Australian Government
Bureau of Meteorology

Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT)

Observation practices

The Australian Climate Observations Reference Network
– Surface Air Temperature (ACORN-SAT): Observation practices

ISBN: 978-0-642-70626-3

Published by the Bureau of Meteorology
GPO Box 1289
Melbourne VIC 3001
Tel: (03) 9669 4000
Fax: (03) 9669 4699
www.bom.gov.au

Cover image: Bare grazing land with mirage in drought conditions near Hillston, NSW.
Source: CSIRO (Photographer: Gregory Heath)

Contents

List of figures

List of tables

Introduction

The observations that are the focus of the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) are daily maximum and minimum surface air temperatures that are a subset of data from the overall set of observation practices and processes for temperature measurement that make up a component of the Bureau of Meteorology's (the Bureau) composite observing network. These surface air temperature measurements are observations made for multiple uses, covering weather (including disaster mitigation, aviation and marine) and climate, using both manual and automatic methods.

The purchases, processes and procedures used for providing surface air temperatures in the Bureau's observation network are focused on a 'one-model-fits-all' approach. Hence in this report's information, ACORN-SAT is unlikely to be mentioned but rather the word 'network' will represent operational temperature measurements across the composite observing network.

The focus of this report is on the measurement of maximum and minimum surface air temperature, inside an instrument shelter located within a relatively well-controlled observing site. It includes information on the thermometers used, their traceability to the national temperature standards, the instrument housings, site exposure, the time of observations, ancillary observations (such as the dry-bulb temperature at time of reset), inspections, metadata and the overarching system that provides quality assurance and control. The method of data relay to the central head office data facilities will be described but not the actions or processes used post their receipt in the central facilities.

Some history

Up until the late 1980s, manual measurements of surface air temperature dominated the observation network. During the early part of the 20th century, observations practice in the Australian meteorological service relied largely on the practice of the United Kingdom. The earliest publication *Instructions to Country Observers* from 1907 clearly states that temperature observations conform to international regulation and content from British meteorological services, and to a lesser extent, USA Weather Bureau documents (Commonwealth Meteorology 1907).

This publication was the forerunner to two key Bureau working (and evolving) documents that serve to control network operations, namely the *Surface Observations Handbook* and the *Inspections Handbook* (Bureau of Meteorology c. 2011a; c. 2011b). These documents, together with continuously improving metrological practice in the Bureau, provided the framework throughout the course of observational history in post-1907 Australia, to ensure the importance of consistency and diligence in taking and recording of observations.

The Bureau's methods for measuring surface air temperature variables have undergone changes in the last 100 years with the introduction of new sensors and data collection systems, with the major changes occurring late in the 1980s. Prior to 1988, surface air temperature (SAT) field site observations were manual observations obtained from either mercury-in-glass (MiG) or alcohol-in-glass (AiG) thermometer readings at standard synoptics times, based on the prevailing local time standard. Since then with the progressive introduction of automated weather stations (AWS), comprising meteorological sensors, an electronic logging device and a message-processing computer with communication connections, SAT data are now dominated by use of platinum-resistance digital thermometers (PRT) made up of a platinum resistance sensor (PRS) and a resistance to digital module built into the AWS.

One aspect of the system unchanged over the past 100 years is that the Bureau does not calibrate SAT thermometers. Instead their outputs are assumed to be in the relevant temperature scale (Fahrenheit or Celsius) within prescribed tolerance limits. However, the sensors are checked regularly to determine if they are within these tolerance limits. The tolerances for field checks of either in-glass or resistance thermometers are ±0.5 °C; documents suggest these limits are largely unchanged since the 1900s regardless of the type of thermometer used.

Observation process

Units of measurement

Meteorological measurements were reported in Imperial British units of measurements until 1972. Australia started transition to SI units in the 1960s, and Australian standard documents related to temperature (Standards Association of Australia 1966) were translated into SI units.

Observations made prior to 1 September 1972 were in Fahrenheit. The Bureau converted to Celsius for temperature measurement on 1 September 1972 (Bureau of Meteorology 1972).

Time and timeliness of observation

Due to the longitudinal span of continental Australia, observations times are divided into three time zones. As shown in Table 1, in the first half of the 20th century there was some variation in the morning observation time based on time zone and whether it was a synoptic or climate observation, but since 1954 the primary morning observation was 0900 (local standard time or summer time) (Bureau of Meteorology 1954).

In the first few decades of the Bureau network, some observations were defined as 'climatological' to be taken at 0900 and 1500 local time (Bureau of Meteorology 1925). Apart from the 0900 observations time there is no explicit document to differentiate the two different types 'synoptic' vs. 'climatological'. It is likely that 'climatological' related to the need for a continuous time series but allowed for longer times between data acquisition and reporting to the relevant centralised data archive. 'Synoptic' had the highest reporting frequency, as close to real-time as possible given the relevant communication technologies.

Daylight saving time (or summer time) was first observed Australia-wide in 1916, but had irregular application over the past century. A reasonably complete record is located on the Bureau's external website (www.bom.gov.au/climate/averages/tables/dst_times.shtml). Only in the last two years has it stabilised with consistent, uniform dates across the four south-eastern States.

While having minor impact on manual observations, the need to reset the AWS clock from local standard time to daylight saving time and vice versa twice a year could have caused a significant issue as it may take some hours to convert all clocks across the network; this was largely avoided as the time of data receipt was logged by the Central Message Switching System (CMSS) which provided (and still provides) an uncertainty of less than two minutes on the time difference between collection and receipt of an observation.

Table 1. Observation times in Australia, as specified in *Instructions to Country Observers* (1907). By 1954 all observations were uniform at 0900 local time.

Zone	Australian times	Offset to UTC	Synoptic	Climatological
Western Australia	Western Standard Time	+8	0800 1500	0900 1500
South Australia **Northern Territory**	Central Standard Time	+9.5	0830 1500	0900 1500
Queensland **New South Wales** **Victoria** **Tasmania**	Eastern Standard Time	+10	0900 1500	0900 1500

Manual data records

Since the earliest days (Commonwealth of Meteorology 1907), observers were provided with official logbooks (called registers) capable of recording a calendar month of manual observations and metadata, that once completed were posted back to the regional office. Since the network's inception, observers were required to maintain a local record in a field book. The field book was the official record for observations made in the field. Prior to the development of the Australian Data Archive for Meteorology (ADAM) database in 1991, data was stored on punch cards and then, when available, magnetic tape for use on the Bureau's computer system. Card formats were carried on in the ADAM database with Card 7 held data stored data currently in the ADAM sfc_lnds table; Card 8 held daily data currently stored in ADAM sfc_days tables. Prior to PRT, data being the primary data source late in 1996, the A8 was sent to head office where the data were manually entered into the ADAM database. The A8 continues to be filled-in at some Bureau-staffed stations and can be used by the Bureau's climate program for quality control of electronic data. The logbooks in common usage are provided in Table 2.

Table 2. The log books in regular use for SAT observations.

Identifier	Description
B10	Monthly register of meteorological observations; this form only recorded daily maximum and minimum, together with the 0900 dry-bulb temperature.
B22	Meteorological observations (capital city)
B52	Meteorological observations (climate)—for CLIMAT database
B220	Recoding and encoding weather conditions booklet; instructions for coding the A8 logbook.
A8	Field book of meteorological observations (daily three-hourly); this form records daily maximum, minimum, dry-bulb and reset temperatures.
F637	Surface observations record; this form retains a record of maximum, minimum, dry-bulb and reset temperatures which are coded into the MDF message.

Transmission of observations

In the beginnings of the Bureau network, once manual synoptic data were collected the data were transmitted by radio, telephone or telegraph lines back to either a regional location or to the Bureau's head office. During the same period, the data compiled in logbooks were posted back to a central archive every month. By the 1960s, the first automatic weather monitoring stations were being used on remote sites and data Morse-coded into radio transmissions for manual translation into site records at Bureau offices (Day 2007).

The practice was refined when teletext (or Telex) options were available. Initially, these data were received by a 'weather desk' in capital city post offices then keyed into a Telex message by the postal service staff to Bureau offices which were then coded by communicator staff for near real-time use.

Prior to automatic ingestion of Telex messages in computer storage in the late 1970s, data saved for climate analyses from the 1950s were manually transcribed onto punched cards for analysis by early computer systems. A prescribe format was the common mode of transmission. Between 1971 and 1986 manual and automated systems continued to be developed and fixed coding formats thus enabling ready ingestion into computer data systems.

In late 1986, the Met Data Format (MDF) (Bureau of Meteorology 1996) was introduced and prepared the way for the introduction of faster communications and digitisation of messages. The MDF was an expanded and simplified SYNOP code that allowed reporting of values at higher resolution and additional parameters such as maximum and minimum reset temperatures and soil temperatures. These values were used for local data entry checks and included in the meteorological message. However, some of these additional parameters were never stored in the main climate database, ADAM. At both Bureau-staffed and cooperative observer sites, the synoptic information was compiled and transmitted to both regional offices and head office using an electronic field book (at fully manual sites) and a manual console and later the meteorological console (MetConsole) at combined manual/automatic sites.

By the early 1990s, automated data collection of hourly data from automated monitoring systems were common, and with the gradual development of better communications and storage capacity, hourly statistical data were being stored in the climate data archive. With the advent of computing systems, punched cards were used to store temperature dataset, and prior to the advent of the ADAM database in 1991, archived data were stored on magnetic tapes.

Reading manual thermometers

The maximum thermometer is read at 0900 and 1500 and reset at 0900. The minimum thermometer is read at both times and reset at 1500 if observations are taken at this time. Otherwise the minimum is reset at 0900. These data were and are recorded in field books at the sites.

Time of commencement of observations was not earlier than ten minutes before the standard hour and completed on the hour or shortly afterwards. At sites with MetConsoles (essentially a computer system with a direct link to the local AWS and communications network), observers are prompted by the console to ensure observations are taken within the appropriate time window, and the manually entered data reported within the appropriate time window.

Where an observation day was missed, observers were instructed to make the 'before touching' observation as normal and enter it into the field book against the previous day. This would be interpreted as a maximum or minimum occurring since the last observation.

Since 1 November 1996, the PRT temperatures from AWS were deemed the primary SAT measurement, and no overwriting of the PRT value with the manual in-glass measurement was allowed. Prior to 1 November 1996, and post the introduction of PRTs in 1986, the observer could replace the temperature observations from the PRT with manual measurements.

Since 1996, the A8 data collection, where both in-glass and PRT measurements are co-located in the same instrument shelter, has been maintained but not digitised.

Automated platinum-resistance digital thermometers data

Since the introduction of AWS able to provide SAT measurements, PRS were used as the preferred sensor for AWS. Prior to 1990, the networks earlier automated systems were mainly the EG&G and Micromac. Post-1990, the ALMOS AWS dominated the land-based AWS network. The PRS used will be described later, but is based on a design developed within the Bureau and produced by local Australian manufacturers.

The A2669 specification (Bureau of Meteorology 1991–2003), first documented in March 1991, provides the algorithmic set for generation of synoptic messages from AWS. The same algorithm was used from 1986 but poorer resolution (typically 1 °C) than available with the ALMOS AWS. The specification sets within the AWS firmware coefficients for translating the resistance measurement into a temperature. The formula used is:

$$R = R_0 (1 + AT + BT^2)$$

where R is the resistance at T (in °C), R_0 the resistance at 0.000 °C and A = 3.9082 10^{-3}, and B = –5.802 10^{-7}. This relationship covers a temperature range of 10 °C < T < +55 °C.

The approximate solution for T is via:

$$T_a = (R - R_0)/AR_0$$

$$T_b = -(B/A)\,T_a^2$$

$$T = T_a + T_b$$

The conversion algorithm introduces a potential error of 0.006 °C in the ALMOS AWS and the Telmet AWS currently under deployment to forecasting sites; the Telmet 320 AWS is not yet approved for use at sites designated as of climatological interest.

Determination of maximum and minimum temperature data from automated monitoring systems has been relatively static since the initial development of the AWS algorithms in 1990. The primary AWS sampling rate is 1 Hz, and mean, maximum temperature statistics are generated from the valid 1 Hz samples over the period of interest. The AWS stores the previous 72 hours of data in the form of statistics for ten minute periods in a circular buffer.

The transmission of the message is dependent on the AWS time clock. These clocks can be out by the order of ±10 minutes, and when transitions from local standard time (LST) to local daylight saving time (LDST) and vice versa are due the clocks can be out by an hour or more from the prescribed time until the clocks are reset via remote manual intervention.

Relevant statistics for 1200 UTC, 0000 UTC and 0900 LST are generated at the required end time. Synoptic messages from AWS have been available since implementation of A2669 (Bureau of Meteorology 1991–2003). MDF reports have only been generated on AWS since 1 November 2001 (Bureau of Meteorology 1991–2003). At those sites where a MetConsole is interfaced to an AWS, MDF data were available in July 2001 after trials started in August 1999.

Exposure of instruments

The maximum and minimum thermometers were housed in an instrument shelter that shielded the instruments from radiation, but allowed free-flow of air (see Figure 1 below and Figure 2 overleaf) as examples of the large Stevenson screen circa 1925). Normally the shelter was exposed above natural vegetation. The *Australian Meteorological Observers Handbook* (Standards Association of Australia 1966) recommended that bare ground was to be avoided. There are a few examples where the growth of grass was artificially encouraged (growth of grass was deemed necessary to control blown dust and sand), or alternatively where the natural vegetation did not lend itself to being kept short and bare ground was maintained.

The instrument shelter was located, where possible, in an open plot of ground 10 x 7 metres (Bureau of Meteorology 1954; 1925; 1973a). Proximity to buildings was to be avoided and objects such as trees and buildings should be at a distance of twice their height from the screen. The shelter itself was to be unshaded (Bureau of Meteorology 1954; 1925; 1973a). The 1954 *Australian Meteorological Observer's Handbook* provided a plan of the layout for a climatological station with the location of the screen specified in the northwest quadrant (Bureau of Meteorology 1954).

A 12 x 12 metres meteorological instrument enclosure was specified in an *Installation Specification 1232* (Bureau of Meteorology 1975) available in November 1975. Furthermore, a clear zone of 30 x 30 metres free of trees, buildings and other obstacles was specified. Natural grasses or vegetation was specified for the surface cover. Grasses requiring watering were disallowed. Where grasses do not grow naturally, the surface cover typical of the district was specified.

Departures from the standards were accepted only if they were unavoidable and notes taken of the deviations. It was also noted that favourable sites might be rendered unfavourable over the passage of time due to the growth of vegetation or development (Bureau of Meteorology 1954; 1925; 1973a).

A larger meteorological instrument enclosure (17 m^2) was specified in 1981 to include provisions for telemetry (Installation Specification 1145 [Bureau of Meteorology 1981]). The shelter was to be located 1.0 m (3' 6") above ground with the door opening to the south in the southern hemisphere. Sensors should be separated from each other, the floor and the sides by 7.5 cm (3") (Bureau of Meteorology 1954; 1925; 1973a). Earlier the bulbs were specified to be 1.2 m (4') about the ground (Commonwealth Meteorology 1907). Considering the double base and three inches above the floor of the screen, these two descriptions are essentially equivalent.

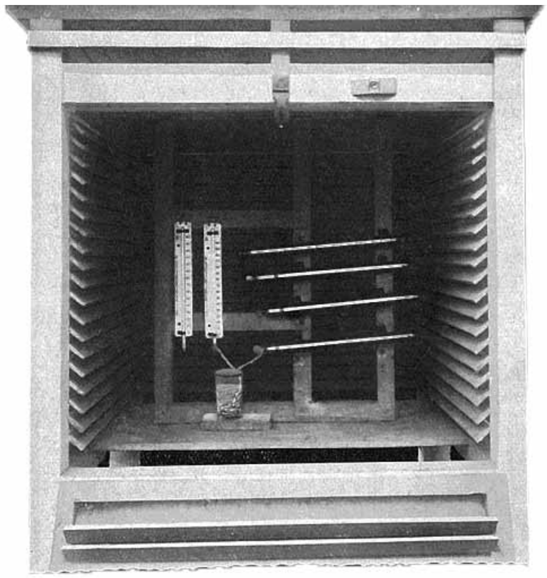

Figure 1. The view inside of a large Stevenson screen used in the Commonwealth Bureau of Meteorology network in 1925.

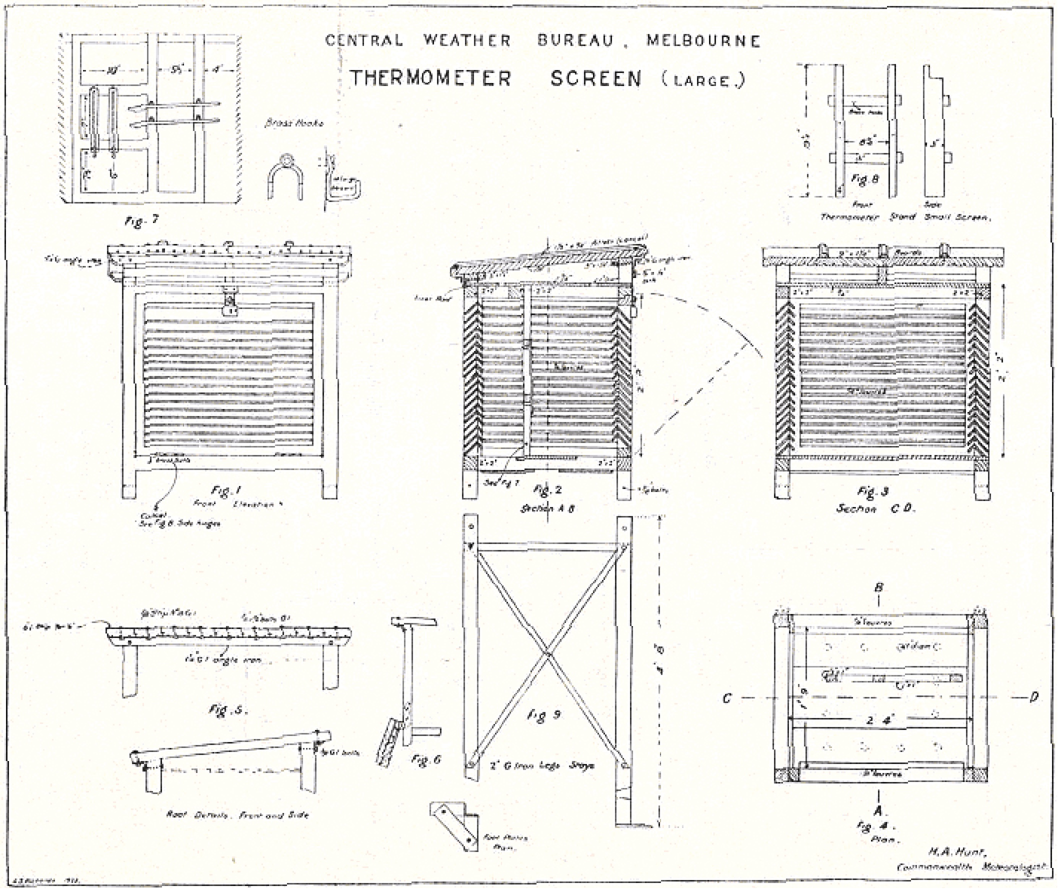

Figure 2. The Commonwealth Bureau of Meteorology large Stevenson screen as specified in 1925.

A separate observation specification (Bureau of Meteorology 1963) was issued for siting of instruments for city conditions. These sites should be within half a mile of city centre and had to be available for at least 15 years. They should be representative of street level and surface could be grass, garden beds or pavement. The metadata of the site consisted of a city map, plans and sketches, photographs from four cardinal directions and a 360° panorama of the skyline. This specification for climatological sites within capital cities has the additional requirement that the site was to be available for 50 years or more. Considering the following capital city sites, as of June 2011, their tenure is provided in Table 3.

Post offices provided a useful location for synoptic observations in the early days of the Bureau. Their regular operation (opening at 0900), access to a small plot of ground to accommodate a Stevenson screen and a raingauge, communications, public profile and wide geographic distribution, led to a large expansion in observations across the country. Bureau field offices, which were established primarily during World War II, in many cases were located at aerodromes. This was due to the complementary advantages of space to conduct balloon-based upper air observations and the direct application of those observations for the rapidly growing aviation industry. The progressive urban build up around post office observing sites and the spreading trend of closure or privatisation made them problematic both in terms of quality and sustainability. The relative attractiveness of airport sites (long-term tenure, security, good meteorological exposure, utility for aviation) for the growing number of automatic weather stations in the 1990s saw a steady shift of observing stations from post offices to airports (Figure 3). The increase is particularly evident from 1990 when the AWS network saw its greatest expansion.

Table 3. The length of tenure of SAT observations at capital city locations. Some locations are included in ACORN-SAT as representative of urban areas.

Station number	Station name	Start date	End date	ACORN-SAT
086071	Melbourne (Regional Office)	1908		Yes
066062	Sydney (Observatory Hill)	1858		Yes
094029	Hobart (Ellerslie Road)	1882		Yes
023000	Adelaide (West Terrace)	1839	1980	Yes, but relocated
009034	Perth (Regional Office)	1876	1992	Yes, but relocated
040214	Brisbane (Regional Office)	1840	1994	No
014161	Darwin (Regional Office)	1967	1973	No

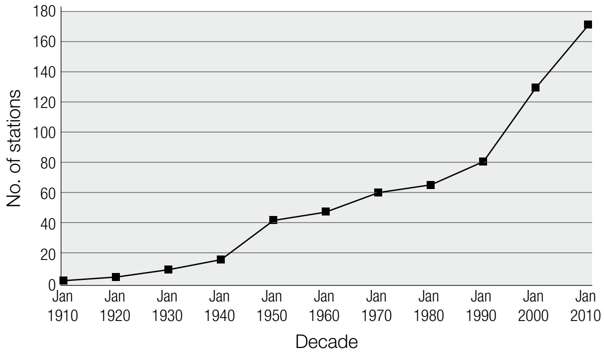

Figure 3. The increase in representation of airport localities for meteorological observations sites over the past 100 years. The slope shows a step increases from 1940 to 1950 with aviation requirements during World War II, and from 1990 to 2010 with the expansion in the AWS network.

Screen maintenance

The instrument shelter (or thermometer screen) was specified for monthly cleaning (Bureau of Meteorology 1975). Instructions from 1973 onwards specified the requirement to clean screens after dust storms, and in 1984 the instruction was modified to indicate that shelters in industrial areas may need weekly cleaning. Cleaning had to be finished at least 30 minutes before the next scheduled observation, and that requirement remains today.

Inspections

During the regular, typically yearly, inspections of the observing site by Bureau inspectors and maintenance staff, a series of checks outlined in the *Inspections Handbook* (Bureau of Meteorology c. 2011b) are performed. In the early days of the network, given that a majority of sites were at post offices, post office inspectors would document the state of meteorological sensors at their offices and pass this information to the Bureau. Network-wide inspections of meteorological sensors and sites by Bureau staff were initiated in the mid-1960s.

Prior to the introduction of the Dostmann electronic thermometer reference in 2008, the temperature checks by Bureau staff for site ordinary MiG and AWS-PRT were performed during site inspections with MiG thermometers that were calibrated or verified by the Bureau's metrology laboratory.

The inspections also required that the MiG and AiG thermometers be examined to ensure the scale on the glass matched the scale on the thermometer support, and was adjusted if perceived to be out of alignment.

Prior to 2002, the inspectors' MiG thermometers were calibrated and correction tables provided for inspectors. However, in 2002 it was found that the need to apply a correction proved difficult for some inspectors and subsequently only MiG thermometers that were within the accepted uncertainty limits were supplied for inspections.

When Dostmann electronic thermometers replaced the inspection MiGs, direct physical contact of the reference probe, the SAT probe and, if used, the dried wet-bulb probe was required. This minimised the uncertainty due to air-proximity factors that had impacted on in-glass testing.

There is evidence to suggest that an ice point check was also used prior to the 1970s during inspections on occasions when ice was available. However, documentary evidence on the procedure is not available.

Infrastructure for surface air temperature measurements

Metadata

As well as the site recordings in record books during normal operations and the site location, a wealth of metadata are acquired on each site or part of the control system used for the operation and maintenance of the network. At the start of the Bureau's network in the early 20th century the metadata was dominated by the station records and regular communications stored in the Bureau's registry file system.

Prior to the introduction of personal computers or data terminals for general usage throughout the Bureau, networks information was maintained in the regions in the form of station files, hosts of lists and in the memories of inspectors. The information in head office was kept on registry station files, numerous lists and a number of independent catalogues stored on the Bureau's mainframe computer. The computer catalogues were cumbersome to maintain, time-consuming to update and not cross-referenced against each other—resulting in many inconsistencies and errors.

Station inspections have been part of Bureau operations over the last several decades. Most historical records of station inspections are stored in the Bureau's registry file system 90-series station files. During the late 1980s, a National Observations Networks Database (NONdBase) was developed to provide an electronic (PC-based) system to record station metadata. This database became operational in all regions in April 1990. Information from inspection visits and updates to station histories were recorded on various forms, including F533 Station history and F624 Station inspection (Staffed and AWS). These forms were used initially to provide a record on registry station files, and following the development of electronic databases, used for data entry.

NONdBase was superseded in 1997 by SitesDb, now the Bureau's corporate database of metadata for its entire network of stations. This includes information on station details, observations program, instruments, associated observing equipment, or systems and engineering maintenance requirements.

The notion of a sites database started as a relatively straightforward concept to satisfy a requirement within the Observations and Engineering Branch of the Bureau and the National Climate Centre to consolidate the NONdBase and ADAM station dictionaries into a single source of station information.

The NONdBase was maintained for many years in the Bureau's head office and the regional observations sections and contained station details, including historical data. It therefore provided initial seeding of metadata, at least from the observations perspective. Since the original purpose of SitesDb was to provide metadata, it is unique in its careful design to provide accurate historical data, especially to meet the requirement for the Bureau's climate database, ADAM. It was also designed to provide the necessary management tool for the observations and engineering programs. Its value as a management tool for other programs across the Bureau was recognised and the resources for the development and implementation of SitesDb had contributions from across these programs.

SitesDb was released in 1997 for national use and metadata entry was performed by regional staff following stations visits to record all aspects of the visit, and included management information (such as station details and observation program) which did not require a physical visit. Data from NONdBase was used to seed SitesDb where possible providing SitesDb with some historical data which preceded 1998. Regions were also encouraged to back seed metadata for significant surface observations stations such as field offices. This was completed for a small subset of stations, however, it is incomplete.

Since its introduction, SitesDb has developed into a comprehensive web-based information system that is a key metadata tool for the operation of the Bureau's composite observing system and is now the dominant repository for metadata. Over the past year, more than 6000 station history changes were made, and over 11 000 field performance verifications entered.

The Bureau registry file system, individual log files from the metrology laboratory, and operational process document and standards dominated the metadata system prior to SitesDb, and still operate in parallel today but with reduced functionality. Policies enacted prior to the move of the Bureau's head office at 150 Lonsdale Street, Melbourne (Australia) to 700 Collins Street, Docklands, meant that a significant number of files that were 30 years old or more were destroyed. As a result, several files relating to observational practices and process prior to 1973 were not available for the preparation of this report.

Prior to the building move, consideration was given to disposing of old instruments, devices and personal logs that were a key part of the early metrology laboratories. However, in this case a metrology museum project was established, and a catalogue (including photos and references) was created (Warne 2003), and storage in the short-term was organised. This catalogue was a particularly useful reference source for historical information regarding all aspects of surface measurements in the Bureau.

One aspect of metadata that was not consistent until the advent of GPS location systems was the representation of latitude and longitude. While the locations were surveyed, the recording and depiction of location coordinates caused confusion. Some locations were determined as degrees and minutes (that is to within one nautical mile), but recorded as decimal; for example, a latitude of 35 E 52' S could be recorded as 35.52. Other locations were recorded with a resolution of 0.1 E with a resultant uncertainty of about six nautical miles. With the arrival of GPS, and uniform recording practices, the information in SitesDb was updated to reflect a better estimate of site location.

Instrument shelter

Since 1907, the approved instrument shelter was the large Stevenson screen (as shown previously in Figure 1). The position of the thermometers was carefully prescribed (Bureau of Meteorology 1973). The screens in use were manufactured in the early part of the century and conformed to the Stevenson pattern (Bureau of Meteorology 1925). This consisted broadly of a wooden box with double louvered sides and double roof and base (as shown previously in Figure 2) with full specifications for construction provided (Bureau of Meteorology 1925). The large Stevenson screen had an internal volume of approximately 0.23 m^3.

A more detailed specification for the large Stevenson screen was published in 1962 (Bureau of Meteorology 1962). A further specification for the large instrument shelter in 1990 provided very similar dimensions to the earlier design in 1907 and 1962 (Bureau of Meteorology 1990).

With the advent of electronic SAT measurement, the small Stevenson screen became the standard screen type. The small instrument shelter was specified in 1973 (Bureau of Meteorology 1973b). Two instrument test reports, ITR 601 in 1988 and ITR 649 in 1998, documented the comparison between the original Stevenson screen, small Stevenson screen (volume 0.06 m^3) and a variety of other screens (Brunt 1988; Warne 1998). The 1998 study showed that the differences in recorded temperatures between the large and small Stevenson screens were less than 0.1 °C; other screen types demonstrated greater difference to the large Stevenson screen.

A shelter for tropical countries, effectively a thatched hut, was specified (Bureau of Meteorology 1925). This appears to simply be a copy of the material contained in the equivalent British document. To date, no records are available indicating that a tropical shelter was used in Australia.

According to SitesDb, the following instrument shelter types are currently in use in the broader network (SitesDb, 21 June 2011). All ACORN-SAT sites have either a large or small Stevenson screen. The type and number of instrument shelters in use throughout the SAT network are provided in Table 4 (see overleaf) and show that the transition to small Stevenson screens is virtually complete. The instrument shelter standard of a Stevenson screen is maintained at all ACORN-SAT sites.

Table 4. Summary of types and number of instrument shelter types for the whole Bureau network, and then for ACORN-SAT sites as of 20 June 2011 as extracted from SitesDb.

Type	Entire network	ACORN-SAT
Large Stevenson	28	5
Marine Stevenson	167	
Other	39	
RM Young 41002	16	
Small Stevenson	894	107
Unknown	25	
Vaisala	14	
Vaisala DTR 13	29	

Examples of the small Stevenson screen at the enclosure at Hobart Airport, Tasmania are shown in Figure 4. Figure 5 shows the internal thermometer and platinum-resistance probe array in the same small Stevenson screen, and this is typical of those SAT sites where both automated and manual SAT observations are continued.

Table 5 lists the start and end dates for each shelter type at ACORN-SAT sites. The general pattern is that the small Stevenson screen replaced the large Stevenson when the station was converted to automated observations. The small screen retained sufficient space for the PRT probes (wet and dry), and if an observer was available, maximum and minimum thermometers for manual recording.

Figure 4. Small Stevenson screen used at the majority of SAT observing sites.

Figure 5. The internal view of a small Stevenson screen set up with both in-glass and platinum resistance probes. Maximum and minimum thermometers are in the upper right, and a spare terrestrial minimum thermometer is in the top left. The photo was taken during the site audit by the Regional Instrument Centre of the Hobart Airport site in 2010.

Table 5. A history of screen type used at sites designated as part of ACORN-SAT. Dates earlier than 1997 are based on reconstruction of station files. Dates which are considered suspect are in italics.

		Screen type			
		Large Stevenson		Small Stevenson	
Stn name	Stn no.	Start	End	Start	End
Kalumburu	001019			16/09/1998	Ongoing
Halls Creek Airport	002012	01/01/1944	25/08/1996	25/08/1996	Ongoing
Broome Airport	003003			01/08/1939	Ongoing
Port Hedland Airport	004032	17/07/1942	08/10/1997	08/10/1997	Ongoing
Marble Bar	004106			25/09/2000	Ongoing
Learmonth Airport	005007	01/03/1975	19/09/2006	29/08/1994	Ongoing
Wittenoom	005026	01/10/1951	Ongoing		
Carnarvon Airport	006011	01/01/1945	11/09/1997	11/09/1997	Ongoing
Meekatharra Airport	007045	01/05/1950	02/05/1996	02/05/1996	Ongoing
Dalwallinu Comparison	008039	01/06/1955	10/04/1975	10/04/1975	Ongoing
Geraldton Airport	008051	01/09/1941	30/09/1999	30/09/1999	Ongoing
Morawa Airport	008296			25/02/1997	Ongoing
Perth Airport	009021	01/05/1944	27/10/1997	27/10/1997	Ongoing
Bridgetown Comparison	009510	01/01/1901	15/12/1987	15/12/1987	Ongoing
Cape Leeuwin	009518	*01/01/1900*	31/10/1978	31/10/1978	Ongoing
Albany Airport	009741	01/04/1965	04/03/1998	04/03/1998	Ongoing
Esperance	009789	28/06/1969	11/05/2004	11/05/2004	Ongoing
Merredin	010092			*14/12/1965*	Ongoing
Cunderdin Airfield	010286			20/08/1996	Ongoing
Katanning Comparison	010579			01/01/1900	Ongoing
Wandering	010917			11/12/1998	Ongoing
Eucla	011003	01/01/1926	05/06/1976	05/06/1976	Ongoing
Forrest	011052			15/03/1993	Ongoing
Kalgoorlie-Boulder Airport	012038	01/03/1939	12/08/1992	12/08/1992	Ongoing
Giles Meteorological Office	013017	01/09/1956	26/08/2009	26/08/2009	Ongoing
Darwin Airport	014015	31/07/2003	02/04/2008	*01/01/1941*	Ongoing
Victoria River Downs	014825			01/08/1968	Ongoing
Tennant Creek Airport	015135	01/08/1969	Ongoing		
Alice Springs Airport	015590	01/11/1941	30/08/1998	30/08/1998	Ongoing
Rabbit Flat	015666			13/11/1996	Ongoing
Woomera Aerodrome	016001	01/01/1949	03/04/2001	03/04/2001	Ongoing
Tarcoola Aero	016098			30/09/1997	Ongoing
Marree Comparison	017031			*01/01/1939*	Ongoing
Oodnadatta Airport	017043	01/03/1939	31/12/1985	03/11/1994	Ongoing
Ceduna AMO	018012	01/03/1939	26/03/1999	26/03/1999	Ongoing
Kyancutta	018044			*18/06/1930*	Ongoing

		Screen type			
		Large Stevenson		Small Stevenson	
Stn name	Stn no.	Start	End	Start	End
Port Lincoln AWS	018192			02/04/1992	Ongoing
Rayville Park	021133			02/04/1998	Ongoing
Cape Borda	022823			*15/07/2002*	Ongoing
Kent Town	023090	26/08/1994	Ongoing	17/02/1977	26/08/1994
Nuriootpa Viticultural	023373			28/08/1996	Ongoing
Mount Gambier Aero	026021	18/08/1941	20/12/2000	20/12/2000	Ongoing
Robe Comparison	026026			01/01/1938	Ongoing
Weipa Aero	027045	01/12/1992	11/11/2000	11/11/2000	Ongoing
Horn Island	027058			10/01/1995	Ongoing
Palmerville	028004	01/01/1907	23/09/1994	23/09/1994	Ongoing
Normanton Airport	029063			10/04/2001	Ongoing
Burketown Airport	029077			10/10/2001	Ongoing
Richmond Post Office	030045			*01/01/1908*	Ongoing
Georgetown Airport	030124			31/05/2004	Ongoing
Cairns Aero	031011	05/05/1941	04/10/2005	04/10/2005	Ongoing
Townsville Aero	032040	01/11/1940	08/12/1994	08/12/1994	Ongoing
Mackay MO	033119	25/09/1959	18/10/1995	18/10/1995	Ongoing
Charters Towers Airport	034084			14/12/1992	Ongoing
Barcaldine Post Office	036007	*01/01/1900*	11/09/1985	11/09/1985	Ongoing
Longreach Aero	036031	01/03/1966	31/05/1996	31/05/1996	Ongoing
Camooweal Township	037010			*01/01/1900*	Ongoing
Boulia Airport	038003			*01/01/1900*	Ongoing
Birdsville Airport	038026			27/06/2000	Ongoing
Gayndah Airport	039066			24/01/2003	Ongoing
Rockhampton Aero	039083	01/04/1939	22/03/2000	22/03/2000	Ongoing
Bundaberg Aero	039128	01/02/1942	19/12/1997	19/12/1997	Ongoing
Amberley AMO	040004	01/09/1941	08/07/1997	08/07/1997	Ongoing
Cape Moreton Lighthouse	040043			03/08/1995	Ongoing
Brisbane Aero	040842			10/12/1992	Ongoing
Miles Constance Street	042112			10/07/1997	Ongoing
St George Airport	043109			01/05/1997	Ongoing
Charleville Aero	044021	01/04/1942	13/11/2003	08/12/1999	Ongoing
Thargomindah Airport	045025			21/07/1999	Ongoing
Tibooburra Post Office	046037	01/01/1910	01/09/1980	01/09/1980	Ongoing
Wilcannia (Reid Street)	046043			*01/01/1900*	Ongoing
Cobar MO	048027	01/06/1962	15/11/2000	01/05/1997	Ongoing
Bourke Airport AWS	048245			03/12/1998	Ongoing

		Screen type			
		Large Stevenson		Small Stevenson	
Stn name	**Stn no.**	**Start**	**End**	**Start**	**End**
Walgett Airport AWS	052088			01/06/1993	Ongoing
Moree Aero	053115			16/06/2000	Ongoing
Gunnedah Resource Centre	055024	01/01/1948	Ongoing		
Inverell (Raglan St)	056242			01/03/1995	Ongoing
Yamba Pilot Station	058012	27/06/1939	17/12/1987	17/12/1987	Ongoing
Coffs Harbour MO	059040	01/02/1943	03/04/2002	03/04/2002	Ongoing
Port Macquarie Airport AWS	060139			06/05/1995	Ongoing
Williamtown RAAF	061078	01/09/1942	07/07/1999	07/07/1999	Ongoing
Scone Airport AWS	061363			12/01/1990	Ongoing
Bathurst Agricultural Station	063005	01/01/1909	26/05/1998	20/11/1969	Ongoing
Dubbo Airport AWS	065070			06/11/1997	Ongoing
Sydney (Observatory Hill)	066062	01/01/1900	20/01/2000	20/01/2000	Ongoing
Richmond RAAF	067105			13/10/1997	Ongoing
Nowra Ran Air Station AWS	068072			09/11/2000	Ongoing
Point Perpendicular AWS	068151			03/05/2001	Ongoing
Moruya Heads Pilot Station	069018	*01/01/1900*	Ongoing		
Wagga Wagga AMO	072150	01/02/1941	10/01/2001	10/01/2001	Ongoing
Cabramurra Smhea AWS	072161			10/12/1996	Ongoing
Wyalong Post Office	073054	11/09/1950	13/04/1988	13/04/1988	Ongoing
Deniliquin Airport AWS	074258			03/06/1997	Ongoing
Mildura Airport	076031	02/01/1946	03/05/2000	03/05/2000	Ongoing
Nhill Aerodrome	078015			11/06/2003	Ongoing
Kerang	080023			01/01/1903	Ongoing
Rutherglen Research	082039			01/01/1913	Ongoing
Gabo Island Lighthouse	084016			*01/01/1900*	Ongoing
Orbost (Comparison)	084030	01/01/1938	13/04/1972	13/04/1972	Ongoing
East Sale Airport	085072	01/05/1943	08/04/2003	08/04/2003	Ongoing
Wilsons Promontory Lighthouse	085096	*01/01/1900*	18/09/2000	18/09/2000	Ongoing
Melbourne Regional Office	086071	31/10/1967	30/01/2001	29/01/2001	Ongoing
Laverton RAAF	087031	01/06/1941	15/08/1999	22/02/1997	Ongoing
Cape Otway Lighthouse	090015			*01/01/1900*	Ongoing
Low Head	091293			05/11/1997	Ongoing
Launceston Airport	091311			14/06/2004	Ongoing
Eddystone Point	092045	01/08/1908	24/07/1997	24/07/1997	Ongoing
Cape Bruny Lighthouse	094010	*01/01/1900*	26/03/1991	26/03/1991	Ongoing
Hobart (Ellerslie Road)	094029	*01/01/1900*	08/11/2007	08/11/2007	Ongoing
Butlers Gorge	096003			25/10/1989	Ongoing

Supply and field use of in-glass thermometers

In-glass thermometers come in a variety of forms: ordinary thermometers used for synoptic observations, maximum and minimum thermometers, terrestrial thermometers and, up until 2008, inspection thermometers.

While these devices provided the means for the primary SAT measurements up until 1 November 1996 (Bureau of Meteorology 1997), a significant number of sites still maintain manual in-glass SAT measurements (previously shown in Figure 5) and input into the Bureau's data collection system via the A8 form.

A clear description of how the thermometer should be read and the process to round the numbers is in the *Surface Observations Handbook* (Bureau of Meteorology c. 2011a), the original of which was probably sourced from the editions of the *British Handbook on Measurement of Temperature* (British Meteorological Office 1956; 1981).

In-glass thermometers purchased for SAT observations, or maximum and minimum thermometers, were never calibrated nor checked by the Bureau's metrology laboratory. Instead, the thermometers are assumed to read in the correct units based on the relevant manufacturing standard. These thermometers are supplied to the Bureau central store directly from the manufacturer and then distributed to the sites. A number of thermometers are held in storage at each site as spares.

Field checks are carried out using a variety of methods including:

a) comparison with an inspection thermometer during an inspection visit, and

b) if the ambient, maximum and minimum temperature via in-glass are available, they are compared on reset at the time of the 0900 observation.

The tolerance checks currently in place appear to be based on the translation of the *British Meteorological Office Handbook on Temperature Measurement* (British Meteorological Office 1956; 1981); namely ±1 °F prior to 1 September 1972 and post that date ±0.5 °C.

The daily routine used by observers at staffed sites at the 0900 observation time has had a similar process for almost a century. Once the normal MiG, maximum MiG, and minimum AiG are read, the maximum and minimum thermometers are reset. On reset the maximum and minimum thermometers are checked to ensure they are reading within the equivalent of ±0.5 °C of the normal MiG. The differences are noted and recorded in the A8 form (or its equivalent). If the maximum or minimum thermometers are outside that difference and corrective action outlined in the *Surface Observations Handbook* (Bureau of Meteorology c. 2011a) cannot correct the apparent fault, the relevant thermometer is replaced with one of the spare thermometers kept on station, and the faulty thermometer disposed of as per procedure; the replacement is noted in the field book and SitesDb.

Maximum and minimum in-glass thermometers purchased for network use have never been calibrated or verified by the Bureau's metrology laboratory, and not field checked during an inspection. The 0900 check is the only verification process for these thermometers.

From 1958 to the present, thermometers (ordinary, maximum and minimum) have been purchased by the Bureau provided they adhere to the relevant standard specifications (Handcock 2011, pers. comm.).

The national tolerance standards used in Bureau in-glass thermometry are summarised in Table 6. The current manufacturing tolerance standards are according to AS 2819 (Standards Association of Australia 1985) and have been in operation since 1985. Prior to 1985, AS R13 (Standards Association of Australia 1966) was the standard from 1966. Prior to 1966, there does not appear to be any Australian standard for meteorological thermometers. However, the specification that thermometers were bought against was Bureau Standard A410 for Meteorological Thermometers (Commonwealth Bureau of Meteorology 1962) which took into account British Standard 692 (1958) (British Standards Institution 1958).

Table 6. A summary of performance requirements for ordinary and maximum thermometers since the 1950s. Specifications for thermometers used from 1908 through to 1950 are likely to follow British Standards, but the file documentation to confirm is not available.

Implied temperature range	British Standard 692 (1951)	Australian Standard A210 (1958)	Australian Standard AS R13 (1966)	Australian Standard AS 2819 (1985)
0 → 55 °C	–0.1 → +0.3 °F		–0.1 → +0.3 °F (–0.05 → 0.15 °C)	–0.05 → 0.15 °C
–10 → 0 °C	–0.3 → +0.5 °F	–0.3 → +0.5 °F	–0.3 → +0.5 °F	

Table 7. Manufacturing tolerances for meteorological thermometers (Celsius scale) as per AS R13 (1966) and subsequently AS 2819 (1985).

Thermometer type	Permissible error at any graduation mark			Permissible algebraic difference at each end of any 10 °C interval		
	<0 °C	>0 °C – 25 °C	>25 °C	<0 °C	>0 °C – <25°C	>25 °C
Maximum	+0.15 –0.3	+0.05 –0.15	+0.05 –0.15	0.2	0.1	0.1
Minimum	±0.2	±0.1	±0.2	0.2	0.1	0.2
Ordinary	+0.15 –0.3	+0.05 –0.15	+0.05 –0.15	0.2	0.1	0.1

The introduction of A410 mercurial thermometers for Bureau operations, purchased in Australia, required that each thermometer was supplied with an individual calibration certificate or a batch calibration certificate from a laboratory that was NATA-accredited for temperature calibration (that is, against ISO 17025). Thermometers purchased for operational use were required to meet the manufacturing specification listed in Table 6, as per the AS R13 (Standards Association of Australia 1966) and hence AS 2819 (Standards Association of Australia 1985).

From 1974, ordinary MiG thermometers were batch tested by the Bureau metrology laboratory according to the Bureau standards in place at the time (Easson 2011, pers. comm.). These tests were performed to determine which of the thermometers was suitable for further testing and ultimately for use in site inspections. Those identified as potentially suitable for use as inspection thermometers were calibrated by the metrology laboratory. Those likely MiG inspection thermometers were calibrated across the temperature range of likely use required to measure the temperature in laboratory conditions with less than a 0.1 °C deviation from the scale read temperature. The majority of ordinary MiG thermometers that did not meet inspection thermometer performance in the first instance or were rejected during the calibration process were transferred to the supply store for ordinary SAT observations.

Maximum and minimum thermometers supplied against AS R13 (Standards Association of Australia 1966) and AS 2819 (Standards Association of Australia 1985) were assumed to be within tolerance based on their manufacturer supplied paperwork. While wastage rates of thermometers used for SAT observations were relatively low, a typical purchase of 100 thermometers per annum was required to sustain network numbers and provide spares on-site. The replacement rate of maximum and minimum thermometers was high given the nature of their use; being manually reset at 0900 every day. However, as automated systems replaced manual observations, the number of MiG and AiG thermometers in the field was greatly reduced.

As indicated above, ordinary MiG thermometers with the better characteristics also had a special use within the observing network; these reliable, well-characterised MiG thermometers were used as inspection thermometers. On a regular basis, typically yearly, each site is inspected by a Bureau inspector to verify the measurements including SAT, using the processes defined in the *Inspections Handbook* (Bureau of Meteorology c. 2011b). MiG thermometers were used as inspection thermometers until 2008, and then replaced with resistance-type Dostmann thermometers with digital outputs and considerably better laboratory-based uncertainties.

The use of the inspection MiG calibration certificate in field inspections has a mixed history. An audit of the process in the early 2000s suggested that some inspectors were concerned about what to do with corrections <0.1 °C as available on the calibration certificate, when related to the ±0.5 °C tolerance limits. As a result, from 12 February 2002 until 2008 (when the inspection MiGs were replaced with Dostmanns) only statements of compliance were supplied with the inspection thermometers (Bureau of Meteorology 2002).

Supply and use of platinum-resistance thermometers for field use

With the introduction of AWS, PRT became the widely used thermometer for SAT monitoring. In the 1980s, the Bureau designed a platinum-resistance probe and sought manufacturers of the probes. The aim of the design was to mimic the time constant of the MiG thermometers to within a tolerance of ±5 seconds.

Four versions of the probe were produced before the design of the sensor stabilised and three are shown in Figure 6; all four varieties of these probes are in use across the observing network. The initial probe had a short thick steel probe but resulted in an extended time constant to that of the MiG thermometers. The second variety developed in the mid-1990 used a smaller diameter and longer steel probe with a time constant almost identical to the MiG thermometers. The third version of the probe had minor adjustments to ensure that the positioning of the resistance element was consistent during manufacture (mainly to make certain of correct usage for wet-bulb measurements), and the final version changed the connector from a Canon to Lemo connector.

The design of the sensors has now stabilised and sensors are supplied by at least two independent manufacturers.

Figure 6. Three versions of the platinum-resistance sensors used in Bureau AWS since the 1980s.

The A2669 Specification (Bureau of Meteorology 1991–2003) of the AWS required an uncertainty tolerance for converting an equivalent platinum-resistance to an equivalent temperature within ±0.02 °C, and an output resolution of 0.1 °C in routine operational mode. Individual AWS digitisation modules were tested in the metrology laboratory on occasion but as with the in-glass probes there is an assumption that the combined resistance-digitisation temperature measurement tolerance of ±0.5 °C is a sufficient test for these thermometers.

In the first two decades of these probes' use, a small number of probes failed the inspection tolerance criterion and were returned to the metrology laboratory for testing. In the majority of cases the probes' resistances were found to be within the ±0.08 °C laboratory tolerance requirements. Investigation suggested that the primary reasons for the failures were either a minor increase in resistance due to connector corrosion, poor comparison conditions, and the use of a higher uncertainty MiG inspection thermometer during the check. As a result, the process for detecting faulty probes in the field was modified to account for connector and lead maintenance and the number of failure returns decreased.

In 2008 after a series of field trials and testing, Dostmann digital thermometers replaced the MiG inspection thermometers. As with each PRS, all Dostmann temperature probes are calibrated in the Bureau metrology laboratory to ensure they provide temperature measurements within ±0.08 °C in laboratory conditions. After a yearly tour of duty in inspections, the Dostmanns are returned to the metrology laboratory for recalibration and verification.

The transition between AiG and MiG thermometers and the electronic PRTs is provided in Table 8. Most sites show a transition to PRTs beginning during the mid-1990s. New sites during this period were exclusively installed with PRTs. However, most Bureau-staffed stations continue to maintain both the manually read thermometers and PRTs. The manual data such as reset temperatures are recorded in the A8 field book.

Table 8. Historical temperature sensor equipment types for ACORN-SAT stations. Dates earlier than 1997 are based on reconstruction of station files. Start dates which no entry indicate lack of metadata information within SitesDb Table.

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Kalumburu	1019	Equip Start			16/09/1998
		Equip End			Ongoing
Halls Creek Airport	2012	Equip Start	1/01/1944	1/01/1944	25/08/1996
		Equip End	Ongoing	Ongoing	Ongoing
Broome Airport	3003	Equip Start	1/08/1939	1/08/1939	27/07/1995
		Equip End	Ongoing	Ongoing	Ongoing
Port Hedland Airport	4032	Equip Start	17/07/1942	17/07/1942	24/11/1994
		Equip End	Ongoing	Ongoing	Ongoing
Marble Bar	4106	Equip Start			25/09/2000
		Equip End			Ongoing
Learmonth Airport	5007	Equip Start	1/03/1975	1/03/1975	29/08/1994
		Equip End	Ongoing	Ongoing	Ongoing
Wittenoom	5026	Equip Start	25/09/1951	25/09/1951	
		Equip End	Ongoing	Ongoing	
Carnarvon Airport	6011	Equip Start	1/01/1945	1/01/1945	22/10/1990
		Equip End	Ongoing	Ongoing	Ongoing
Meekatharra Airport	7045	Equip Start	1/05/1950	1/05/1950	7/02/1991
		Equip End	Ongoing	Ongoing	Ongoing
Dalwallinu Comparison	8039	Equip Start	1/06/1955	1/06/1955	
		Equip End	Ongoing	Ongoing	
Geraldton Airport	8051	Equip Start	1/09/1941	1/09/1941	24/06/1990
		Equip End	Ongoing	Ongoing	Ongoing
Morawa Airport	8296	Equip Start			25/02/1997
		Equip End			Ongoing
Perth Airport	9021	Equip Start	1/06/1944	1/06/1944	20/06/1994
		Equip End	Ongoing	Ongoing	Ongoing
Bridgetown Comparison	9510	Equip Start	1/01/1901	1/01/1901	
		Equip End	Ongoing	Ongoing	
Cape Leeuwin	9518	Equip Start	1/01/1900	1/01/1900	3/02/1993
		Equip End	3/02/1993	3/02/1993	Ongoing

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Albany Airport	9741	Equip Start	1/04/1965	1/04/1965	17/08/1992
		Equip End	Ongoing	Ongoing	Ongoing
Esperance	9789	Equip Start	28/06/1969	28/06/1969	24/06/1994
		Equip End	Ongoing	Ongoing	Ongoing
Merredin	10092	Equip Start	14/12/1965	14/12/1965	
		Equip End	Ongoing	Ongoing	
Cunderdin Airfield	10286	Equip Start			31/07/1996
		Equip End			Ongoing
Katanning Comparison	10579	Equip Start	1/01/1900	1/01/1900	
		Equip End	Ongoing	Ongoing	
Wandering	10917	Equip Start			11/12/1998
		Equip End			Ongoing
Eucla	11003	Equip Start	1/01/1926	1/01/1926	25/03/1995
		Equip End	Ongoing	Ongoing	Ongoing
Forrest	11052	Equip Start			15/03/1993
		Equip End			Ongoing
Kalgoorlie-Boulder Airport	12038	Equip Start	30/09/1999	30/09/1999	12/08/1992
		Equip End	Ongoing	Ongoing	Ongoing
Giles Meteorological Office	13017	Equip Start	1/09/1956	1/09/1956	1/06/1992
		Equip End	Ongoing	Ongoing	Ongoing
Darwin Airport	14015	Equip Start	1/02/1941	1/02/1941	10/01/1998
		Equip End	Ongoing	Ongoing	Ongoing
Victoria River Downs	14825	Equip Start	1/08/1968	1/08/1968	29/06/1997
		Equip End	Ongoing	Ongoing	Ongoing
Tennant Creek Airport	15135	Equip Start	1/08/1969	1/08/1969	1/07/1990
		Equip End	Ongoing	Ongoing	Ongoing
Alice Springs Airport	15590	Equip Start	1/11/1941	1/11/1941	21/03/1991
		Equip End	Ongoing	Ongoing	Ongoing
Rabbit Flat	15666	Equip Start	6/02/2007	6/02/2007	27/05/1997
		Equip End	Ongoing	Ongoing	Ongoing
Woomera Aerodrome	16001	Equip Start	1/04/1949	1/04/1949	20/06/1991
		Equip End	Ongoing	Ongoing	Ongoing
Tarcoola Aero	16098	Equip Start			30/09/1997
		Equip End			Ongoing
Marree Comparison	17031	Equip Start	1/01/1939	1/01/1939	
		Equip End	Ongoing	Ongoing	

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Oodnadatta Airport	17043	Equip Start			2/11/1994
		Equip End			Ongoing
Ceduna AMO	18012	Equip Start	1/03/1939	1/03/1939	1/07/1990
		Equip End	Ongoing	Ongoing	Ongoing
Kyancutta	18044	Equip Start	18/06/1930	18/06/1930	
		Equip End	Ongoing	Ongoing	
Port Lincoln AWS	18192	Equip Start			2/04/1992
		Equip End			Ongoing
Rayville Park	21133	Equip Start			2/04/1998
		Equip End			Ongoing
Cape Borda	22823	Equip Start			15/07/2002
		Equip End			Ongoing
Kent Town	23090	Equip Start	17/02/1977	17/02/1977	26/10/1992
		Equip End	1/03/2007	1/03/2007	Ongoing
Nuriootpa Viticultural	23373	Equip Start			28/08/1996
		Equip End			Ongoing
Mount Gambier Aero	26021	Equip Start	18/08/1941	18/08/1941	5/07/1993
		Equip End	Ongoing	Ongoing	Ongoing
Robe Comparison	26026	Equip Start	1/01/1938	1/01/1938	
		Equip End	Ongoing	Ongoing	
Weipa Aero	27045	Equip Start	1/12/1992	1/12/1992	1/12/1992
		Equip End	Ongoing	Ongoing	Ongoing
Horn Island	27058	Equip Start			10/01/1995
		Equip End			Ongoing
Palmerville	28004	Equip Start	1/01/1907	1/01/1907	12/07/2001
		Equip End	18/10/1999	18/10/1999	Ongoing
Normanton Airport	29063	Equip Start			10/04/2001
		Equip End			Ongoing
Burketown Airport	29077	Equip Start			10/10/2001
		Equip End			Ongoing
Richmond Post Office	30045	Equip Start	1/01/1908	1/01/1908	
		Equip End	Ongoing	Ongoing	
Georgetown Airport	30124	Equip Start			31/05/2004
		Equip End			Ongoing
Cairns Aero	31011	Equip Start	5/05/1941	5/05/1941	5/05/1941
		Equip End	Ongoing	Ongoing	Ongoing

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Townsville Aero	32040	Equip Start	1/11/1940	1/11/1940	8/12/1994
		Equip End	Ongoing	Ongoing	Ongoing
Mackay MO	33119	Equip Start	25/09/1959	25/09/1959	18/10/1995
		Equip End	Ongoing	Ongoing	Ongoing
Charters Towers Airport	34084	Equip Start	14/12/1992	14/12/1992	
		Equip End	Ongoing	Ongoing	
Barcaldine Post Office	36007	Equip Start	1/01/1900	1/01/1900	
		Equip End	Ongoing	Ongoing	
Longreach Aero	36031	Equip Start	1/03/1966	1/03/1966	31/05/1996
		Equip End	Ongoing	Ongoing	Ongoing
Camooweal Township	37010	Equip Start	1/01/1900	1/01/1900	11/11/1997
		Equip End	30/09/1997	30/09/1997	Ongoing
Boulia Airport	38003	Equip Start	1/01/1900	1/01/1900	
		Equip End	Ongoing	Ongoing	
Birdsville Airport	38026	Equip Start			27/06/2000
		Equip End			Ongoing
Gayndah Airport	39066	Equip Start			24/01/2003
		Equip End			Ongoing
Rockhampton Aero	39083	Equip Start	1/04/1939	1/04/1939	1/04/1993
		Equip End	Ongoing	Ongoing	Ongoing
Bundaberg Aero	39128	Equip Start	1/02/1942	1/02/1942	19/12/1997
		Equip End	19/12/1997	19/12/1997	Ongoing
Amberley AMO	40004	Equip Start	1/09/1941	1/09/1941	3/07/1997
		Equip End	Ongoing	8/07/1997	Ongoing
Cape Moreton Lighthouse	40043	Equip Start			3/08/1995
		Equip End			Ongoing
Brisbane Aero	40842	Equip Start	14/02/2000	14/02/2000	10/12/1992
		Equip End	Ongoing	Ongoing	Ongoing
Miles Constance Street	42112	Equip Start			10/07/1997
		Equip End			Ongoing
St George Airport	43109	Equip Start			1/05/1997
		Equip End			Ongoing
Charleville Aero	44021	Equip Start	1/04/1942	1/04/1942	23/08/1990
		Equip End	Ongoing	Ongoing	Ongoing
Thargomindah Airport	45025	Equip Start			21/07/1999
		Equip End			Ongoing

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Tibooburra Post Office	46037	Equip Start	1/01/1910	1/01/1910	
		Equip End	Ongoing	Ongoing	
Wilcannia (Reid St)	46043	Equip Start	1/01/1900	1/01/1900	
		Equip End	Ongoing	Ongoing	
Cobar MO	48027	Equip Start	1/06/1962	1/06/1962	1/05/1997
		Equip End	Ongoing	Ongoing	Ongoing
Bourke Airport AWS	48245	Equip Start			3/12/1998
		Equip End			Ongoing
Walgett Airport AWS	52088	Equip Start			21/05/1997
		Equip End			Ongoing
Moree Aero	53115	Equip Start	10/04/1995	10/04/1995	10/04/1995
		Equip End	Ongoing	Ongoing	Ongoing
Gunnedah Resource Centre	55024	Equip Start	1/01/1948	1/01/1948	
		Equip End	Ongoing	Ongoing	
Inverell (Raglan St)	56242	Equip Start	1/03/1995	1/03/1995	
		Equip End	Ongoing	Ongoing	
Yamba Pilot Station	58012	Equip Start	1/01/1900	1/01/1900	20/09/2007
		Equip End	16/10/2007	16/10/2007	Ongoing
Coffs Harbour MO	59040	Equip Start	1/02/1943	1/02/1943	31/01/1995
		Equip End	Ongoing	Ongoing	Ongoing
Port Macquarie Airport AWS	60139	Equip Start			6/05/1995
		Equip End			Ongoing
Williamtown RAAF	61078	Equip Start	1/09/1942	1/09/1942	7/07/1999
		Equip End	Ongoing	Ongoing	Ongoing
Scone Airport AWS	61363	Equip Start			1/11/1988
		Equip End			Ongoing
Bathurst Agricultural Station	63005	Equip Start	1/01/1909	1/01/1909	
		Equip End	Ongoing	Ongoing	
Dubbo Airport AWS	65070	Equip Start			18/12/1992
		Equip End			Ongoing
Sydney (Observatory Hill)	66062	Equip Start	1/01/1900	1/01/1900	1/04/1990
		Equip End	31/05/1995	31/05/1995	7/06/2011
Richmond RAAF	67105	Equip Start			21/10/1993
		Equip End			Ongoing
Nowra Ran Air Station AWS	68072	Equip Start			23/11/2000
		Equip End			Ongoing

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Point Perpendicular AWS	68151	Equip Start			3/05/2001
		Equip End			Ongoing
Moruya Heads Pilot Station	69018	Equip Start	1/01/1900	1/01/1900	
		Equip End	Ongoing	Ongoing	
Wagga Wagga AMO	72150	Equip Start	1/02/1941	1/02/1941	21/10/1994
		Equip End	Ongoing	Ongoing	Ongoing
Cabramurra Smhea AWS	72161	Equip Start			10/12/1996
		Equip End			Ongoing
Wyalong Post Office	73054	Equip Start	11/09/1950	11/09/1950	
		Equip End	Ongoing	Ongoing	
Deniliquin Airport AWS	74258	Equip Start			23/05/1997
		Equip End			Ongoing
Mildura Airport	76031	Equip Start	1/09/1946	1/09/1946	1/10/1989
		Equip End	Ongoing	Ongoing	Ongoing
Nhill Aerodrome	78015	Equip Start			11/06/2003
		Equip End			Ongoing
Kerang	80023	Equip Start	1/01/1903	1/01/1903	
		Equip End	Ongoing	Ongoing	
Rutherglen Research	82039	Equip Start	1/01/1913	1/01/1913	29/01/1998
		Equip End	29/01/1998	29/01/1998	Ongoing
Gabo Island Lighthouse	84016	Equip Start	1/01/1900	1/01/1900	17/08/2007
		Equip End	1/09/2007	1/09/2007	Ongoing
Orbost (Comparison)	84030	Equip Start	1/01/1938	1/01/1938	
		Equip End	Ongoing	Ongoing	
East Sale Airport	85072	Equip Start	1/05/1943	1/05/1943	11/06/1996
		Equip End	Ongoing	Ongoing	Ongoing
Wilsons Promontory Lighthouse	85096	Equip Start	1/01/1900	1/01/1900	18/09/2000
		Equip End	18/09/2000	18/09/2000	Ongoing
Melbourne Regional Office	86071	Equip Start	1/01/1908	1/01/1908	1/08/1986
		Equip End	Ongoing	Ongoing	Ongoing
Laverton RAAF	87031	Equip Start	1/06/1941	1/06/1941	22/02/1997
		Equip End	15/08/1999	15/08/1999	Ongoing
Cape Otway Lighthouse	90015	Equip Start	1/01/1900	1/01/1900	15/04/1994
		Equip End	15/04/1994	14/04/1994	Ongoing
Low Head	91293	Equip Start	6/11/1997	6/11/1997	6/11/1997
		Equip End	Ongoing	Ongoing	Ongoing

Stn name	Stn no.	Data	Thermometer, AiG	Thermometer, MiG	Dry-bulb temperature probe
Launceston Airport	91311	Equip Start			14/06/2004
		Equip End			Ongoing
Eddystone Point	92045	Equip Start	11/08/1908	11/08/1908	1/06/1993
		Equip End	24/07/1997	24/07/1997	Ongoing
Cape Bruny Lighthouse	94010	Equip Start	1/01/1915	1/01/1915	
		Equip End	Ongoing	Ongoing	
Hobart (Ellerslie Road)	94029	Equip Start	1/01/1900	1/01/1900	29/06/1992
		Equip End	4/04/2011	4/04/2011	Ongoing
Butlers Gorge	96003	Equip Start	1/09/1941	1/09/1941	20/05/2008
		Equip End	7/10/1993	7/10/1993	Ongoing

Table 9. A summary of the change in uncertainties for metrology laboratory calibrations and verification since 1908.

Period	95% uncertainty estimate for laboratory temperature measurements	Methodology
1908–1973	Largely unknown but likely > 0.2 °C	Ice point and reference in-glass thermometers
1973–1993	0.05 °C	Ice point, oil bath, PRT reference
1993–2002	0.03 °C (oil bath improved + PRT reference)	Improved oil bath, PRT reference, PRT working standards
2002–2008	0.023 °C (oil bath + multiple PRT reference + absolute standards)	Highly stable oil bath Multiple PRT references 3 fixed point cells including water triple point
2008–present	0.019 °C	Improved oil bath, fixed point cell

Traceability and verification of surface air temperature measurements

While none of the temperature measurements resident in the climate database have an explicit uncertainty of measurement, the traceability chain back to the national temperature standards, and the processes used both in the Regional Instrument Centre (the current name of the metrology laboratory in the Bureau) and the field inspection process suggest that the likely 95% uncertainty of a single temperature measurement is of the order of 0.5 °C. This is estimated from a combination of the field tolerance and test process uncertainties.

The Bureau's standards of temperature measurement have varied over the period of measurement since 1900. Uncertainties in the measurement of temperature in laboratory conditions have decreased slowly with time. Since 1938, for the meteorological range of –10 to +55 °C, uncertainties have been traceable to Australia's national measurement laboratories methods and processes (Cornish 1996). A summary of the change in 95% uncertainties for laboratory-based calibration since 1908 is provided in Table 9.

Between 1908 and 1938 there is little evidence to suggest a well-defined and traceable temperature system was in place, apart from adherence to methods used in the Australian States and Territories and prior to formation of the Bureau in 1908. However, based on documentation that is available, it is highly likely that any standard system was developed from the British standards, as copies of observing handbooks of the era closely match British handbooks of the same period (Bureau of Meteorology 1925).

The Bureau's first metrology laboratory was established in 1938 (called the Instrument Laboratory) with a focus on barometry (Cornish 1996). At that time an original member of the laboratory, Alan Cornish, was trained by the then National Standards Laboratory on temperature measurement. The reference thermometers used in the metrology laboratory until 1966 were precision in-glass thermometers purchased from British suppliers with a likely uncertainty of 0.3 °F. Typical testing of thermometers included an ice point check and electric fan-based testing at room and higher temperatures. Between 1946 and 1966 a resistance thermometer was purchased, but there is anecdotal evidence to suggest it was rarely used and was more an object d'art in the office of the laboratory manager at the time (Handcock, D 2011, pers. comm.). This is likely the case as only two-wire resistance measurements could be supported at the time and uncertainties for platinum-resistance measurements were higher than expected for in-glass thermometry.

Between 1908 and 1973, the Bureau maintained temperature standards using procedures developed mainly by the British Meteorological Office and using high quality in-glass thermometers (Warne 2003). These thermometers were held in the metrology laboratory and used as standards to calibrate and/or verify the inspection thermometers used for field testing. The thermometers were bought from the UK at that time, of type Negretti and Zambra, and each likely had a calibration certificate. However, the move of the Bureau head office in 2003, and the lack of storage in the new building, meant that a significant number of instrument related files were destroyed, particularly those 30 years and older.

Between 1963 and 1973, long stem precision Celsius thermometers were in use as secondary standards (Warne 2003). These were quoted to have a maximum error of 0.15 °C (DOBROS precision thermometers in 1974 promotional material) with uncertainties meeting the AS R34 (1969) standard (Standards Association of Australia 1969).

Unlike the MiG and AiG thermometers, automated processes developed in the late 1980s and the next two decades, enabled all PRS purchased for use to be checked prior to use in the field; to ensure they met manufacturing standards and provided readings within measurement tolerances of ±0.08 °C over a temperature range from –10 to +55 °C. If a PRS failed to satisfy those tolerances, it was returned to the manufacturer for replacement. As they were also used for wet-bulb thermometry, the PRS were batch-tested to ensure the platinum-resistance element was located in the required position in the probe shaft.

The uncertainty of a PRS calibration for a fixed temperature, using the current systems within the metrology laboratory, is estimated to be 0.019 °C. This is through the use of four absolute fixed point temperature standards, reference transfer based on the properties of materials, referenced PRTs and an highly stable oil bath. The fixed point and reference PRTs are check against the Australian temperature standards held by Australia's National Measurement Institute every five years. The latter initially proved problematic as the Bureau has identical primary standards to the National Measurement Institute.

While it is possible to provide a calibration certificate for each probe with a likely 95% uncertainty of <0.02 °C using either tabulated or polynomial coefficient corrections, no calibration data were used for field PRTs. Currently there is no method to incorporate these coefficients into the AWS for routine measurement process, as a fixed resistance to temperature conversion is part of the system firmware.

Future

(a) Restoring redundancy

A key difference between routine observations now and prior to the dominance of automated weather observations is redundancy in air temperature measurement. Manual measurements of SAT temperatures and maximum and minimum temperatures at the 0900 reset of the maximum and minimum thermometers provided a cross-check between all thermometers albeit within the ±0.5 °C range, and problematic thermometers could be replaced as soon as a problem was identified. No such option exists at current AWS-only locations during routine operation, and several logistical problems would need to be solved before providing regular operational health checks at each AWS-only site.

To provide operational tolerance checks, through use of redundant temperature sensor measurements, would require the ability to record and transmit alternate data streams or their differences. While simple in concept, execution within the end-to-end current observing system could require significant and resource-intensive changes in instrument specification and design of data transmission and storage infrastructure.

First, the AWS systems must be able to cope with parallel measurements of air temperature using multiple thermometers ideally of different design (e.g. thermistors, transistors or speed of sound variations). Second, key quality parameters, such as alternate temperature measurements, uncertainty etc., need to be incorporated in the transmitted message or data stream with a reporting resolution better than the current 0.1 °C. Third, the AWS needs to be able to cope with changing the primary sensor input if the primary sensor is found to be faulty and generate an increased measurement uncertainty if the secondary sensor acts as a temporary replacement; this also would assist greatly in data continuity. Fourth, the long-term data stores for these data need to be able to cope with parallel second (and possibly third) air temperature measurement (including uncertainties) at the one site. As by definition a traceable measurement includes an uncertainty, each SAT datum should have an associated and recorded uncertainty rather than rely solely on the use of data flags. It would be possible for all these modifications to be adopted throughout the current observing network so that the 'one-model-fits-all' operational model could be maintained if desired.

The above suggestions will not improve the uncertainty of individual air temperature measurements but should reduce the uncertainty of period averages through reduction of missing data, and reduce the duration of higher uncertainty measurements, through targeted maintenance responses.

A small improvement in the consistency of the temperature record at AWS-only sites would be possible through the use of a triplet of identical PRT thermometers. Two would be on-site and a third at the metrology laboratory. On-site, the primary reference SAT would be the PRT with the longest continuous measurement; the second on-site would have been installed at the last inspection; and the third would be at the metrology laboratory for calibration—being the primary thermometer prior to the last inspection. The continuous cycle of instruments would enable regular referencing to the metrology standards but, most importantly, the instrument installed during an inspection would have a continuous comparison with the new primary thermometer until the next inspection. Hence the relationship between all PRTs would be very well known, thereby ensuring very tight tolerances consistency across the temporal record. This would be relatively simple to realise in a measurement sense for those AWS that are capable of but do not measure PRT terrestrial temperatures. However, the necessary identifiers and associated coding and metadata would require a redesign of the end-to-end SAT system, and would be very difficult to manage for the dominant AWS in the Bureau network, as core modifications to the firmware and software are not possible.

(b) Significantly improved measurement uncertainty

The current 95% uncertainty specification from the WMO Commission for Instruments and Methods of Observations Guide (World Meteorological Organization 2011) for the measurement of surface air temperature is 0.1 °C with a reported resolution of 0.1 °C, but a realisable uncertainty of 0.2 °C. The Bureau does not meet this specification for network observations given the accepted tolerance limits of ±0.5 °C. However, it should be noted that any system reporting with a WMO required resolution of 0.1 °C is unlikely to meet the WMO required 95% uncertainty of 0.1 °C for a single SAT measurement.

Assuming a sub-network of the Bureau SAT network, such as ACORN-SAT, was required to meet a WMO realisable uncertainty of 0.2 °C, a significant shift in resource balance is needed as improved uncertainty of individual SAT measurements can only be achieved by improvements in the quality assurance and measurement processes.

For example, the likely uncertainty of PRT measurements could be reduced if each sensor was calibrated and the resultant calibration used in the field realisation of temperature. Currently the uncertainty of any calibration using the current metrology laboratory facilities is less than 0.02 °C. The AWS resistance-to-digital modules in the most recent AWS deployed by the Bureau are required to have an 95% uncertainty of 0.02 °C and can report data in units of 0.01, hence assuming zero correlation between the two uncertainties, a combined uncertainty for laboratory-based measurements with an AWS of about 0.03 °C could be expected.

Translating laboratory-based uncertainties to a WMO realisable uncertainty for routine observations will require substantial effort.

First, each individually indentified sensor response for a time series of calibrations needs to be incorporated into either the coefficient tables of an AWS or the mechanism that generates the final temperature value, and enable updates of the coefficients when a probe or AWS changes at a site. Infrastructure would have to be built from the ground up to support its operation as this is a fundamentally different concept for network management and metadata management for wide-scale Bureau network operations. Currently there are only two relatively small sub-networks (not providing SAT) that operate with a database of individual sensor sensitivities and algorithms: the solar and terrestrial radiation network (nine sites), and the absolute sea-level network (28 sites). Both these networks operate largely independent of the mainstream surface observation network.

Second, the inspection process would need to be enhanced to enable an improved tolerance of the order of ±0.18 °C (that includes the afore-mentioned redundancy requirement). This would necessitate significant metrology support infrastructure, including metrology training for inspectors.

Third, it would require introduction of an internal or external audit framework to enable demonstration rather than assumption of tolerance compliance. Typically this would entail the metrology laboratory and site protocols and procedures being accredited under ISO 17025 or similar. Note ISO 9001 does not require technical competence to be audited successfully and therefore would be unsuitable to maintain the required uncertainty.

Hence, while possible, it would require a significant investment in metrology, quality systems and data infrastructure well above the current capability and capacity.

Summary

Apart from a move to platinum-resistance thermometry as the primary SAT measurement method in 1996, all other components of the measurement environment and instrument shelters are based on measurement principles and practices from the start of the 20th century. Since 1908, the Bureau has used the same field practices for SAT measurements, and since 1938, metrology standards have been available to achieve a likely stable 95% uncertainty of 0.5 °C for maximum and minimum temperatures across its network.

The stability has been provided by checking measurement tolerances, with a paper and lately computerised metadata system. Since 1938, the metrology and transfer standards related to national standards of measurement have improved by an order of magnitude.

The current SAT network uncertainty does not meet WMO guidelines for realisable uncertainty. Improving the 95% uncertainty of SAT measurements to 0.2 °C will require significant changes in the way measurement traceability is performed in the Bureau.

The move to AWS measurements in the last two decades reduced the ability for daily redundancy checks, and increased the likelihood of missing data. For continuity of future SAT time series redundant measurements at AWS are required. However, to do so would require a change in automated data collection processes, from the AWS to the final data archive.

References

British Meteorological Office 1956, *Handbook of meteorological instruments, Part 1 Instruments for surface observations*, HMSO, London, Great Britain.

British Meteorological Office 1981, *Handbook of meteorological instruments, Vol. 2 Measurement of temperature*, HMSO, London, Great Britain.

British Standards Institution 1958, *British standard: Meteorological thermometers*, (BS 692 1958) British Standards Institution, Great Britain.

Brunt, M 1988, 'Comparison of a monitor thermometer screen with a standard Stevenson screen', *Instrument Test Report 601*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1925, *Australian meteorological observers' handbook*, Commonwealth Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1954, *Australian meteorological observers' handbook*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1962, *Installation Specification 1036*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1963, *Observation Specification 2011*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1972, *Weather News*, Issue No. 193, September, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1973a, *Australian Meteorological Observers' Handbook*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1973b, *Equipment Specification 354*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1975, *Installation Specification 1232*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1981, *Installation Specification 1145*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1990, *Equipment Specification A177*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1991–2003, *Equipment Specification A2669*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1996–2011, *Met Data Format*, Chapter 11, Australian Codes Handbook, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 1997, *Observation Instruction 97/5*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 2002, *Regional Instrument Centre Calibration Records*, Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology 2010, *Implementation Dates of Daylight Saving Time within Australia*, http://www.bom.gov.au/climate/averages/tables/dst_times.shtml

Bureau of Meteorology c. 2011a, *Surface Observations Handbook* (continuously developed document), Bureau of Meteorology, Melbourne, Australia.

Bureau of Meteorology c. 2011b, *Inspections Handbook*, (continuously developed document), Bureau of Meteorology, Melbourne, Australia.

Commonwealth Meteorology 1907, *Instructions to Country Observers*, Commonwealth Meteorology, Sydney, Australia.

Commonwealth Bureau of Meteorology 1962, *Equipment Specification A410 for meteorological thermometers — ordinary, maximum and minimum*, Issue 2, April.

Cornish, A 1996, 'Memories of the Bureau of Meteorology 1929 to 1946', *METARCH papers: No. 8*, Bureau of Meteorology, Melbourne, Australia.

Day, D 2007, *The Weather Watchers: 100 Years of the Bureau of Meteorology*, Melbourne University Publishing, Melbourne, Australia.

Easson, J 2011, Bureau of Meteorology, personal comm.

Handcock, D 2011, retired leader, Instrument Labratory personal comm.

Standards Association of Australia 1966*, Australian standard: maximum, minimum and ordinary meteorological thermometers*, (AS13-1966), Standards Australia, Sydney, Australia.

Standards Association of Australia 1969*, Australian standard: Long solid stem thermometers for precision use*, (AS34-1969), Standards Australia, Sydney, Australia.

Standards Association of Australia 1985*, Australian standard: Thermometers — meteorological — maximum, minimum and ordinary*, (AS2819-1985), Standards Australia, Sydney, Australia.

Warne, J 1998, 'A preliminary investigation of temperature screen design and their impacts on temperature measurements', *Instrument Test Report 649*, Bureau of Meteorology, Melbourne, Australia.

Warne, J 2003, *Catalogue of museum items*, Bureau of Meteorology, Melbourne, Australia.

World Meteorological Organization 2011, *Guide to Meteorological Instruments and Methods of Observation*, 7th ed, World Meteorological Organization, Geneva, Switzerland.

Acronyms and definitions

ADAM	Australian Data Archive for Meteorology
AiG	alcohol-in-glass
AWS	automated weather stations
CLIMARC	Climate Archives
CMSS	Central Message Switching System
LDST	local daylight saving time
LST	local standard time
MDF	Met Data Format
MiG	mercury-in-glass
NONdBase	National Observations Networks Database
PRT	platinum-resistance digital thermometers
PRS	platinum resistance sensor
SAT	surface air temperature
SitesDb	Bureau's database of metadata for its entire network of stations
UTC	Coordinated Universal Time
WMO	World Meteorological Organization

Australian Government
Bureau of Meteorology

For more information
Visit our website at: www.bom.gov.au

DOT6723/12