8 No Evidence of Warming at Mawson, Antarctica

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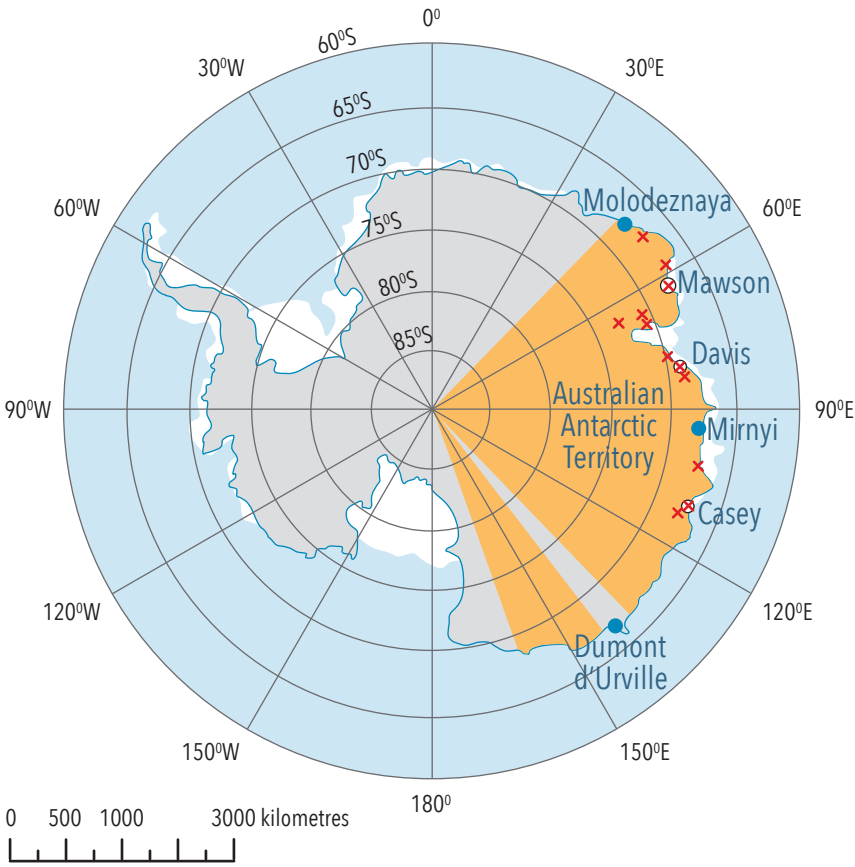
The Australian Bureau of Meteorology has measured surface air temperatures at the Mawson weather station in Antarctica since early 1954. Temperatures oscillate within a relatively narrow band, showing no statistically significant long-term warming trend. This is the case whether considering the actual historical measurements, or the temperatures subsequently adjusted by the Bureau before incorporation into other databases. The other weather stations in the Australian Antarctic Territory with long records are at Davis and Casey. The temperature series from these locations move up and down in synchrony with the temperatures recorded at Mawson and also show no warming or cooling trends, whether considering the actual measurements or the homogenised series. The temperature series from Mawson, Davis and Casey represent an amalgamation of measurements from different instruments, which could affect trends. In order to properly assess the equivalence of measurements from the electronic probes versus mercury and alcohol thermometers, there would need to be some assessment of values measured at the same time in the same shelter – known as the parallel data. This data is not publicly available.

Mawson temperature record

Mawson was the first official Australian Bureau of Meteorology weather station in Antarctica, and was named after Sir Douglas Mawson, an Australian geologist and Antarctic explorer (Bureau of Meteorology 2013). This is one of 49 weather stations (measuring air temperature), that have been

operated by the Bureau in Antarctica at different times, with data from sixteen of these stations publicly available (Bureau of Meteorology 2019a). The locations of these sixteen weather stations are shown in Figure 8.1 as red crosses. Some red crosses represent more than one weather station.

Figure 8.1 Map of Antarctica with weather station locations



The Australian Antarctic Territory spans nearly 5.9 million km^2 of Antarctica, south of 60°S and between 45°E and 160°E, excluding the French Terre Adélie (between 136°E and 142°E). The red crosses are all the locations that have surface air temperature data available in the Australian Data Archive for Meteorology (ADAM). Some of the red crosses represent the location of more than one data series and/or weather station. The blue dots are the locations of two Russian and one French weather station that are used as reference stations during homogenisation of Mawson, Davis and Casey data.

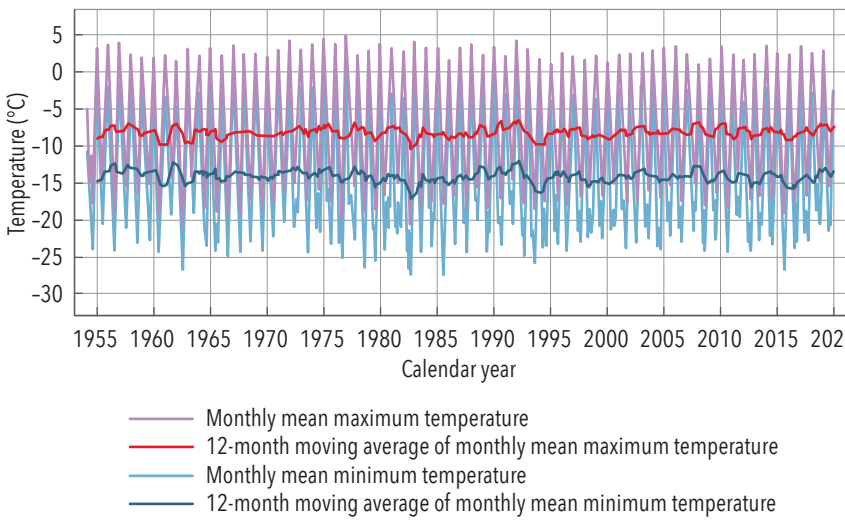
Locations sourced from Australian Bureau of Meteorology, March 2020, http://www.bom.gov.au/climate/data/stations/.

The historical temperature record of Mawson is shown in Figure 8.2, including monthly and twelve-month moving averages. The twelve-month moving average is a measure of annual change in surface maximum and minimum temperatures. Maximum temperatures fluctuate between an annual average of –6.7 °C and –10.5 °C. Minimum temperatures fluctuate between an annual average of –12.2 °C and –17.3 °C.

The metadata for Mawson indicates that temperature measurements have been taken at the same location since 1954 (Bureau of Meteorology 2019b) with temperature measuring equipment mounted in a Stevenson screen similar to the shelters shown in Figure 8.3.

Over the period of the temperature record, different equipment was placed in the Stevenson screen at Mawson, and used to measure air temperature. According to the Antarctic station catalogue, daily extremes at Mawson were initially obtained from a thermograph in a Stevenson screen and since early 1973 also from a Fielden (Bureau of Meteorology 2013). This is an instrument with remote temperature measuring equipment and a transmitter that was used especially during heavy snowfall or

Figure 8.2 Temperature data measured at the Mawson weather station since March 1954



The monthly mean maximum and minimum temperature series were calculated from historical daily observations available in the ADAM database.

Data from Australian Bureau of Meteorology, March 2020, http://www.bom.gov.au/climate/data/.

Figure 8.3 Stevenson screens used to house weather recording equipment in Antarctica

Stevenson screen at Casey (left) in June 2014 and Davis (right) in May 2015. Stevenson screens are used globally to house thermometers and standardise weather measurement.

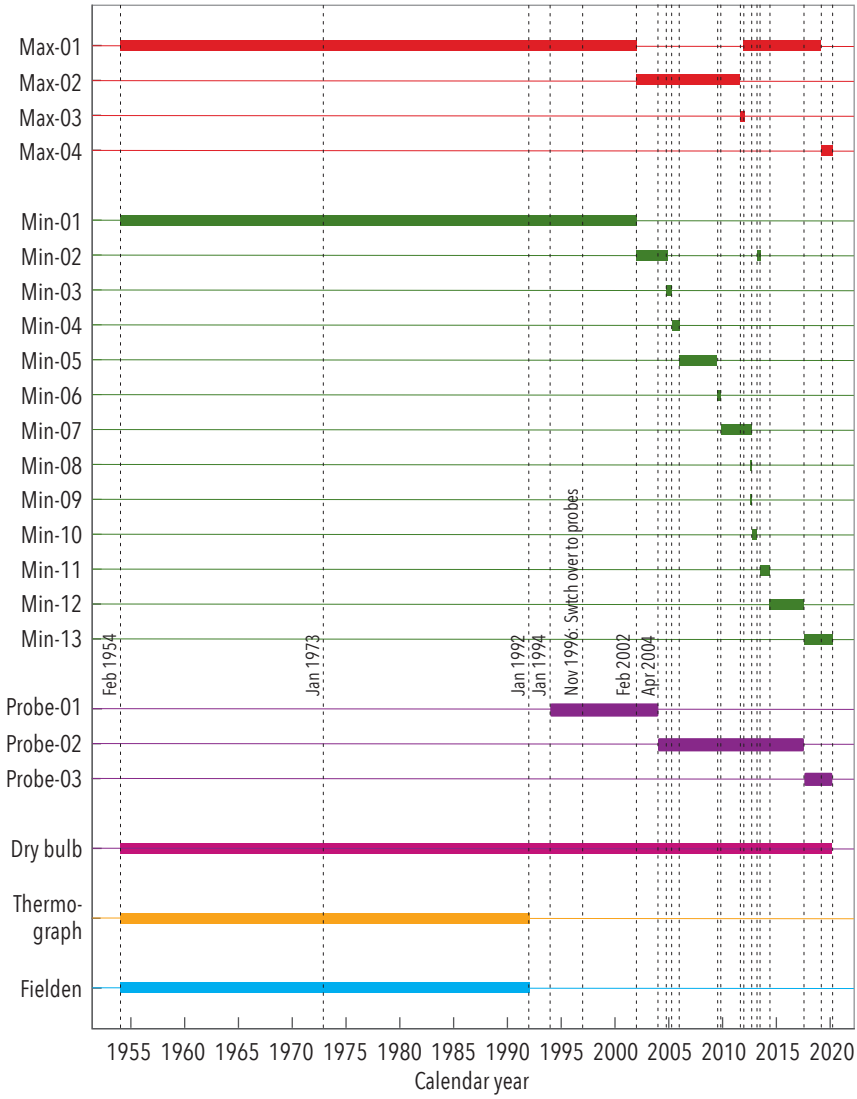
Source: Australian Antarctic Division, March 2020, http://www.antarctica.gov.au/.

when the Stevenson screen could not be accessed (Jovanovic et al. 2012). Liquid-in-glass thermometers were then used from January 1992, specifically a mercury thermometer to measure maximum temperatures and an alcohol thermometer to measure minimum temperatures (Bureau of Meteorology 2018). According to the online station metadata, however, these liquid-in-glass thermometers were in place since February 1954 (Bureau of Meteorology 2019b). So, there is some inconsistency in the available metadata regarding what equipment was actually used, and when.

The online station metadata furthermore indicates that an electronic probe (also known as a platinum resistance thermometer, PRT) was installed in the Stevenson screen in January 1994. This probe became the primary measuring instrument on 1 November 1996 (Bureau of Meteorology 2012). So, from 1 November 1996 the highest and lowest values from the probe were recorded as the maximum and minimum temperature each day in the ADAM database. These daily values are used to compile temperature statistics for this chapter, as shown in Figures 8.2 and 8.5.

I have summarised the equipment changes as best I can for Mawson as a Gantt chart (Figure 8.4), showing the timelines over which different instruments were used to measure temperatures at Mawson. Clearly

Figure 8.4 Thermometer usage Gantt chart for the Mawson weather station



Four mercury thermometers (measuring daily maximum), thirteen alcohol thermometers (measuring daily minimum), three electronic probes (also known as platinum resistance thermometers, with the one instrument measuring both maximum and minimum temperatures) and one dry bulb mercury thermometer (measuring air temperature continuously) are listed as having variously been used to measure temperatures. The Antarctic station catalogue furthermore details the use of a thermograph and the Fielden, consisting of remote temperature sensors and a display.

Until 31 October 1996, measurements from the mercury and alcohol thermometers were entered into the ADAM data base as the maximum and minimum temperatures, respectively. From 1 November 1996, measurements from the electronic probe were recorded in ADAM as the maximum and minimum. While both probes and thermometers were present, the parallel data is not available. Analysis of the parallel data for the period January 1994 to February 2002 would enable some comparison of the values from the first probe with values from the mercury and alcohol thermometers.

Source: Data from the Mawson online climatological station metadata (Australian Bureau of Meteorology 2019b) and Antarctic station catalogue (Bureau of Meteorology 2013) were used to construct this chart.

there have been many changes to the equipment at this one location. The historical temperature record of individual weather stations such as Mawson (Figure 8.2) should therefore typically be viewed as a collection of measurements taken by different instruments over different time periods, and sometimes at different locations.

To make any conclusions regarding long-term patterns or temperature trends it is important to ensure equivalence between the different instruments used over time. The Bureau has taken parallel measurements at several weather stations across Australia, specifically recording temperatures as measured by both liquid-in-glass thermometers and electronic probes (PRTs) at the same location. This is ostensibly done to enable analysis of the difference between these two types of instruments and to ensure equivalence between them (Trewin 2012). This information has not, however, been published by the Bureau. It has therefore not been established that the recordings are equivalent. To be clear, while mercury and alcohol thermometers were always in place, and maintained in parallel with an electronic probe at Mawson since January 1994, this parallel data for Mawson has not been made publicly available. Neither has there been any report from the Bureau providing an indication of the equivalence between the measurements taken from the liquid-in-glass thermometers (mercury and alcohol) versus the electronic probes (PRTs) at Mawson, or at any of the other Antarctic weather stations.

Adjustments are made to individual temperature series following equipment changes, but this is not done based on an assessment of the parallel data. Rather it is made through an assessment of the series relative to neighbouring sites through a process known as homogenisation.

Homogenised temperature series

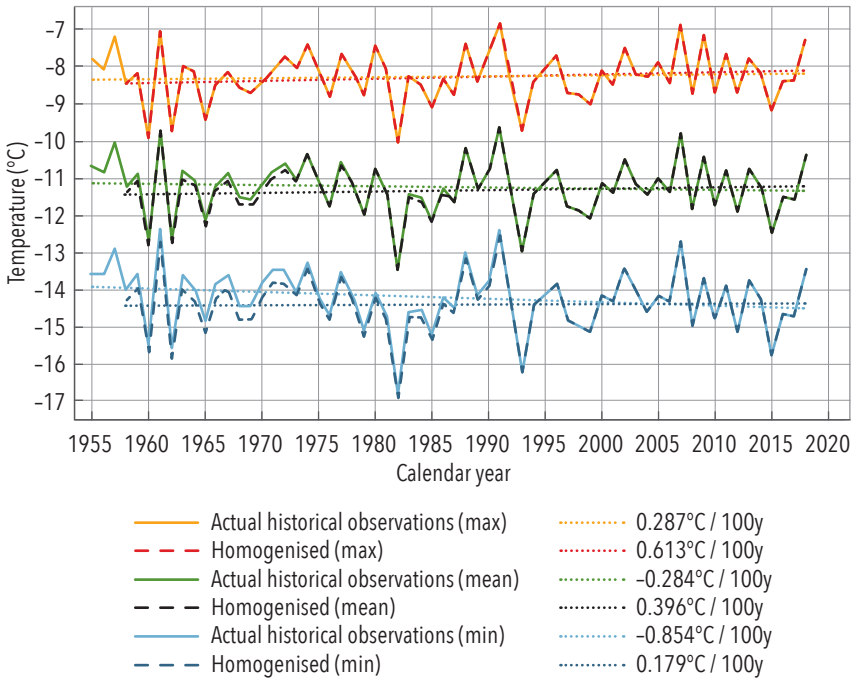
The Bureau's official temperature reconstruction, known as the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) dataset includes the three longest temperature series from the Australian Antarctica Territory: Mawson, Davis and Casey after they have been homogenised. This ACORN-SAT dataset is used by the Bureau, and also CSIRO, to report annually to the government on climate change.

The annual mean maximum and minimum temperature series for Mawson for both the ACORN-SAT and actual measurements from the ADAM database are shown in Figure 8.5.

Homogenisation is ostensibly done to remove non-climatic effects that may be present in the temperature record (Peterson et al. 1998), for example, changes in measuring methods and instrumentation, such as replacing a thermometer with an electronic probe (PRT), as has occurred at the Mawson weather station.

Through the process of homogenisation, actual measurements are adjusted after the identification of breakpoints in individual time series. According to published papers detailing the technique, adjustments

Figure 8.5 Historical observations versus homogenised temperature series for Mawson



The 'actual historical observations' series were calculated from ADAM data and the homogenised series from ACORN-SAT data. Each mean series in green is the average of the corresponding maximum and minimum series.

Data as daily values was downloaded from Australian Bureau of Meteorology, March 2020, http://www.bom.gov.au/climate/data/ and http://www.bom.gov.au/climate/data/acorn-sat/.

could be made based on statistical analyses of individual temperature records in isolation, or in combination with measurements at neighbouring locations (reference stations), or both together, along with an analysis of metadata or documents describing the history of each weather station (Ribeiro et al. 2016). This theoretically depends on the availability of suitable reference stations and reliable metadata, or any other evidence supporting a potential breakpoint. In the case of the data from Mawson and other Antarctic stations, the adjustments are made with reference to neighbouring stations and the metadata.

As can be seen in Figure 8.5, the Bureau created the official or homogenised Mawson series from the actual historical observations by discarding the first three years of observational data, and dropping the minimum series down over the period 1958–1991. Specifically, the annual mean minimum temperature values were reduced by 0.35 °C and 0.15 °C for the two periods: 1958–1972 and 1973–1991, respectively. These changes are the result of unique monthly adjustments shown in Table 8.1 below.

The Bureau homogenised the Antarctic records ostensibly by identifying statistical breakpoints through comparison of meteorological data from neighbouring sites and analyses of metadata (Jovanovic et al. 2012). The 'homogeneity' of the Mawson data was apparently tested through comparison with neighbouring reference sites, specifically Davis and Russia's Molodeznaya, shown in Figure 8.1. The first three years of Mawson were excluded, as reference data for this period does not exist.

The effect of this homogenisation process, as applied to the Mawson record, is an increase in the warming trend in the maximum temperature series. Homogenisation (the adjustment of the values) also changes the long-term cooling to a warming trend in the minimum series, as shown in Figure 8.5. Overall, the mean temperature trend at Mawson in the historical observations is changed from cooling at a rate of 0.284 °C per century to warming of 0.396 °C per century in the official ACORN-SAT record.

Table 8.1 Adjustments (°C) made to Australian Antarctic records during homogenisation

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Mawson minimum temperature													
Jan 1958–Dec 1972	–0.4	–0.2	–0.2	–0.9	–1.7	1.0	–0.1	–0.4	–0.7	–0.1	0.0	–0.5	–0.35
Jan 1973–Dec 1991	–0.9	0.1	0.4	–0.6	–0.6	0.8	0.6	0.0	–0.2	–0.3	–0.2	–0.9	–0.15
Davis maximum temperature													
Jan 1958–Jan 1970	2.0	0.2	–0.1	0.3	0.6	0.1	0.2	0.5	1.1	0.3	0.8	0.9	0.575

Each calendar month within a given period is uniquely adjusted by the Bureau to create the official ACORN-SAT record. For example, in the Mawson minimum record, all January values from 1958 to 1972 are adjusted downwards by 0.4 °C, and all July values over 1973 to 1991 are adjusted upwards by 0.6 °C.

Data, as daily values, was downloaded from the Australian Bureau of Meteorology, March 2020, http://www.bom.gov.au/climate/data/ and http://www.bom.gov.au/climate/data/acorn-sat/.

Other long temperature records

While nearly 50 weather stations have been operated at one time or another by the Bureau at Antarctica, temperature data is only publicly available for sixteen of these, and only five have records spanning several years. The five longest records shown in Figure 8.6 include the three locations included in ACORN-SAT and two stations that are no longer active, including Wilkes and Casey (The Tunnel) that were operated in close proximity to the current Casey station (Australian Antarctic Division 2018).

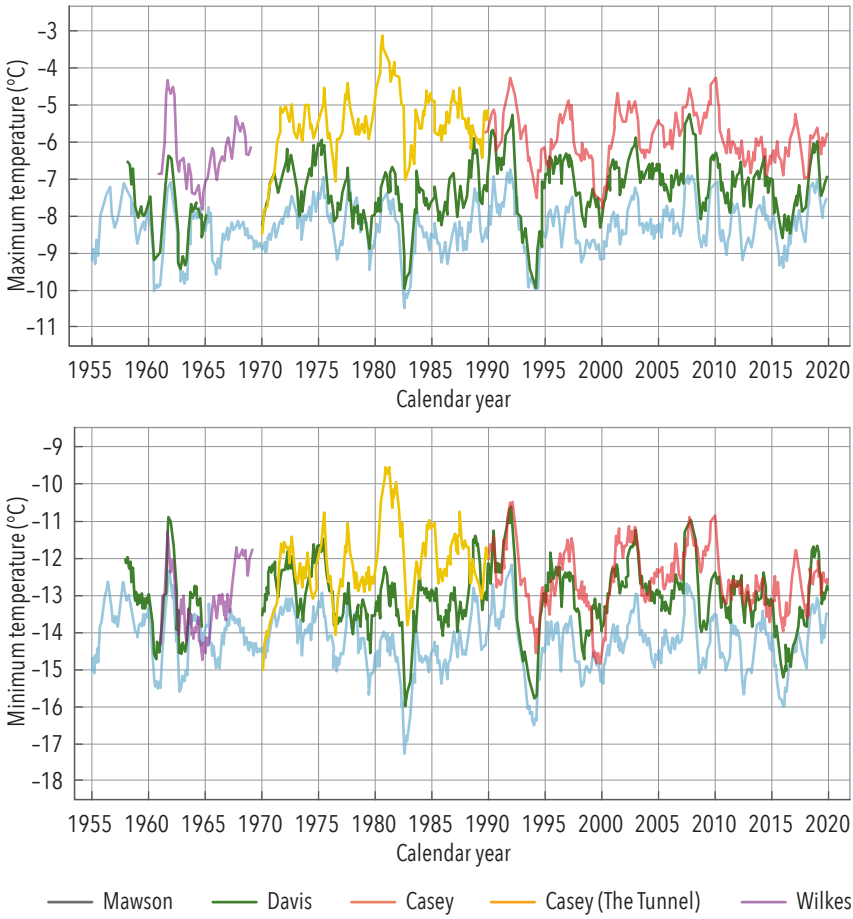
Considering the twelve-month moving average for these five series (unadjusted), including Mawson (unadjusted), there is significant inter-annual variability, while overall there is no clear warming or cooling trend, as shown in Figure 8.6. The synchronisation between the temperature series based on the historical observations from the different locations is remarkable. For example, maximum and minimum temperatures rise in the early 1980s, then drop suddenly before rising again in unison, before dipping once more in the mid-1990s.

The temperature measurement history at Davis and Casey is similar to Mawson; initially a thermograph and the Fielden were used (Bureau of Meteorology 2013). Liquid-in-glass thermometers were also used, and automatic weather stations were deployed at all three sites in early 1994, with the installation of electronic probes (PRTs).

The actual historical temperature data available in the online ADAM database (Bureau of Meteorology 2019a) for Davis and Casey, as for Mawson, were therefore taken using different equipment over time. There were also site relocations, particularly at Casey. Initially measurements were taken at 'The Tunnel' from February 1969 to December 1988, after which a new weather station was opened nearly a kilometre away (Bureau of Meteorology 2013). Measurements were taken at both locations for a period of thirteen months, after which the old station was closed down.

Every change, including equipment changes and weather station relocations, can potentially undermine the reliability of long-term temperature trends. The standard practice in climate science to mitigate

Figure 8.6 Temperature trends at the Bureau's five longest-running Antarctic stations



The twelve-month moving average series, calculated from the BoM's longest Antarctic records, show similar patterns and they all track together over time. None of these shows a clear warming pattern.

Data sourced from the Australian Bureau of Meteorology, March 2020, http://www.bom.gov.au/climate/data/.

the effect of these changes is to remodel the temperature measurements through homogenisation, as mentioned in the previous section (Homogenised temperature series).

The Bureau has homogenised the Davis record by adjusting the maximum measurements upwards from 1958 to 1970 using the values given in Table 8.1, and leaving the minimum record unchanged.

The effect of these adjustments is a reduction of the long-term warming rate in the Davis maximum record of 1.281 °C to 0.609 °C per century. The remodelling of the Davis temperature series was performed using Mawson and Russia's Mirnyi as reference stations, with a breakpoint identified in February 1970 aligning with the installation of the Fielden (Jovanovic et al. 2012).

Homogenisation of the Casey record was performed somewhat differently by the Bureau. No adjustments were made to the actual measurements as the record was found to be homogenous using Mirnyi and France's Dumont d'Urville as reference stations. The ACORN-SAT Casey record consists of the monthly means observed at 'The Tunnel' from January 1970 to January 1989, and at the current Casey weather station thereafter – without any adjustment, despite multiple instrument changes and a site relocation. There are thirteen months of overlapping measurements corresponding to the period when the two weather stations were operating. My comparison of maximum temperatures for this period indicates the new site is on average nearly 0.5 °C cooler. To be clear, the Bureau made no adjustment to the data to account for this difference.

No evaluation of measurements from different instruments

Temperature measurements from different instruments (for example, mercury thermometers versus electronic probes) and different site locations are variously combined by the Bureau and then evaluated for potential breakpoints through comparison with neighbouring weather stations. Specifically, if the difference between the data series being homogenised and neighbouring series changes over time, a potential breakpoint is identified. Adjustments are then made according to these breakpoints and differences, if supported by metadata (Jovanovic et al. 2012).

The equivalence of measurements from the different instruments used at each weather station is not evaluated. This could be done through an assessment of the parallel data. For example, both an electronic probe and mercury and alcohol thermometers were in place at Mawson for the period January 1994 to February 2002, as shown in Figure 8.4. Parallel data for this period should therefore exist, assuming the Bureau took daily measurements from both instruments.

Rather, measurements from the electronic probes (PRTs) from 1 November 1996 onwards were simply added to the measurements from mercury and alcohol thermometers before 1 November 1996. This change affected all three ACORN-SAT sites in Antarctica at the same time. Using Mawson and Davis to homogenise each other will, therefore, likely result in no detection of a potential breakpoint at this switch-over date. To know the true underlying long-term trend, it might be necessary to adjust individual records based on the equivalence between different instruments used at a given weather station at the same time. Such an analysis could only be undertaken if the parallel measurements were made available, which they have not been. Only one series is ever archived in the ADAM database.

Statistical analysis

Despite the potential limitations of the temperature series resulting from them being an amalgamation of measurements from different instruments, I nevertheless undertook a statistical analysis of each of the longer temperature series to test for a warming trend.

Long-term temperature trends are generally reported using the best linear fit (IPCC 2013), which is obtained through linear least-squares regression. The slope b of the regression line expresses the rate of temperature change over time, which can be viewed as an estimate of the true temperature change or slope β, an unknown value. Given a series of temperature observations over time, hypothesis testing concerning the slope can be used to infer whether there is significant warming or cooling over time (James 2006). A two-tailed hypothesis test can thus be formulated in terms of the true slope β as:

H_0: $\beta = 0$ (There isn't sufficient evidence of a trend)
H_1: $\beta \neq 0$ (There is a statistically significant trend)

The standard approach to perform hypothesis testing is to calculate a test statistic t and the associated p-value, expressing the probability that the statistic could have been obtained under the null hypothesis H_0. A smaller p-value therefore indicates stronger evidence that H_0 should be rejected. Statistics of the slope and the p-values are shown in Table 8.2.

Table 8.2 Temperature trends statistical significance test

Station	Temperature series	Period	Data points *N*	Slope *b*	Standard error of *b* ($x10^{-3}$)	95% CI of *b*	*p*-value
Mawson	Max (ADAM)	1955–2018	64	0.287	4.643	−0.641, 1.215	0.538
(300001)	Max (ACORN)	1958–2018	61	0.613	4.946	−0.377, 1.603	0.220
	Min (ADAM)	1955–2018	64	−0.854	5.448	−1.943, 0.235	0.122
	Min (ACORN)	1958–2018	61	0.179	5.813	−0.984, 1.342	0.759
Davis	Max (ADAM)	1958–2018	55	1.281	6.860	−0.094, 2.657	0.067
(300000)	Max (ACORN)	1958–2018	55	0.609	6.768	−0.748, 1.966	0.372
	Min (ADAM)	1958–2018	55	−0.176	7.941	−1.768, 1.417	0.826
	Min (ACORN)	1958–2018	55	−0.176	7.941	−1.768, 1.417	0.826
Casey	Max (ADAM)	1970–2018	49	−1.489	7.580	−3.013, 0.036	0.055
(300006 and 300017)	Max (ACORN)	1970–2018	49	−1.478	7.577	−3.003, 0.046	0.057
	Min (ADAM)	1970–2018	49	−1.388	9.354	−3.270, 0.494	0.145
	Min (ACORN)	1970–2018	49	−1.387	9.352	−3.268, 0.495	0.145

Statistical values were calculated using linear regression (SciPy). The unit of the slope *b* is in °C per century. The statistical significance level was chosen as $\alpha = 0.05$, with associated 95% confidence interval.

Data was sourced from the Australian Bureau of Meteorology, March 2020, http://www.bom.gov.au/climate/data/ and http://www.bom.gov.au/climate/data/acorn-sat/.

The *p*-values for the actual measurements as archived in the ADAM dataset, and the homogenised ACORN-SAT temperature series for Mawson, Davis and Casey, are all greater than the chosen threshold level $\alpha = 0.05$. Therefore, the null hypothesis H_0 should not be rejected. In other words, there is no statistically significant warming or cooling trend in the three longest temperature series as measured by the Bureau in the Australian Antarctic Territory, whether using actual historical observations from the ADAM dataset or the homogenised ACORN-SAT values.

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