenches over hundreds of meters are costly). Nevertheless surge protection of a digital line remains necessary, because high frequency spikes are able to cross transformers, even with galvanic isolation.

## 1.3.4 Power supply

The design and capability of an AWS depend critically upon the method used to power it. The most important characteristics of an AWS power supply are high stability and interference-free operation. For safety reasons, and because of the widespread use and common availability of 12 V batteries, consideration should be given to the use of 12 V direct current power. Where mains power is available, the batteries could be float-charged from the main supply. Such a system provides the advantage of automatic backup power in the event of a mains power failure. The capacity of the buffer batteries depends on the mean power consumption of the system (AWS+sensors, incl. heating+modem) and the accepted duration of missing mains power.

Automatic weather stations deployed at remote sites where no mains power is available must rely upon batteries nearly always sourced by solar cells or other power source, such as a diesel generator, wind- or water-driven generator. However, such low-power systems cannot, in general, support the more complex sensors required for cloud height and visibility measurements, which require large amounts of power. Furthermore, AWSs with auxiliary equipment such as heaters (e.g. anemometers, rain gauges) and aspirators can also consume considerable power, thus restricting the installation of an AWS to locations where mains power is available. If, because of the need for a versatile and comprehensive system, only the mains can supply sufficient power for full operation, provision should be made for support, from a backup supply, of at least the system clock, the processor and any volatile memory that may contain recent data needed to restart the station automatically. It is also a good practice to shut down the system when the voltage of the batteries is going down a fixed threshold, in order to protect the batteries which do not support a deep discharge.

It is important that the system be designed to measure and report the status of the power supply: battery voltage, charging current delivered by solar panels, presence or absence of the mains power, etc. These status parameters should be transmitted to the central system, to optimize the maintenance operations and to alert the maintenance staff of any problem. Mains power is protected by a circuit breaker, which may trip off in case of surge. On an isolated site, a staff displacement just to reactivate a circuit breaker may be very costly and time consuming, so it can be useful to install a circuit breaker with a remote command to reactivate it (unless, the tripping off is linked to an electrical circuit default, to be fixed).

## 1.3.5 Enclosure protection

The electronics part of an AWS has to be protected from the outside atmosphere, unless it is installed indoor. A protective box is highly recommended. It should be large enough to allow an easy access to the internal equipment, unless the system is designed for replacing the whole equipment, protective box included, in case of failure.

The protection against water and condensation should be made by one of the two following techniques:

* The protective box is completely sealed and not designed to be opened in the field. It should then include an internal bag of hygroscopic salts.
* The protective box is aerated with gills fenced in against the entrances of insects. The box should be designed to avoid the entry of water when opening its door.

The material should be chosen to avoid corrosion, especially close to the sea side. A metallic box helps in protecting the electronics against surge.

## 1.3.6 Installation structure

When installed outside, the AWS box(es), the sensors, the terminal distribution of the mains power or the solar panels have to be installed on basements. The installation structure must not be neglected, as it can be costly. It is a good practice to define standard accessories for the installation of an AWS and its’ components. Supporting structures may be proposed by the AWS’s manufacturer. It is important to check that the sensors and other equipment are not disturbing each other; in particular, the clearance rules described in the siting classification (see chapter 1, annexe 1B of this guide) should be respected by the design of the supporting structure.

Some concrete basement may be necessary. An alternative may be the use of metallic ground screws, designed to support pylons, fences, etc.

The need for a local earth electrode and buried earth network must be considered.

Depending on the location of the station and the surrounding risks (animals, humans, …), fencing of the observing area may be necessary.

1.4 Automatic weather station software

The three main designs of AWS have different frameworks for the software:

* A stand-alone AWS uses a specific software developed by the AWS’s manufacturer. Few or no modifications are possible by the end user, except some configuration choices. But the AWS is often delivered ready to use. Modifications in the AWS functionalities have to be developed by the manufacturer itself.
* An industrial data-logger is usually designed with a command language, to allow the user to configure the equipment according to his sensors and needs (of course in the limits allowed by the data logger design). The software configuration may be more complicated and realized either by the data-logger distributor, or by a third party integrator, or by the user itself.
* The software of a laptop or industrial PC with digital sensors directly connected on it is less dependent on the hardware and may make use of more standard tools and languages. Some meteorological services develop their own software with this type of AWS configuration.

The software is a major part of the AWS. Unless great care is taken in the preliminary design and strong discipline maintained while coding, complex software readily become inflexible and difficult to maintain. Minor changes to the requirements — such as those often induced by the need for a new sensor, code changes, or changes in quality-control criteria — may often result in major and very expensive software revisions.

In general, a distinction can be made between application software consisting of algorithms for the proper processing of data in accordance with user specifications, and system software inherently related to the hardware configuration and comprising all software to develop and run application programs.

Discussion of the design of algorithms for synoptic AWSs is found in WMO (1987), and for the processing of surface wind data in WMO (1991). Information on the algorithms used by Members can be found in WMO (2003).

## 1.4.1 Operating system

The operating system of a stand-alone AWS or a data-logger is generally very specific to the hardware and based on industrial real-time embedded operating system (so-called firmware), thus turning the CPU into a sort of black box. Sometimes the operating system is more classic, such as a Unix based system. The user can execute only predetermined commands and, as a consequence, depends entirely on the manufacturer in the event of malfunctions or modifications.

When a laptop PC or industrial PC is used as a CPU, its operating system is more standard, such as a Unix based system or a Windows operating system. The full range of administration tools and communication layers are therefore available. In return, such a system is more opened to hackers and IT security protections have to be set and software updates and upgrades have to be applied.

1.4.2 Application software

The processing functions that must be carried out either by the CPU, the sensor interfaces, or a combination of both, depend to some extent on the type of AWS and on the purpose for which it is employed. Typically, however, some or all of the following operations are required: initialization, sampling of sensor output, conversion of sensor output to meteorological data, linearization, averaging, manual entry of observations, quality control, data reduction, message formatting and checking and data storage, transmission and display. Quality-control may be performed at different levels: immediately after sampling, after deriving meteorological variables, after the manual entry of data and message formatting or in the central system (quality-control is often split between the AWS itself and the central system). If there are no checks on data quality-control and message content, the AWS data are likely to contain undetected errors. While linearization may be inherent in the sensor or signal-conditioning module, it should always be carried out before the calculation of an average value.

The execution of the application software is governed by a schedule that controls when specific tasks must be executed. The overview of AWS application software in the following paragraphs is limited to some practical aspects related to AWSs.

1.4.2.1 Initialization

Initialization is the process that prepares all memories, sets all operational parameters and starts running the application software. In order to be able to start normal operations, the software first requires a number of specific parameters, such as, among others, those related to the station (station code number, altitude, latitude and longitude); date and time; physical location of the sensor in the data-acquisition section; type and characteristics of sensor-conditioning modules; conversion and linearization constants for sensor output conversion into meteorological values; absolute and rate of change limits for quality-control purposes; and data buffering file location. Depending on the station, all or part of these parameters may be locally input or modified by the user through interactive menus on a terminal. In the latest generation of AWSs, initialization may be executed remotely, for instance, by the central network processing system or by a remote personal computer. In addition to full initialization, a partial initialization should be programmed. This automatically restores normal operation, without any loss of stored data, after a temporary interruption caused by real-time clock setting, maintenance, calibration or power failure. The central system (typically a collecting platform) should be able to report the full set of initialization parameters of each AWS, for network and maintenance management.

1.4.2.2 Sampling and filtering

Sampling is the process of obtaining a discrete sequence of measurements of a quantity. To digitally process meteorological sensor signals, the question arises of how often the sensor outputs should be sampled. It is important to ensure that the sequence of samples adequately represents significant changes in the atmospheric variable being measured. A generally accepted rule of thumb is to sample at least once during the time constant of the sensor. However, as some meteorological variables have high frequency components, proper filtering or smoothing should be accomplished first by selecting sensors with a suitable time-constant or by filtering and smoothing techniques in the signal-conditioning modules. More details are presented in Part IV, Chapter 2.

Sensors needing a high frequency sampling have often their own embedded microprocessor to calculate the relevant meteorological parameters, thus reducing the task of the AWS. A typical example is a wind sensor, which recommended sampling frequency is 4 Hz.

The natural small-scale variability of the atmosphere, the introduction of noise into the measurement process by electronic devices and, in particular, the use of sensors with short time-constants make averaging a most desirable process for reducing the uncertainty of reported data.

Annex 1.E of this guides recommends that “instantaneous” values of meteorological variables be a 1 min average (except for wind and Meteorological Opticla range which are special cases).

[[14]](#footnote-14)

1.4.2.3 Raw-data conversion

The conversion of raw sensor data consists of the transformation of the electrical output values of sensors or signal-conditioning modules into meteorological units. The process involves the application of conversion algorithms sometimes making use of constants and relations obtained during calibration procedures.

An important consideration is that some sensors are inherently non-linear, namely their outputs are not directly proportional to the measured atmospheric variables (for example, a resistance thermometer), that some measurements are influenced by external variables in a non-linear relation (for example, some pressure and humidity sensors are influenced by the temperature) and that, although the sensor itself may be linear or incorporate linearization circuits, the variables measured are not linearly related to the atmospheric variable of interest (for example, extinction coefficient, and not visibility or transmittance, is the proper variable to average in order to produce estimates of average visibility). As a consequence, it is necessary to include corrections for non-linearity in the conversion algorithms as far as this is not already done by signal-conditioning modules. Linearization is of particular importance when mean values must be calculated over a certain time. Indeed, when the sensor signal is not constant throughout the averaging period, the “average then linearize” sequence of operations can produce different results from the “linearize then average” sequence. The correct procedure is to only average linear variables. More details are presented in Part IV, Chapter 3.

The knowledge of raw data values may be very valuable for the maintenance staff, therefore considerations must be given to the transmission of some raw data values towards the central system. A typical example is the use of analogue relative humidity sensors. If a 0-1 V output hygrometer is used, 0V stands for 0% and 1V for 100%, the maximum operational value. But such a hygrometer might output a raw value above 1V, e.g. 1,03 V. Obviously it is not an operational value of 103 % of relative humidity, it may be a drift of the sensor or a value inside the tolerance limits of the sensor. In the conversion to meteorological units, these 1,03 V should be limited to 100%, with a threshold limit (such as a value above 1,05 V is considered as an invalid value). But for the maintenance process, it is important to know that these 1,03 V have been reported by the hygrometer, it may be an indication of a drift of the sensor.

[[15]](#footnote-15)

1.4.2.4 Manual entry of observations

For some applications, interactive terminal routines have to be developed to allow an observer to enter and edit visual or subjective observations for which no automatic sensors are provided at the station. These typically include present and past weather, visibility, cloud layers, state of the ground and other special phenomena. If some sensors for these parameters are installed in the system, they should be considered as an aid for the observer during the periods with human observation. That means that a terminal system (often a PC) used for manual entry shall also display the measured parameters for the local human observer.

1.4.2.5 Data reduction

Beside instantaneous meteorological data, directly obtained from the sampled data after appropriate conversion, other operational meteorological variables are to be derived and statistical quantities calculated. Most of them are based on stored instantaneous values, while, for others, data are obtained at a higher sampling rate, as for instance is the case for wind gust computations. Examples of data reduction are the calculation of dewpoint temperature values from the original relative humidity and air temperature measurements and the reduction of pressure to mean sea level. Statistical data include data extremes over one or more time periods (for example, temperature), total amounts (for example, rain) over specific periods of time (from minutes to days), means over different time periods (climatological data), and integrated values (radiation). These variables or quantities can be computed at the AWS’s level or in a central processing platform, from instantaneous data or extremes and total amounts calculated over small periods (e.g. one hour). A tendency with recent systems when the telecommunication network allows it, is to collect centrally one minute data (instantaneous values and meteorological variables calculated every minute, such as wind parameters) and to process this data in a central processing platform. This allows a greater flexibility in the development and upgrade of the processing software and simplifies the AWS software. One minute data may greatly help the maintenance team to detect and identify possible measurement problems (see §1.2.2.1).

CIMO is involved in a regular programme to survey and standardize algorithms for all variables. The results are published in the WMO (2003). See also the corresponding Chapters of Part I of this guide for details on the meteorological variables.

[[16]](#footnote-16)[[17]](#footnote-17)

[[18]](#footnote-18)[[19]](#footnote-19)

1.4.2.6 Local data storage

Meteorological data are regularly transmitted to a central system in nominal conditions. Nevertheless, a break in the telecommunication scheme may occurs or data can be lost in the collecting process. Therefore, it is important that the local AWS have a local data storage and an associated procedure to access the data. Local data storage is no longer a problem with flash memories components. The AWS software generally manages the data in a circular memory over a given period, replacing old data by new ones. The depth of data storage shall be compatible with the accessibility of the observing site, up to several months for a very isolated site. It may be the same set of data that are normally transmitted to the collecting platform. If necessary, in order to reduce the memory size needed and/or to facilitate the procedure of recovery of the data, hourly instantaneous variables and hourly statistical variables (extremes, totals) may be also locally stored.

The procedure to access the local data can be:

* A transmission of old data when the telecommunication infrastructure becomes available again.
* A local transfer of the data with a portable terminal locally connected to the AWS, during a maintenance operation.
* A local recuperation of a memory card (e.g. a flash memory card) during a maintenance operation.

The recovery procedure must be accompanied with a mechanism of complementing the central data base, with the old recovered data.

1.4.2.7 Message coding

Functional requirements often stipulate the coding of meteorological messages in accordance with WMO (2016b). Message coding algorithms should not be underestimated and require noticeable efforts not only for their development but also for updating when formats are altered by international, regional and national regulations. The transition from alphanumeric codes (typically SYNOP) to Table-Driven Code Forms (BUFR or CREX) facilitates the update of the content of observing messages.

The coding of standard messages is generally easier in a central processing platform, where more power is available and also more standard software tools (free BUFR coding software is available from several sources). Therefore, the majority of network of AWSs are designed for a central coding in standard codes. The format of the messages between an AWS and the collecting platform varies. It should also be based on the principle of a table driven code, allowing the upgrade of the transmitted variables without needing any changes in the transmission layers. In addition to the requested meteorological variables, additional service data should be coded and transmitted, such as service data from smart sensors, battery voltage, raw data from some sensors (e.g. the raw value output by a 0-1V hygrometer, see above), etc. As such parameters are very specific to the AWS design and not listed in BUFR tables, it is an additional reason to code standard WMO messages at a central level.

1.4.3 Remote diagnostics and maintenance

Specific software routines are incorporated in the application software allowing field maintenance and calibration. Such activities generally involve running interactive programs for testing a particular sensor, AWS reconfiguration after the replacement of sensors or models, resetting of system parameters, telecommunication tests, entering new calibration constants, and so on. In general, maintenance and calibration is conducted in an off-line mode of operation, temporarily interrupting the normal station operation.

Some of these functions may be available also on line, via the collecting system. Any function allowing a distant diagnostic should be encouraged in the design of the system, in order to reduce maintenance costs: in practice, transportation of maintenance staff to the measuring site is a huge percentage of the maintenance cost and any on-line possibility is welcomed. Examples are the transmission of service parameters, the resetting of a circuit breaker, the downloading a new software version for the AWS or one of its component.

1.5 Quality control

The purpose of quality-control at an AWS is to minimize automatically the number of inaccurate observations and the number of missing observations by using appropriate hardware and software routines. Both purposes are served by ensuring that each observation is computed from a reasonably large number of quality-controlled data samples. In this way, samples with large spurious errors can be isolated and excluded and the computation can still proceed, uncontaminated by that sample.

Quality-control achieves assured quality and consistency of data output. It is achieved through a carefully designed set of procedures focused on good maintenance practices, repair, calibration, and data quality checks.

In modern AWSs, the results of data quality-control procedures for sensors which reveal the reasons why a measurement is suspect or erroneous, and the results of hardware self-checks by built-in test equipment, are stored in appropriate housekeeping buffers. The transmission of these results and the visual display of these status indicators forms a very handy tool for continuous monitoring of the network, and during field and remote maintenance. The transmission of housekeeping buffers – either as an appendix to the routine observational message, a separate bulletin, or as a clocked or on-request housekeeping message, from a network of AWSs to a central network processing system – is highly recommended to support the maintenance of meteorological equipment.

Real-time procedures for the quality-control of AWS data are highly advisable, and detailed recommendations exist in Appendix VI.2 of the Guide to the Global Observing System (WMO 2013) and in Part IV, Chapter 1 of this Guide. The following is a brief summary of the guidelines of WMO 2013.

Intra-sensor checks: Each sensor sample is checked at the earliest practical point in the processing, taking into account sensor and signal-conditioning response functions, for a plausible value and a plausible rate of change. Some additional tests are possible, for example:

* If barometers with 2 or 3 pressure cells are used, the difference between cells could generate an alarm if this difference is larger than a given threshold (e.g. 0.3 hPa).
* If relative humidity is measured by a hygrometer, the maximum daily value indicated by the sensor could be calculated (see §1.4.2.3). This parameter analysed over long periods may help to identify clues of a possible drift at the saturation point (100%).

Plausible value: A gross check that the measured value lies within the absolute limits of variability. These limits are related to the nature of the meteorological variable or phenomena but depend also on the measuring range of selected sensors and data-acquisition hardware. Additional checks against limits which are functions of geographical area, season and time of year could be applied. The checks help identifying erroneous or suspect values.

Plausible rate of change: Checks for a plausible rate of change from a preceding acceptable level. The test settings depend on the observed parameter and the atmospheric phenomena which could influence it. It is also dependent on the sensor characteristic (e.g. time constant, persistency).

Minimum required variability of instantaneous values: Checks that the sensor is still reacting on atmospheric changes. A long period without significant change in the measured data is an indication for malfunctioning (e.g. a cup and vane anemometer starting to jam). Variability and time response are dependent on the observed parameter, and on the sensor characteristic.

Maximum allowed variability of instantaneous values: Identic to previous.

Inter-sensor checks: It is possible to make internal consistency checks of a variable against other variables, based upon established physical and meteorological principles. Some examples are as follows: dewpoint cannot exceed ambient temperature; precipitation without clouds overhead or just after they have passed overhead is very unlikely; non-zero wind-speed and zero wind-direction variance strongly suggest a wind-direction sensor problem.

Technical monitoring of all crucial AWS components

Message checking

For AWSs equipped with software for directly coding messages and for transmitting the messages over the Global Telecommunication System, it is of vital importance that all the above checks are executed very carefully. In addition, compliance with regulations concerning character, number, format, and so forth, should be controlled. Proper actions are to be considered in cases of values that are classified as suspect.

For AWSs associated with a central collecting and processing system, the quality control checks are split between the AWS software and the central software. Only the checks using the raw data samples must be implemented inside the AWS, if the raw data samples are not transmitted to the central system. When one minute data are transmitted centrally, the other quality control checks are best implemented in the central processing system.

1.6 Automatic weather station siting considerations

The siting of an AWS is a very difficult matter and much research remains to be done in this area. The general principle of siting is that a station should provide measurements that are, and remain, representative of the surrounding area, the size of which depends on the meteorological application. Existing guidelines for conventional stations are also valid for AWSs and are given in Part I as well as in WMO (2013, 2017, 2014).

The surrounding area and the obstacles close to the sensors should not decrease the representativeness of the measurements. The site classification defined in Appendix 1B of this guide should help in choosing a representative site: the ideal location should be a site of class 1 for all the measurements, but compromise are sometimes necessary, since criteria and factor of influences are not identical for all atmospheric parameters. The network designer should defined the maximum classes allowed for selecting a measuring site and a derogation procedure in case of special difficulties to find a site following the selected rules. A split of the station, with delocalized sensors, might also be considered. The current available technology allows it relatively easily (see Chapter 1.2.1).

Some AWSs have to operate unattended for long periods at sites with difficult access both on land and at sea. Construction costs can be high and extra costs can be necessary for servicing. They may have to operate from highly unreliable power supplies or from sites at which no permanent power supply is available. The availability of telecommunication facilities should be considered in the choice of the site. Security measures (against lightning, flooding, theft, vandalism, and so forth) are to be taken into account and the stations must, of course, be able to withstand severe meteorological conditions. The cost of providing systems capable of operating under all foreseen circumstances at an automatic station is high and may be prohibitive; it is essential that, before specifying or designing an AWS, a thorough understanding of the working environment anticipated for the AWS be obtained. At an early stage of planning, there should be a detailed analysis of the relative importance of the meteorological and technical requirements so that sites can be chosen and approved as suitable before significant installation investment is made.

[[20]](#footnote-20)

1.7 Maintenance

The cost of servicing a network of automatic stations on land and, in particular, at sea can greatly exceed the cost of their purchase. It is, therefore, of central importance that AWSs are designed to have the greatest possible reliability and maintainability. Special protection against environmental factors is often justified, even when initial costs are high.

It is evident that any complex system requires maintenance support. Corrective maintenance is required for component failures. Hardware components may fail for many reasons; computer programs can also fail because of errors in design that can go undetected for a long time. To minimize corrective maintenance and to increase the performance of an AWS, well-organized preventive maintenance is recommended. Preventive maintenance is required for all system components, not only cleaning and lubricating the mechanical parts. With the increasing reliability of the electronic components of an AWS, preventive maintenance, including services and sensor calibration, becomes the controlling factor in maintenance.

Adaptive maintenance is required to take into account the rapid changes in technology and the availability of spare parts after a few years. Indeed, costs for repair and components often increase quite rapidly after a system is no longer in active distribution, making it necessary to replace modules by new ones with different technology, as exact replacements are seldom found. Examples include transferring programs and operating systems from one processor to another, introducing modular changes for system reliability, connecting with new telecommunication systems, and so on. In order to reduce the costs for this kind of maintenance, it is desirable that widely accepted standards on equipment and interfaces, as well as on software, be established and included in AWS technical specifications.

The installation of a network of automatic stations must not be seen as a one shot investment. It is essential to organize maintenance according to a rational plan that details all the functions and arranges them so as to minimize costs without adversely affecting performance. The modular structure of many modern automatic stations allows maintenance to take place in the field, or at regional and national centres.

Field maintenance: In general, it is not advisable to repair AWS sensors or other modules in the field because conditions do not favour effective work. . It is recommended that corrective maintenance in the field be carried out by specialized technical personnel from a regional or national centre, depending on the size of the country, and to leave simple preventive or corrective maintenance to the local observer (when available) or a local designed operator. The regular transmission of self-checking diagnostic information by the AWS is a very desirable practice to ensure rapid response to failures.

Regional centre: At a regional centre, technical personnel should be available to replace or repair modules and sensors which require the detection and elimination of simple defects. The personnel should have good knowledge of the station hardware operation and must be trained in the execution of software maintenance routines. Such regional centres should be equipped with appropriate test equipment and sufficient spare modules and sensors to support the maintenance of the stations in their area. They also need the necessary access via telecommunication network to the AWSs, the backbone network, and, possibly, the central servers. These centres need adequate transportation facilities for conducting field work. Care should be taken to plan and visit periodically the remote sites to check for operational problems, vandalism, site conditions, changes, and so forth. Procedures for emergency visits to the different stations must be established, based on priorities defined at the station.

National centre: A national centre requires more skilled technical personnel, who should be capable of detecting and eliminating complex problems in sensors, modules and data transmission means. The equipment necessary for checking and correcting all parts of an AWS should be available and the work should be performed in the centre. Any recurring defects should be referred to designers or suppliers in charge of correcting the design fault.

As software plays a very important role in each AWS and in the central network processing system, personnel with a profound knowledge of the AWS and central network system software are required. The necessary software development and test facilities should be available. Moreover, the national centre should be able to execute all tasks associated with adaptive maintenance.

With reference to the quality-control of network data, it is of utmost importance to establish effective liaison procedures between the monitoring service and the appropriate maintenance and calibration service in order to facilitate rapid response to fault or failure reports from the monitoring system.

For small countries, the tasks of the regional centres could be taken over by the national centre. Developing countries could consider establishing joint maintenance arrangements with neighbouring countries. A common international maintenance centre could be envisaged in order to keep maintenance costs reasonably low. However, such international cooperation would probably require the use of similar equipment. If the Meteorological Service is unable to expand its staff or facilities, contractor services could be used to perform many of the support functions. Such support could, for example, be negotiated as part of the system procurement. However, a maintenance contract should be extremely well prepared and the execution of the contract should be very carefully verified by the appropriate staff.

Suggestions for quality-management techniques are given in Part IV, Chapter 1.

## 1.7.1 Service levels

A service level for maintenance should define the maximum delay to diagnose a problem and a maximum delay to fix it. Examples of such maximum delays, used by one NMS, are given below:

* 4 hours on a very large aerodrome. This implies a local maintenance team, available 24 hours a day and spare parts available locally.
* 15 hours on important aerodrome or synoptic station. 15 hours stands for a rapid maintenance action in the day of the failure detection or the next morning if the failure occurs during the evening or the night. This implies maintenance staff available close to the site (e.g. at less than 2-3 hours of driving), with spare parts available and working hours, every day of the week.
* 2 or 3 days on other stations. This allows longer driving displacement and/or getting spare parts from a distant location (e.g. a national centre) and staff only during working days.
* 5 days for lower priority stations

Service levels should be defined during the network definition, taking into account the users’ needs, the maintenance organization, the distances between the maintenance centres and the observing stations, the cost of spare parts stocks. The result is necessarily a compromise between the users’ expectations and the human and the recurring costs. Different service levels may be defined for different stations.

## 1.7.2 Calibration and site inspection

Sensors, in particular AWS sensors with electrical outputs, show accuracy drifts in time and, consequently, need regular inspection and calibration. In principle, the calibration interval is determined by the drift specifications given by the manufacturer and the required accuracy. WMO international instrument intercomparisons also provide some objective indications of sensor accuracy drifts and desirable calibration intervals. As signal conditioning modules and data-acquisition and transmission equipment also form a part of the measuring chain, their stability and correct operation also have to be controlled or calibrated periodically. The summary given below is limited to practical aspects related to AWSs. Refer to the different chapters of Part I and to Part IV, Chapter 4, for more detailed information on calibration techniques and methods.

Initial calibration: Appropriate calibration facilities and instrumentation should be available prior to the procurement and installation of AWSs in order to be able to verify the specifications given by the manufacturer, to test the overall performance of the station and to verify that transportation did not affect the measuring characteristics of the equipment.

Field inspection: The periodic replacement or comparison of AWS sensors with travelling standards at the station is an absolute requirement to monitor the performance of the sensors. Travelling standards having similar filtering characteristics to the AWS measuring chain and with a digital read-out are to be preferred. In many countries, two travelling standards of the same type are used to prevent possible accuracy change problems due to transportation. In order to be able to detect small drifts, the travelling standards should have an accuracy that is much better than the relevant station sensor and should be installed during the comparison process in the same environmental conditions as the sensors for a sufficiently long time. As signal conditioning modules and data-acquisition equipment, such as the A/D converter, can also show performance drifts, appropriate electrical reference sources and multimeters should be used to locate anomalies.

Before and after field inspections, the travelling standards and reference sources must be compared with the working standards of the calibration laboratory. The maintenance service must be informed as soon as possible when accuracy deviations are detected.

Field inspections should also be used to control the state of the observing site:

* The site environment (obstacles such as trees, vegetation, buildings, etc.) in order to detect possible changes in the siting classification (Annex 1.B).
* The state of the vegetation in the instrument field and vegetation cutting if necessary.
* The state of all hardware: fencing, supporting structures of the AWS and the sensors (e.g. corrosion)
* The state of the power supply system: cleaning of solar panels, periodic change of batteries
* The state of the surge protections
* The cleaning of sensors, as appropriate
* Any other task to be defined, as appropriate (according to the equipment user manual provided by the manufacturer).

The network manager should organize a regular field inspection every 6 to 12 months, depending on the sensors installed in the network, on the accessibility of the observing sites and on the maintenance organization.

Laboratory calibration: Instruments at the end of their calibration interval, instruments showing an accuracy deviation beyond allowed limits during a field inspection and instruments repaired by the maintenance service should return to a calibration laboratory prior to their re-use. Sensors should be calibrated in a conditioned environment (environmental chambers) by means of appropriate working standards and well defined procedures. These working standards should be compared and calibrated periodically with secondary standards and be traceable to international standards.

## 1.7.3 Training

As an AWS is based on the application of technology that differs considerably from the equipment at conventional stations and networks, a comprehensive review of existing training programmes and of the skills of the necessary technical staff is obviously required. Any new training programme should be organized according to a plan that is geared to meeting user needs. It should especially cover the maintenance and calibration outlined above and should be adapted to the system. Requesting existing personnel to take on new functions, even if they have many years of experience with conventional stations, is not always possible and may create serious problems if they have no basic knowledge of electrical sensors, digital and microprocessor techniques or computers. It could be necessary to recruit new personnel who have such knowledge. Personnel competent in the different areas covered by automatic stations should be present well before the installation of a network of AWSs (see WMO, 1997).

It is essential that AWS equipment manufacturers provide very comprehensive operational and technical documentation together with operational and technical training courses. Generally, two sets of documentation are required from the manufacturer: user manuals for operational training and use of the system, and technical manuals with more complex documentation describing in great technical detail the operating characteristics of the system, down to sub-unit and even electronic component level and including maintenance and repair instructions. These manuals can be considered as the basic documentation for training programmes offered by the manufacturer and should be such that they can serve as references after the manufacturer’s specialists are no longer available for assistance.

For some countries, it may be advisable to organize common training courses at a training centre that serves neighbouring countries. Such a training centre would work best if it is associated with a designated instrument centre and if the countries served have agreed on the use of similar standardized equipment.

1.8 Consideration about system specifications and cost

The installation of a new network of AWS or the transition from manual to automatic stations is a difficult matter and shall be managed as a project:

* A project team with the necessary management skills should be set up.
* Users’ needs should be clearly established and translated into functional and technical specifications.
* Future processes of procurement, sites selection, initial installation and maintenance during the whole life time of the system have to be identified and documented.
* Explicit quality objectives should be defined:
  + Target uncertainty of measurement, understanding that it may be a compromise between the state of art and the cost which can be paid to get it, with associated calibration periodicity .
  + Target siting classification for observing sites and accepted compromises in case of difficulties to find class 1 sites.
  + Target of the availability of data, both in real-time and delayed
  + Definition of an accepted service level (e.g. maximum delay for fixing a problem on site)
  + Identification of the life duration of the network
  + Definition of the system redundancy (measurement, telecommunication, central unit system)
* The available telecommunication networks have to be identified and selected.
* Existing equipment to reuse (sensors, central processing system, sites, site infrastructure, etc.) or not should be identified.
* The procurement laws to follow, the initial budget and the running costs should be identified.
* The specifications for the full system should be written and the procurement procedure (tender, in-house development, external or internal installation and maintenance, etc.) should be selected.
* Define and execute the procurement process, the acceptance tests for the first equipment, the acceptance tests for the serial equipment.
* Validate the first installations on site and the link to the central system (collecting platform, processing platform).
* Deploy the stations and the central supervision tools and methods, with appropriate indicators
* Plan regular site inspection
* Measure the reached performances and compare to the target and take corrective and preventive action accordingly

It must be understood that AWSs have many advantages but do not eliminate the need of a well-established organization for using and maintaining them.

The cost of a network of AWSs is split between many parts, the cost of the AWS itself being a small percentage of the total cost:

* Cost of the observing site itself: piece of land, fence, possible trench for mains power or telecommunication lines;
* Cost of the equipment: AWS, sensors, telecommunication modem or interface;
* Cost of the on-site installation and installing structures;
* Cost of the development and implementation of the central collecting and processing systems;
* The running expenditure for communications;
* The running cost for maintenance and calibration.

**Annex 1.A: Low-Cost Automatic Weather Stations**

**1 Introduction**

Historically the measurement of weather phenomena has been an activity performed by professional meteorological organisations, but in the last ten years, there has been a continually increasing number of lower cost automatic weather stations on the market (here-in referred to as low-cost AWS). These AWS range in price from as low as 100 US$ up to typically 5000 US$ and come in a variety of designs and configurations.

There are some common features that are generally exhibited by low cost AWS including:

* Relatively low cost;
* Low or very low power consumption;
* Transmission of data in real lime (with or without logging);
* Often small and compact.

There are three main categories of low-cost AWS: Compact; *All in One*; and Stand Alone Sensors (IoT or Internet of Things)[[21]](#footnote-21).

**2. Main categories of low-cost AWSs**

**2.1 "Compact" AWS**

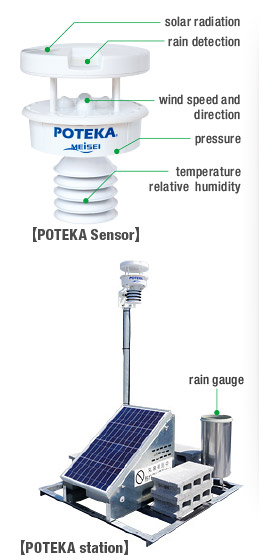
"Compact" AWS consists of a mast, stand or pole with mounting arms for a variety of sensors and usually a cabinet to house a logger or processor, power supply and other modules (see Figure 1). These AWS are similar to professional metrological weather stations, in that they typically use individual sensors for each variable and the sensors are capable of being calibrated and adjusted, and replaced individually. The AWS may have some data logging capability, and/or data transmission capability with flexibility to tailor the message communications to fit into an existing data reception system.



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Figure 1: Examples of “Compact” AWSs

**2.2 "*All in One*" AWS**

"*All in One*" generally refers to the sensor component of the low cost AWS. The most common configuration of an *All in One* AWS includes temperature, relative humidity and pressure sensors with the capacity to add independent sensors (see Figure 2). Some also have one or more of: wind speed, wind direction, precipitation and solar radiation. There are also units that measure present weather variables such as hail and thunderstorms. Typically they are designed to be a single unit and mounted on a small post or mast. Some models include integral solar cells and battery storage that provide the entire system power supply, including transmission of limited volumes of data.



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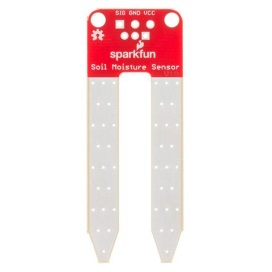


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Figure 2: Examples of “All-in-one” AWSs

**2.3. *Stand Alone Sensors***

"*Stand Alone Sensors*" are a rapidly emerging technology and these are more commonly referred to as the "Internet of Things - IoT" (see Figure 3). These systems use a network of individual intelligent sensors, transmitting information using low-power consumption, low-cost and low bandwidth via wifi, Bluetooth or internet interfaces to centralised processing servers (WMO, 2012). There are a growing number of add-ons to phones that measure weather parameters, as well as home product that meet this criteria.



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Figure 2: Examples of “*Stand Alone Sensors*”

**Table 1 – Comparison of price and functionality of some commonly known low cost AWSs**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | *Price AU$* | *Air Temp* | *Press* | *RH* | *Wind Speed & Dir* | *Rain* | *Extra* |
| *Compact* |  |  |  |  |  |  |  |
| Environdata Mestro | $3500 | X | X | X | X | X |  |
| HoBo U30-NRC | $3700 | X | X | X | X | X |  |
| Meisei Poteka Compact | $7400 | X | X | X | X | X |  |
|  |  |  |  |  |  |  |  |
| *All in One* |  |  |  |  |  |  |  |
| Davis 6163AU | $1881 | X | X | X | X | X |  |
| Fronttech FWS | $2530 | X | X | X | X | X |  |
| Gill GMX500 | $3400 | X | X | X | X | X |  |
| Lufft WS500 | $2800 | X | X | X | X | X |  |
| MetOne AIO2 | $3850 | X | X | X | X | X |  |
| MetOne-MSO | $2450 | X | X | X | X |  |  |
| Pulsonic | $4100 | X | X | X | X | X |  |
| Rainwise Hazmat | $9460 | X | X | X | X |  | Nuclear Rad, Heat Index |
| Rainwise MkIII | $2530 | X | X | X | X | X |  |
| Rainwise Prolog | $6380 | X | X | X | X | X | Solar Rad |
| Vaisala WXT536 | $3400 | X | X | X | X | X |  |
|  |  |  |  |  |  |  |  |
| *Stand Alone IoT* |  |  |  |  |  |  |  |
| Acurite 5 in 1 Pro | $350 | X | X | X | X | X |  |
| Acurite Basic Weather Station | $80 | X | X | X | X | X |  |
| Davis 6250AU | $715 | X | X | X | X | X |  |
| Netatmo Urban Weather Station | $640 | X | X | X | X | X | Indoor T, Sound, CO2 |
| Skyboom Pro | $660 | X | X | X | X | X | Camera |

(Note: this table is only for edification not a recommendation of any of the brands or models. Prices are as of 1 Jan 2018 and in Australian dollars (AU$). No example of Compact system using professional sensors was included in the Table as these are strongly dependant on the sensor selection however these typically start at 10,000 AU$).

**2. Advantages and disadvantages**

Depending on the intended use, each of these categories has its advantages and disadvantages.

*All in One* systems are simple to install and operate, however the design tends to result in compromises in the quality of the information gathered. The sensors all being in one small unit means not all sensors can be exposed correctly and some may compromise the measurements of others. Typically they also have small screens that can result in biased coupling of the sensor to the environment, e.g. significant increases in the observed temperature during the day and moderately decreases the temperature during the night. This biased coupling also results in significant spikes in temperature. *All in Ones* also have the disadvantage that when a single sensor fails the entire unit needs repair or replacement. Calibration of these units is difficult and for some sensors this can only be performed by returning the unit to the factory. Studies by KNMI (Vega, 2017) and Aston University (Bell et al., 2015) demonstrate that these sensors exhibit significant biases in in their measurements. For example, the Aston University study showed hourly mean bias in the temperature of +0.7 °C in the summer and +0.4 °C in the winter. Additionally, the KNMI research demonstrated spikes of 1 to 2 °C in air temperature and gross underestimation of rainfall (62 % losses).

Robustness is also consideration with these units. The units tend to be made of mass produced plastic component that deteriorate with exposure to UV radiation and mounted on light weight poles. As sold, the devices often include a rechargeable battery which is topped up by a small solar cell. Although this is adequate in warm climates, the battery often fails in sub-zero temperatures. Typically the devices do not include the facility for the use of an external power supply.

Compact AWSs have the advantage that they can use commercial off-the-shelf sensors; they offer the capability of changing out faulty sensors and allow for a better siting configuration. They are however less robust than professional stations, being more likely to fail during severe weather events due to lighter-weight masts and weaker attachments. An advantage of many of the *All in One* and Compact AWSs is that they are provided with software for local collection and display of data. Increasingly suppliers are providing cloud services where they collect and display data, and provide network statistics via a web browser interface and an application program interface (API) for interfacing to other data processing systems. This has the advantage that information is available from anywhere at any time and by many con-current users. However these software and data management systems reduce the users' options to expand networks. Most of these system will not interface to other compact AWS and *All in Ones*.

The Internet of Things provides the ability to individually optimise the siting and the sensor choice, however, the operation and management of a network can become complicated. This distributed technology is much newer and not as proven as compact and *All in One* AWS. Another disadvantage is the that the lower cost end of these devices the manufacturing quality and handling of measurement uncertainty is very much at a consumer grade, meaning the ongoing quality of data very quickly becomes unknown.

**3. Selection Considerations**

When choosing a low-cost AWS there is a large range of issues to consider to ensure "Fitness for Purpose". One of the most significant considerations is defining the user requirements and then creating an appropriate specification of the AWS. Most manufacturers provide a specification for the sensor element, but this specification usually relates to testing under laboratory conditions. Additionally, there may be constraints on the way the instrument has been tested to achieve that number. For example, the specification for relative humidity sensors is often for the sensor tested at a single temperature in the laboratory. It does not include considerations such as the effect of the full range of temperatures the sensor may experience in the field. Some may include testing over a range of temperatures but not always the full range of operational range temperatures. At the lower cost end there may be no factory manufactured acceptance testing or calibration and adjustment, the manufacturer instead relying on design and development specifications to "represent" all manufactured units. All this means that when selecting an AWS, significant care needs to be taken to ensure specifications from different manufacturers are genuinely comparable. For example, if the specified measurement uncertainty is small compared to other manufacturers, it is possible that this may only be applicable over a narrower range of conditions.

When considering systems like an *All in One*, the specifications will not typically include the effect of enclosures such as the screen on the sensor in the field. They are unlikely to include the impact of effects such as turbulence on wind measurements or precipitation.

In the case of *All in One* systems, purchasers should look for AWS with symmetrical design. This symmetry minimises the impact of turbulence and shadowing on sensors. Some systems have a significant amount of electronics which has the potential to affect temperature and humidity sensor readings. Consequently it is advisable to choose instruments that have some separation between the electronics and the screen. Ideally, the screen should be at the bottom of the cylindrical system minimising heat transfer from other parts of the *All in One*. The materials from which the system is constructed are also important. Metal screens can have a significant effect on the measured temperature (Warne, 1998) as can the size and colour of the screen. Screens significantly smaller than 200 mm in diameter and 250 mm height will result in poor performance and significant warming under insolation and some cooling under radiative cooling (Warne, 1998). In general, the smaller the screen, the larger the impact. Even the colour of the screen in the visible and infra-red spectrum is important: where possible "white" should be used, but some manufacturers may provide a suitable screen and have large structures such as black or dark grey rain gauges, that act as nearby radiation sources, will affect other sensors (Bell et al., 2017).

**4. Other means of lowering operational cost**

The use of *Compact*, *All in One* or *Internet of Things* technologies as a means of obtaining low-cost observations is not necessarily straightforward. Depending on the quality of data required, and the cost of human resources these solutions may not represent value for money. *All in One* AWS sensors are generally more inclined to drift and fail, and thus require more servicing. For countries where the workforce is the most significant expense, this can result in maintenance costs (including calibration) that outstrip the upfront savings in capital investment. If however, the intended use is to provide an increased density of observations in crowded environments, these systems may be the most economical solution. Using the manufacturers stated drift characteristics, these systems may need to be replaced from typically three to seven times in a ten year period, and maintained or calibrated twice per year to keep them within their stated manufacturer's specification.

Compact AWS and Internet of Things systems can be constructed with high-quality sensors. However, if the value the systems provide is their contribution to recording extreme weather events, then the savings in infrastructure investment may be wasted if the system is lost or damaged during this extreme event. Currently most of the IoT sensor(s) are aimed at the amateur and home market (See Table 1), and as such are not suitable for use by meteorological agencies.

Low-cost AWSs have their place in a tiered network and can provide significant value if their performance and operating limitations are understood. Alternately substantial operational costs can be saved on professional standard AWSs if time and energy is put into understanding the performance standards that the network is achieving, and the drivers of the cost to maintain the required standard. Analysis of before-and-after calibration checks, failures of systems in the field, root-cause analysis, and effective asset management, can all contribute substantially to reducing the cost of operating a network. It is important for network managers to ask questions such as *“Are our systems being over or under serviced?”; “Is the right preventative maintenance in place?”, “Are staff adequately trained?”, “Do we have the proper infrastructure in place for the environment in which the AWS is operating?”*. For countries where labour costs are high, then optimisation of maintenance can bring more significant savings than the reduction in the quality and robustness of capital investment. In countries where the capital cost of investment is high and labour costs are relatively low, then there should be careful consideration of what should be automated.

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SECTION: Chapter\_book

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4. Recommended by the Commission for Instruments and Methods of Observation at its twelfth session (1998) through Recommendation 2 (CIMO‑XII). [↑](#footnote-ref-4)
5. Recommended by the Commission for Instruments and Methods of Observation at its twelfth session (1998) through Recommendation 3 (CIMO‑XII). [↑](#footnote-ref-5)
6. Recommended by the Commission for Instruments and Methods of Observation at its twelfth session (1998) through Recommendation 3 (CIMO‑XII). [↑](#footnote-ref-6)
7. Note also WMO (2010a2013), section 3.2.1.4.4.4(c) “one year of parallel measurements does not suffice; preference is given to at least two years, depending on the climatic region”. [↑](#footnote-ref-7)
8. Note also WMO (2013), section 3.2.1.4.4.4(c) “one year of parallel measurements does not suffice; preference is given to at least two years, depending on the climatic region”. [↑](#footnote-ref-8)
9. See Part I, Chapter 1, section 1.1.3. [↑](#footnote-ref-9)
10. See Part I, Chapter 1, Annex 1.E. [↑](#footnote-ref-10)
11. For example, see WMO (1997), especially Part II – “Implementation and user training considerations”. [↑](#footnote-ref-11)
12. Ibid. [↑](#footnote-ref-12)
13. As specified by the Meeting of Experts on Operational Accuracy Requirements (1991) and approved by the forty-fourth session of the Executive Council (1992) for inclusion in this Guide. [↑](#footnote-ref-13)
14. Recommended by the Commission for Instruments and Methods of Observation at its tenth session (1989) through Recommendation 3 (CIMO‑X). [↑](#footnote-ref-14)
15. Recommended by the Commission for Instruments and Methods of Observation at its ninth session (1985) through Recommendation 6 (CIMO‑IX). [↑](#footnote-ref-15)
16. Recommended by the Commission for Instruments and Methods of Observation at its ninth session (1985) through Recommendation 7 (CIMO‑IX). [↑](#footnote-ref-16)
17. Recommended by the Commission for Instruments and Methods of Observation at its tenth session (1989) through Recommendation 7 (CIMO‑X). [↑](#footnote-ref-17)
18. Recommended by the Commission for Instruments and Methods of Observation at its first session (1953) through Recommendation 13 (CIMO‑I) and adopted by EC-IV. [↑](#footnote-ref-18)
19. Based on the recommendations by the CIMO-I Working Committee II on “Reduction of Pressure” (WMO, 1954, Part 2). [↑](#footnote-ref-19)
20. Recommended by the Commission for Instruments and Methods of Observation at its ninth session (1985) through Recommendation 5 (CIMO‑IX). [↑](#footnote-ref-20)
21. Note: all images and examples are included for illustration and are not a recommendation by the WMO of any particular Brand or Model of equipment. [↑](#footnote-ref-21)