Temperature Change at Rutherglen in South-East Australia

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Public interest in the homogenisation of temperature trends was stimulated by a series of newspaper articles by Graham Lloyd, which were published in *The Australian* newspaper in 2014. A panel of statisticians (including Michael Martin, Professor of Statistics at the Australian National University; Patty Solomon, Professor of Statistical Bioinformatics at the University of Adelaide; and Terry Speed Professor, Bioinformatics at Monash University) was subsequently appointed by the government to review methodologies used by the Australian Bureau of Meteorology. Recommendations in their first report emphasised the importance of quantifying uncertainty, which, in turn, resulted in this detailed reanalysis of temperature data from Rutherglen.

The reanalysis of the minimum temperature component of this study was first submitted for publication to the Elsevier journal *Atmospheric Research*. Peer review of that manuscript was undertaken by John Nicol (former Dean of Science at James Cook University), and two anonymous reviewers (chosen by José Luis Sánchez, Editor of *Atmospheric Research*). Their comments and recommendations are included (see Appendix 3).

Foreword

Much of the science upon which governments base their decisions – policy-science – is not sufficiently tested, checked, or replicated to be reliable. This problem of reliability is a 'hot' issue in many areas of science.[1] For example, Richard Horton, the editor of one of medicine's most respected journals, *The Lancet*, recently stated:[2]

> The case against science is straightforward: much of the scientific literature, perhaps half, may simply be untrue. Afflicted by studies with small sample sizes, tiny effects, invalid exploratory analyses, and flagrant conflicts of interest, together with an obsession for pursuing fashionable trends of dubious importance, science has taken a turn towards darkness.

It is useful to compare the quality assurance processes used in different disciplines. Industrial applications often use a much more rigorous quality assurance system than is applied in environmental science. Both types of science may use peer-review and the journal comment-and-reply process, but industrial applications insist upon replication and incorporate proper due diligence.

In this first issue of *New Climate*, Dr Jennifer Marohasy makes the case that homogenisation[3] – a technique used extensively in climate science – is not 'quality assurance'; remodelling temperatures based on complex algorithms can produce contrived results.

Dr Marohasy's solution is for climate science to do away with homogenisation altogether, and adopt more traditional methods of quality assurance. In this case study, she demonstrates the application of a method routinely used in manufacturing industries to the quality control of temperature data from Rutherglen.

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[1] Ioannidis, JPA 2014, 'How to make more published research true', *PLOS Medicine*.
[2] Horton, R 2015, 'What is medicine's 5 sigma?' *The Lancet,* vol. 385.
[3] Appendix 1 details the theory and practice of homogenisation as a technique used extensively in climate science.

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1. Summary

Temperature measurements are a form of observation. Observations are central to the scientific method; they enable the elucidation of patterns and the testing of theories.

Understanding temperature variability can also be important for governments and industries when planning. This is particularly so in an agricultural industry such as viticulture, where the choice of a wine variety planted in any given region may be primarily dictated by its temperature optimum.

Since November 1912, surface air temperatures have been measured using thermometers inside a Stevenson screen at an agricultural research station near Rutherglen in northern Victoria. After applying standard quality control techniques to monthly data from this site – from the beginning of the record through until February 2016 – it is apparent that the data are of high quality. There are no transcription errors, systematic errors, or breakpoints (also known as discontinuities). Therefore, there is no scientific reason to apply any adjustments to these temperature measurements in order to accurately calculate temperature trends.

Mean annual temperatures as measured at Rutherglen – for this period of approximately 100 years – oscillate between 15.8°C and 13.4°C, as shown in Figure 1. The hottest years are 1914 and 2007; there is no overall warming trend. Hotter years occur during periods of drought, which occur with some frequency in this part of the lower Murray–Darling catchment.

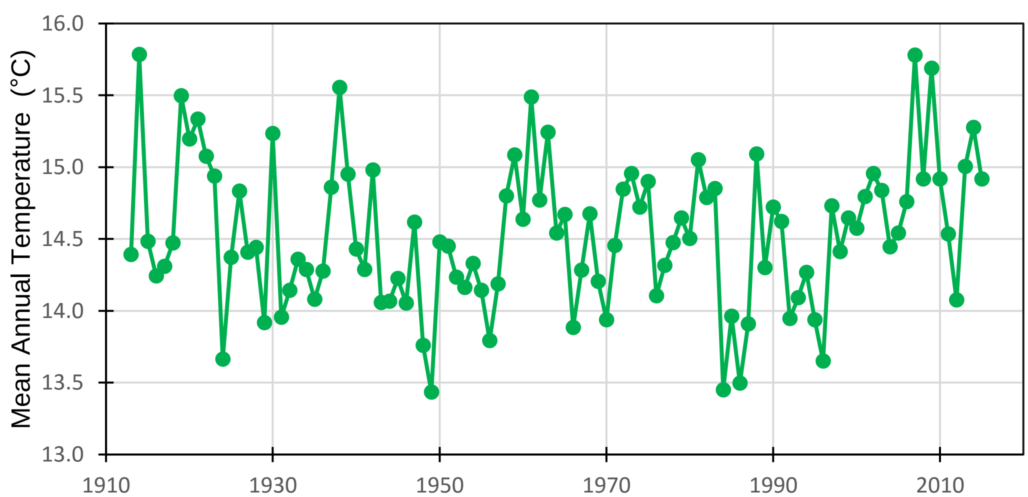

Figure 1. Mean of annual raw temperatures as measured at Rutherglen, 1913 to 2015.

The mean annual temperatures at Rutherglen were calculated as the average of the minima and maxima. This is standard practice.

Charting of only the maximum temperatures, and only during summer, indicates that the hottest summer on record at Rutherglen was in 1938–1939, as shown in Figure 2. During this exceptionally hot summer, bushfires burnt to the south and east of Rutherglen. On 13 January 1939 this region experienced one of the worst bushfire disasters in Australia's history; it became known as Black Friday. At 33.5°C, the summer of 1938–39 was 2.2°C hotter than the average maximum temperature during the ten most recent summers at Rutherglen, and a full 3°C hotter than the average maximum summer temperature at Rutherglen for the entire period of the record.

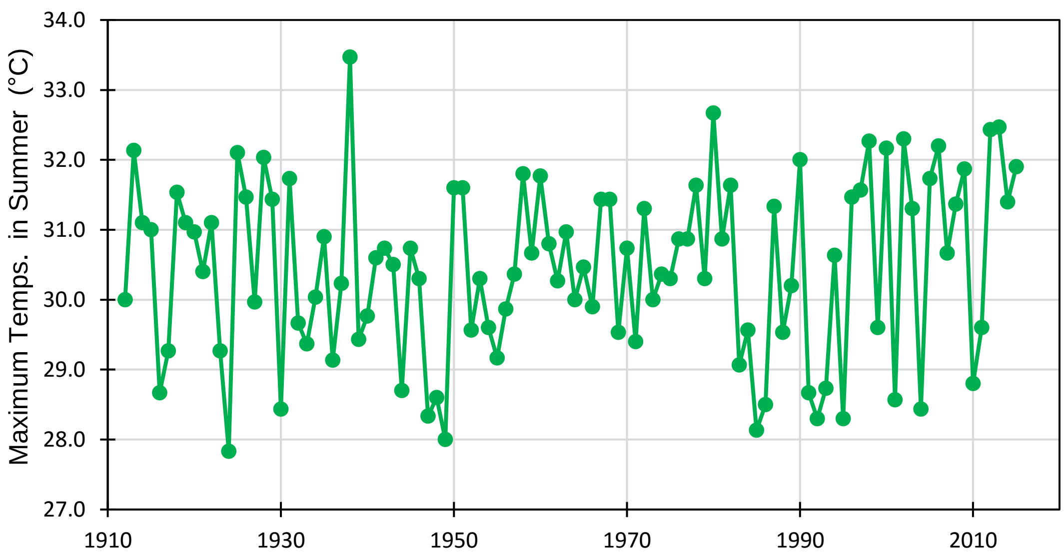

Figure 2. Mean maximum temperatures as measured at Rutherglen during each summer (December, January and February) from 1912 to 2016.

Minimum annual temperatures, as measured at Rutherglen, also show significant inter-annual variability, and a slight overall cooling trend as shown in the green series in Figure 3.

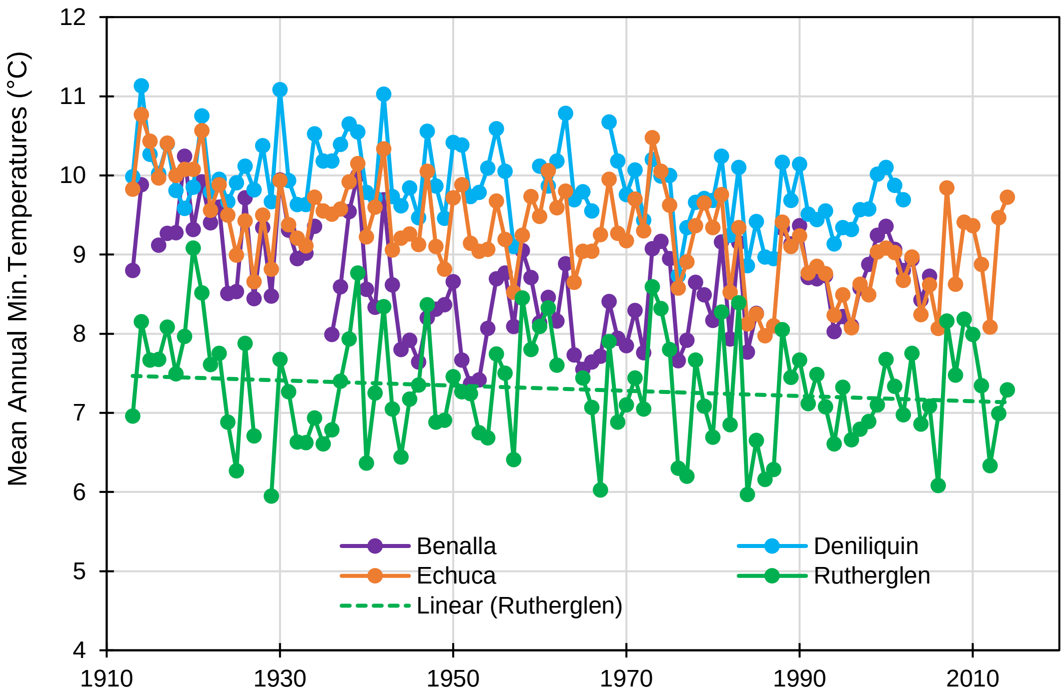

Figure 3. Mean minimum of annual raw temperatures as measured at Benalla (1913–2005), Echuca (1913–2014), Deniliquin (1913–2002) and Rutherglen (1913–2014).

There is also a cooling trend at the three nearby sites of Benalla, Deniliquin and Echuca, also shown in Figure 3.

The actual values and uncertainty estimates are detailed in Table 1.

SITE	MEAN	STANDARD ERROR	VARIANCE	SLOPE	NUMER IN SAMPLE	MEAN	STANDARDERRO R	VARIANCE	SLOPE	NUMBER IN SAMPLE
	$\bar{x}$	$\pm$	s^2	°C/100	n	$\bar{x}$	$\pm$	s^2	°C/100	n
	Based on annual values (1913-2014)					*Based on monthly values (1913-2014)*				
Rutherglen										
Mean:										
Raw	14.52	0.05	0.26	+0.1	99	14.53	0.16	30.85	+0.1	1210
Homogenised	14.30	0.05	0.30	**+0.7**	99	14.30	0.16	30.90	+0.6	1210
Maxima:										
Raw	21.74	0.08	0.60	+0.5	99	21.75	0.20	47.13	+0.5	1210
Homogenised	22.01	0.08	0.60	-0.3	99	22.02	0.20	47.13	-0.3	1210
Minima:										
Raw	7.30	0.07	0.48	-0.3	99	7.32	0.13	20.0	-0.3	1210
Homogenised	6.58	0.09	0.75	**+1.6**	99	6.59	0.13	20.23	**+1.6**	1210
Raw minima at comparative sites:										
Beechworth	7.82	0.10	0.71	-2.2	69	7.79	0.14	17.10	-2.3	871
Benalla	8.65	0.07	0.44	**-0.7**	89	8.64	0.13	18.90	-0.7	1112
Deniliquin	9.90	0.05	0.23	**-0.8**	87	9.91	0.14	20.19	-0.7	1223
Echuca	9.28	0.06	0.38	**-1.2**	102	9.29	0.12	17.32	**-1.2**	1223
Hay	10.14	0.07	0.54	**+1.2**	101	10.14	0.14	23.04	**+1.2**	1223
Tatura	8.36	0.08	0.30	+1.0	50	8.36	0.17	17.32	+1.0	600
Wagga PO	9.56	0.12	0.58	+2.1	38	9.36	0.24	25.85	+2.1	456
Wagga Air	0.05	0.07	0.37	+0.2	73	9.04	0.17	25.40	+0.2	876

Table 1. Uncertainty, including variance (s^2) and standard errors ($\pm$), for maximum, minimum and mean ($\bar{x}$) temperatures at Rutherglen for raw and homogenised (ACORN-SAT), and for minimum temperatures at nearby sites with long and continuous records (raw only). Series have not been infilled for missing values. The calculations based on annual values do not include years with missing months. Statistically significant trends ($p<0.05$) are marked in bold and are also underlined.

Note that the upswing in the temperature minima at Deniliquin in 1914, 1930 and 1942, is mirrored in the other series (Figure 3). This synchrony affirms that the temperature measurements from Rutherglen are accurate and that these observations are a true representation of the pattern of temperature change.

The general cooling trend in the Rutherglen temperature minima may be a consequence of land-use change associated with the development of irrigation in this region. Cooling trends have been reported for other irrigation areas (Fawcett, Trewin, Braganza, Smalley, Jovanovic and Jones 2012; Trewin 2012).

While the raw minimum temperatures as measured at Rutherglen show cooling, the official minimum temperature series for Rutherglen has a warming trend, as shown in Figure 4. This homogenised series is part of the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT), which was sourced from the Bureau of Meteorology (2015b).

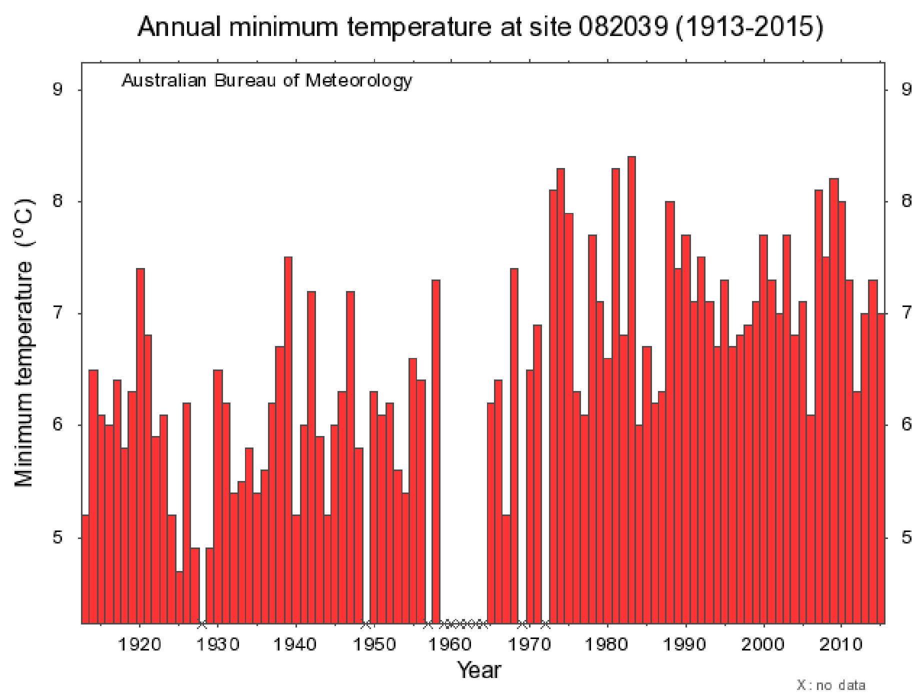

Figure 4. Mean minimum of homogenised ACORN-SAT temperatures from Rutherglen, 1913 to 2015. Source: Australian Bureau of Meteorology.

This ACORN-SAT series is based on the same measurements from Rutherglen used to plot Figure 3, but with these values subsequently passed through algorithms that change the slight cooling of -0.3°C per century into a warming trend of +1.6°C, as shown in Figure 5.

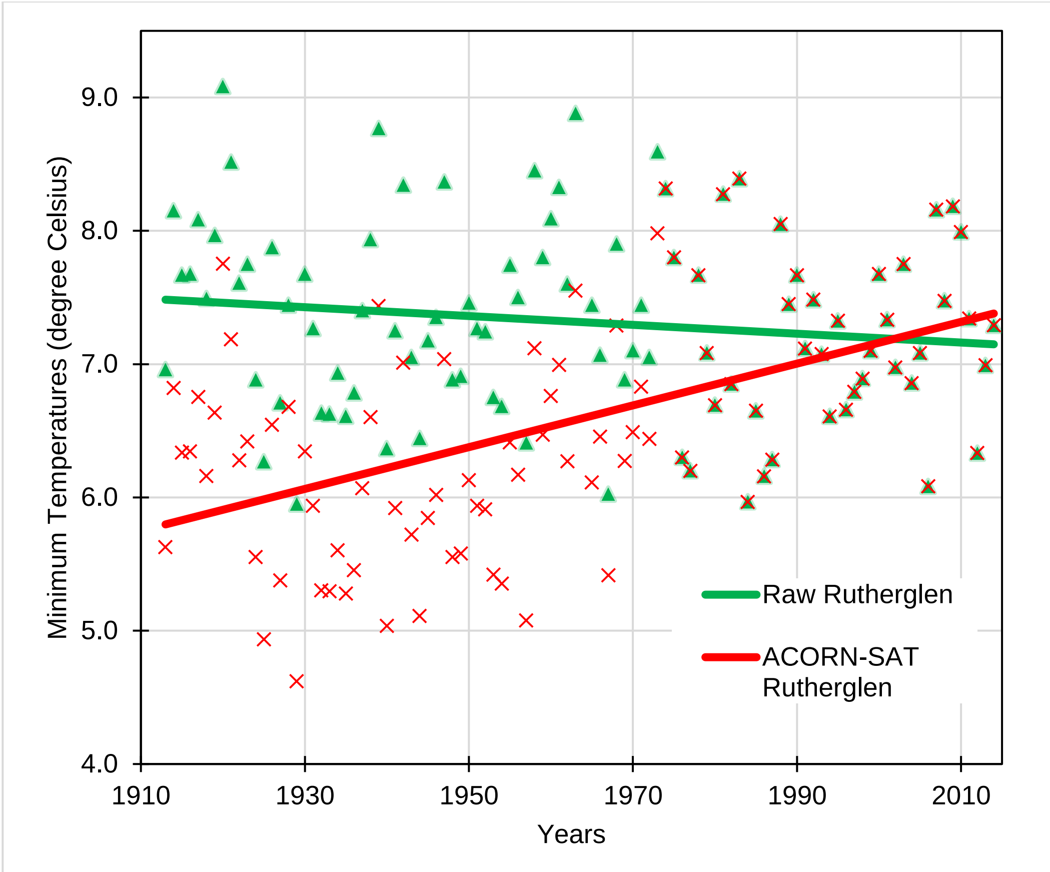

Figure 5. Mean of annual raw and annual homogenised minimum temperatures as measured at Rutherglen, 1913 to 2014.

Adjustments are made by the Bureau to the minima temperatures from the beginning of 1974 and 1966, and then propagated backwards in time.[4] For the year 1913, there is a significant 1.3°C difference between the annual raw minimum value and the homogenised ACORN-SAT value (Figure 5).

In a special advisory issued by the Bureau in September 2014, it is claimed that the adjustments – which create the artificial warming trend in the homogenised temperature minima – were necessary to make the Rutherglen series consistent with the trends measured at neighbouring weather stations. However, it is apparent that in this advisory, annual raw minima values from Rutherglen are compared with data from neighbouring sites that have already been homogenised. This approach, which may once have been

[4] The 1966 and 1974 adjustments to the temperature minima made in this study are based on the listings in an advisory issued by the Bureau in September 2014 that was specific to Rutherglen (BOM 2014a). A previous summary adjustment document for all ACORN-SAT weather stations, issued in August 2014, included an additional adjustment to the temperature minima in 1928. More information is available in Appendix 1.

considered fraudulent, is now consistent with the postmodernist epistemology that underpins homogenisation as practiced by the Bureau – as detailed in Appendix 2.

Not surprisingly, the homogenised ACORN-SAT minimum temperature series for Rutherglen – which shows a warming trend – is quantifiably *less* consistent with the actual measured (raw) temperatures from neighbouring sites when assessed through regression (see Section 4.2.4). Homogenisation of the minima temperatures at Rutherglen also has the effect of *increasing* uncertainty estimates: in the case of the standard error from 0.07 to 0.09 (Table 1). Yet, if homogenisation corrected for outliers or transcription errors, as claimed by the Bureau, then the standard errors in the ACORN-SAT series would be smaller than in the raw measurements. This increase in the standard error should have been of concern to the Bureau, and was highlighted in my submission to the Auditor-General of Australia in October 2015. In this submission I asked that the National Audit Office undertake a performance audit of the procedures, and validity of the methodology, used by the Bureau in the construction of the official historical temperature record for Australia[5].

The maximum temperature series for Rutherglen is also homogenised by the Bureau before incorporation into ACORN-SAT (Bureau of Meteorology 2014b). The most significant adjustment corresponds with the spike in temperatures in the summer of 1938–39, as shown in Figure 2. The discontinuity detected through the Bureau's homogenisation process at this point is likely to be a consequence of drought and bushfires. Therefore, no adjustment should have been made, because the outlier is a consequence of a real physical change in the local environment. In describing the 'cause' of this discontinuity as 'statistical' (Table 2), and making no mention of the Black Friday bushfires, the Bureau displays an extraordinary disregard for Victorian history and the legacy associated with this tragedy.

In conclusion, there has been temperature change at Rutherglen throughout the last 100 years. The slight cooling in temperature minima can be attributed to land-use change associated with the development of water infrastructure. The inter-annual variability in temperatures evident in the temperature minima and maxima is likely a consequence of drought – caused by rainfall variability. The Black Friday bushfire of 13 January 1939 occurred during a period of drought and the exceptionally hot summer of 1938–39. Summer temperatures over the last decade have been relatively mild.

[5] Submission to Grant Hehir, Auditor-General of Australia, can be accessed online at http://jennifermarohasy.com/wp-content/uploads/2016/06/Request-Audit-BOM-Marohasy-Ver2.pdf

In taking a revisionist approach to this history – in extensively remodelling both the temperature minima and maxima from Rutherglen – the Bureau obscures understanding of the patterns and relationships in this real observational data. A real consequence is that planning by government and industries, including the local wine industry, becomes fraught with deception.

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2. Introduction

Rutherglen is the regional centre for a wine growing industry in south-eastern Australia between the Yarrawonga and Hume reservoirs, near the Murray River (see Figure 6). An understanding of surface air temperatures is important in wine growing areas; wine varieties are often chosen so they are at the limit of their optimum temperature range. An accurate knowledge of historical temperatures and temperature trends – as measured at the local agricultural research station since November 1912 – is, therefore, important to this industry.

Figure 6. Location of Rutherglen, Deniliquin, Echuca and Benalla near the Murray River in south-east Australia.

Temperature trends are also of intense political interest. Reports of year-on-year increases in national and global temperatures are used to justify large government subsidies for renewable energies. These subsidies, and mandated targets, have affected the price of energy with subsequent impacts on regional and national economies. Indeed, at the beginning of every calendar year, the Australian Bureau of Meteorology reports on how hot the last year was relative to previous years back to 1910. The content of this Annual Climate Statement is extensively disseminated in the mainstream media, and has formed the basis for claims of imminent environmental catastrophe, unless there is an immediate transition away from 'fossil fuels' through a mandated transition to renewable energies.

Temperature observations from the Rutherglen agricultural research station are combined with data from up to 111 other locations to produce the dataset that forms the basis of the Annual Climate Statement. However, of these 112 locations, the data from 109 are remodelled through a process known as homogenisation; then a weighting is applied to each before annual mean temperature trends are calculated (Bureau of Meteorology 2012; Bureau of Meteorology & CSIRO 2014). This dataset is known as the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT). Temperature series from ACORN-SAT are also incorporated into the UK Met Office's HadCRUT dataset[6].

HadCRUT informs deliberations by the United Nation's International Panel on Climate Change (IPCC). The IPCC's Fifth Assessment Report (AR5), in turn, informed the 2015 United Nations Climate Change Conference (COP21), which negotiated the Paris Accord. This legally binding agreement has created emissions reductions targets for 174 countries.

Climate variability and change is routinely reported as an annual mean increase in land surface temperatures of 0.8°C globally since 1880, and 1°C for Australia since 1910. A high degree of consistency has been reported in trends, and sensitivities, across key global and national gridded data sets (Brohan, Kennedy, Harros, Tett & Jones 2006; Fawcett et al. 2012). Uncertainty estimates of the aggregated and homogenised data have been made, with the conclusion that they are small relative to the significant increase in temperatures during the 20th century (Brohan et al. 2006). However, and importantly, the often-quoted Brohan et al. (2006) study acknowledges that HadCRUT, the global data set which was the focus of their study, only archive single temperature series for particular locations, and any adjustments

[6] HadCRUT is the dataset of monthly instrumental temperature records formed by combining the sea surface temperature records compiled by the Hadley Centre of the UK Met Office and the land surface air temperature records compiled by the Climatic Research Unit (CRU) of the University of East Anglia.

made by national meteorological services may be unknown. As Brohan et al. (2006) acknowledge, it is impossible to quantify the effect of such adjustments by national meteorological services on uncertainty estimates. Yet, as I will show in this study, these adjustments may be so significant that they change the magnitude and direction of the temperature trends in the original data.

ACORN-SAT and HadCRUT are designated high-quality data-sets, and are subsequently used as a basis for climate-related research, including by the CSIRO's Oceans and Atmosphere program. Many studies erroneously refer to values from these data sets as 'observations' (e.g. Lewis & Karoly 2014). It is unclear whether raw or homogenised values are used to provide advice to the local Rutherglen wine industry.

In a seminal paper by James Hansen (then at NASA's Goddard Institute for Space Studies) and colleagues (including from NOAA's National Climatic Data Centre), it is clearly stated that the aim of homogenisation is to obtain the best estimate of long-term climate change: 'in which the temperature change is due only to local weather and climate' (Hansen, Ruedy, Sato, Imhoff, Lawrence, Easterling, Peterson & Karl 2001). In the same paragraph it is stated that: 'in the absence of metadata defining all changes, it is better *not* to adjust discontinuities'. Furthermore: 'We would be relying on the fact that absolute temperature calibrations have existed for the past century, and observers were generally aiming to measure the monthly mean temperature for the undisturbed environment at the specified location.'

According to the Australian Bureau of Meteorology website: 'Homogenisation refers to the method of adjusting temperature records to remove artificial biases, such as the impact of a weather station moving from one location to another.'

In reality, however, most adjustments are made based on 'statistical methods' that detect perceived breakpoints (discontinuities) relative to temperature series from comparative weather stations. That is, adjustments are made to a temperature series from a particular site when this record is shown to diverge from trends at neighbouring sites. In the case of the Bureau's ACORN-SAT, this remodelling of measured observations can even occur relative to temperature series from comparative stations that have already been remodelled (as detailed in Appendix 2) and from sites more than 1000 kilometres away and in a different climate zone[7].

The rational for using comparative sites – a technique that is central to homogenisation as practiced at all key institutions – is explained by Easterling and Peterson (1995). This paper details the combination of regression analysis and non-parametric statistics used to achieve 'relative' homogeneity and to detect undocumented discontinuities. Indeed, while Hansen et al. (2001) stress the importance of *not* making 'adjustments' unless there is supporting metadata, the actual method employed by these same researchers routinely results in adjustments to raw data based on statistical analysis *without* any regard to documentation that might provide a physical basis for the purported discontinuity. The adjustments are typically achieved by dropping down all the temperatures prior to a particular year, by a specified amount, back to the beginning of the record.

Table 2 shows the adjustments for Rutherglen as detailed in the most recent advisory from the Bureau. Two adjustments are made to the temperature minima: the first listed adjustment in column six applies to all data prior to 1 January, 1974; the second listed adjustment in column six applies to all data prior to 1 January 1966. The net effect of these adjustments on minimum temperatures at Rutherglen prior to 1966 is a reduction of 1.33°C (0.61°C plus 0.72°C). A two-stage process has been applied to the measured (raw) daily data from Rutherglen to achieve this. As detailed in Trewin (2013) the technique involves first detecting a perceived breakpoint in the temperature series relative to comparative sites, and then making the adjustment ostensibly to make the temperature series 'homogenous' with comparative sites.

The cumulative effect of back-propagating these types of step-changes can be dramatic on the overall temperature trend at a location such as Rutherglen. Not surprisingly, recent studies of the effect of homogenisation on regional and national temperature trends have found a warming bias in local, regional and national homogenised temperature series (Stockwell & Stewart 2012; Boretti 2013; Zhang, Ren, Ren, Zhang, Chu & Zhou 2014; de Freitas, Dedekind & Brill 2014).

[7] For example, temperature data from the town of Cobar in central western New South Wales is used by the Bureau of Meteorology to homogenise temperature data at Alice Springs in the Northern Territory (Bureau of Meteorology, 2014a). Gavin Schmidt, director of NASA's Goddard Institute for Space Studies, has explained that data from across the Coral Sea, and also across the Great Dividing Range, is used to homogenise temperatures at Amberley in south-east Queensland (Marohasy, Abbot, Stewart & Jensen 2014).

Station name	Station number	Temperatures adjusted	Date (adj app to all data prior to this date, unless stated)	Cause	Impact of adjustment (°C)	Seasonal (if applicable)	Comparative stations	Notes
Rutherglen	82039	Min	1/1/1974	Statistical	-0.61		74034, 82503, 82002, 72097, 82100, 74106, 81049, 81084, 72023, 82001	Station documents suggest likely move c. 1974
Rutherglen	82039	Min	1/1/1966	Statistical	-0.72		82053, 82002, 82001, 72150, 74114, 80015, 74039, 74062, 74128, 75032	Station documents suggest likely move c. 1966
Rutherglen	82039	Max	1/1/1965	Statistical	0.39		82053, 72023, 82001, 82002, 75028, 75031, 80043, 72000, 72150, 80015	Station documents suggest likely move c. 1966
Rutherglen	82039	Max	1/1/1950	Statistical	0.62		82053, 72023, 82001, 82002, 75028, 75031, 80043, 72000, 72150, 80015	Site reported as overgrown at 1949 inspection
Rutherglen	82039	Max	1/1/1938	Statistical	-0.62		82053, 72023, 82001, 82002, 75028, 75031, 80043, 72000, 82016, 80015	

Table 2. The list of temperature adjustments published in the advisory issued by the Bureau in September 2014. http://www.bom.gov.au/climate/change/acorn-sat/documents/station-adjustment-summary-Rutherglen.pdf

Homogenisation of minimum temperatures at Rutherglen was the focus of a series of articles in *The Australian* newspaper by journalist Graham Lloyd in August and September 2014 (e.g. Lloyd 2014a; Lloyd 2014b). In December 2014, the Australian government established the ACORN-SAT Technical Advisory

Forum to review methodologies. Membership of the Forum included professors in statistics from Australian universities. Their first report (Commonwealth Government of Australia 2015) recommended that:

‘The Bureau seek to better understand the sources of uncertainty and to include estimates of statistical variation such as standard errors in reporting estimated and predicted outcomes, including:

- quantifying the uncertainty for both raw and adjusted data;
- prioritising the provision of explicit standard errors or confidence intervals, which should further inform the Bureau’s understanding and reporting of trends in all temperature series maintained by the Bureau;
- examining the robustness of analyses to spatial variation; and
- articulating the effect of correcting for systematic errors on the standard error of resulting estimates.’

Disappointingly, the Forum’s report made no specific mention of Rutherglen, or any of the other 111 individual locations that inform the Bureau’s reporting of climate change. To be clear, the professors of statistics did not work through a single example of homogenisation.

In this study, I apply the general statistical advice in the Forum report, initially to quantify uncertainty in the temperature trends from Rutherglen, and also to understand the trends, ranking, and variability in the measured observations (raw data) from Rutherglen for temperature minima, maxima and mean. This analysis is detailed in Part 1 of the results (Section 4.1).

Part 2 of the results (Section 4.2) is a comparative analysis of trends in the measured minimum temperatures with the homogenised ACORN-SAT values. This includes the calculation of variance and standard errors, and also graphical analysis of variation using I-MR-R/S control charts of temperature minima. The control charts are used to both further quantify uncertainty, and also to detect potential discontinuities (breakpoints) at Rutherglen and nearby comparative sites.

The Bureau also homogenises maximum temperatures for Rutherglen. The consequences of this are shown in Part 2 (Section 4.2), and discussed in detail in Section 5.2.

Following Bureau convention (Fawcett et al. 2012), I use the term ‘site’ to denote a specific weather stations, while ‘location’ is used in the case of ACORN-SAT to denote a homogenised composite of one or more sites. It is current Bureau policy, in accordance with practice recommended by the World Meteorological Organization (WMO), that any significant site relocation results in a new site number.

Stevenson screens were introduced as the standard equipment for measuring shade temperature into south eastern Australia between 1898 and 1908 (Nicholls, Tapp, Burrows & Richards 1996). It is assumed that all temperature data used in this study was recorded in a Stevenson screen. Equipment changes associated with the introduction of automatic weather stations, which began in the early 1980s, and other potentially relevant equipment changes, are detailed in Table 3.

3. Method

3.1 Quantifying uncertainty, and detecting discontinuities

The Bureau changes the temperatures as measured at 109 of the 112 weather stations that comprise ACORN-SAT. This is the dataset used to report climate variability and change across Australia. The method applied to individual temperature time series is not replicable, consistent, or even well-documented. For example, there is no consistency in the timing of the breakpoints, or the amount by which values have been adjusted, in the two different advisories issued by the Bureau for Rutherglen in August and September 2014 (Bureau of Meteorology 2014a; Bureau of Meteorology 2014b).

For more information on the specific methodology used by the Bureau, Trewin (2013) directs readers to a review paper by Peterson et al. (1998). In this review of methods used to homogenise temperature data, we are informed that 'subjective judgement' by experienced climatologists is an important tool (ibid). Furthermore, it is acknowledged that this can modify the weight given to various inputs based on a 'myriad of factors too laborious to program' (ibid). In the Forum's report it was acknowledged that it would be advantageous if a 'plain-language description of the criteria for adjustment and the basis for the adjustment itself' were published by the Bureau (Commonwealth of Australia 2015).

Metrology is the science of measurement. Standardised methods, overseen by international committees, have been developed for the characterisation of uncertainty in measurement in other disciplines. In manufacturing, for example, there has been a commercial imperative to achieve continual improvement relative to competitors, while ensuring adequate transparency in all aspects of quality. I proceed with reference to this literature (International Organisation of Standards 2015). That is, temperature measurements from Rutherglen are considered observations from equipment correctly deployed to give accurate readings for that environment. Considered from this perspective, the extensive statistical literature for testing process stability and control – including by assessing the between-sample, and also the within-sample component of variation – becomes relevant (Ryan 1989; Taylor 1991). In particular, control charts (also known as Shewhart charts) can be used to understand variability within and between samples, and to distinguish common cause variation (random error) from special cause effects (Boulanger et al 2012; Gibbons 1986).

In this study, I specifically use I-MR-R/S control charts in the statistical package *Minitab* (Version 17), to detect discontinuities and quantify confidence intervals in the minimum temperature measurements, as recorded at Rutherglen, and also at comparative sites.

I-MR-R/S control charts can show annual temperature trends relative to sample (i.e. annual) standard deviation, and the moving range of the annual mean. Upper and lower control limits are set at three standard deviations from the overall mean. The centre line is defined by the overall annual mean of the statistic-of-interest. I hypothesise that if the process of recording temperatures at Rutherglen, and comparative sites, is affected by non-climatic variables (e.g. site moves), the location of the average annual temperature for the period of recordings will *not* be randomly distributed and may exceed either the upper or lower control limits, or both.

It follows that if 'Rutherglen's raw minimum temperatures are very much cooler after 1974', as a consequence of the claimed site move (Bureau of Meteorology 2014b), then this should be evident in the control chart for the raw measured series as a change in measurements relative to the centre line, and possibly also in either the exceedance of the lower control limit before 1974, or the exceedance of the upper control limit after 1974.

The statistic of most interest in the Bureau's Annual Climate Statements is the annual mean: calculated as the average of the maxima and minima. An advantage in using annual values is that this negates diurnal and seasonal fluctuations. The Rutherglen temperature record is long enough that change in the location of such mean annual values over the period of the available record, possibly caused by increases in concentrations of carbon dioxide or natural climate cycles, should be evident as a displacement of the annual mean relative to the overall mean. For example, significant global warming from elevated levels of carbon dioxide superimposed on natural weather and climate variability would be expected to result in a significant upward displace of the annual mean temperature maxima and minima over the period of the record.

While mean annual values are important for understanding such overall trends, monthly data provides a convenient measure of the associated within-year and between-year variation; this is also a measure of uncertainty.

So, monthly data is used to calculate key statistics associated with the quantification of uncertainty, including the confidence interval, variance and standard errors for the annual values. The monthly data is also run through I-MR-R/S control charts to check for possible discontinuities, and also as a visual representation of changes in the standard deviation of the annual mean for the period of each series, as well as the moving range of the annual mean.

3.2 Source of data and adjustments

Raw temperature data for Rutherglen, and comparative sites, was downloaded from the Bureau website as monthly time series (Bureau of Meteorology 2015a). The maximum and minimum temperature values are the average for that month of the highest and lowest (respectively) values recorded for each 24-hour period starting at 0900 local time. This convention means that the minimum and maximum temperatures will have usually occurred on the same calendar day (in the morning and afternoon, respectively). The ACORN-SAT monthly time series for Rutherglen used in this study was then generated from these raw temperature series by applying the adjustments as listed in the September 2014 advisory (Bureau of Meteorology 2014b).

In particular, for the minimum temperature series, all months prior to January 1974 had 0.61°C *subtracted* from the actual physical temperature measurements (i.e. the raw data), and 0.72°C was *subtracted* from this data for all months prior to January 1966. The adjustments to the maximum temperature series were also in accordance with this advisory (Bureau of Meteorology 2014b), with 0.39°C *added* to all months prior to 1965, 0.62°C *added* to all months prior to 1950, while 0.62°C was *subtracted* from all months prior to 1938. These adjustments are not the same as those listed in the original 'adjustment summary' issued by the Bureau just one month earlier, in August 2014 (Bureau of Meteorology 2014a).

These adjustments are justified on the basis that in making them, the temperature series for Rutherglen becomes consistent with series at comparative sites, and also temperatures at the three nearby locations of Kerang, Deniliquin and Wagga (Bureau of Meteorology 2014b). Table 3 was compiled in order to understand the quality of the temperature data from the comparative sites, and from the sites that make up the series for the nearby locations of Kerang, Deniliquin and Wagga. For example, Chart 3 (Bureau of Meteorology 2014b) shows a Deniliquin temperature series through to 2013 and, therefore, must have incorporated the Deniliquin airport site number 74258 – though it is not listed as a comparative station in the September 2014 advisory.

Site no.	Site name	Start and end of record	For the period from January 1913 to December 2014:				
	(Distance from Rutherglen shown for key sites only)		No. months	No. of missing months	%	Site moves	Equip. changes
72000	Adelong	01/1907–02/1994	827	397	67.6		
72097	Albury Pumping Station	06/1970–08/1986	195	1029	15.9		
82001	Beechworth (40 km)	01/1908–06/1986	871	351	71.3	1972, 1977	1986
82002	Benalla (70 km)	01/1908–10/2006	1112	112	90.8	1921, 1951, 1960, 1968, 1985	2000, 2006
82100	Bonegilla	06/1968–06/1986	217	1007	17.7		
74034	Corowa	01/1907–02/1994	1004	220	82.0		
74039	Deniliquin Falkiner Research	10/1947–11/1977	360	864	29.4		
74128	Deniliquin, Wilkinson St* (146 km)	02/1867–06/2003	1083	141	88.5	1971	None
74258	Deniliquin, Airport*	06/1997–12/2014	211	1013	17.2		2003, 2004
80015	Echuca (156 km)	06/1881–12/2014	1223	1	99.9	1939, 1969, 1974, 1985	None
82016	Euroa	08/1909–02/1976	642	582	52.5		
75028	Griffith CSIRO	01/1915–06/1989	815	409	66.6		
75031	Hay (226 km)	01/1881-12/2014	1223	1	99.9	1970, 1972, 1993	2005, 2006

75032	Hillston	01/1907–06/2015	920	304	75.2		
72023	Hume Weir	01/1922–06/2015	1001	223	81.8		
80023	Kerang*	01/1903–12/2014	1124	100	91.8	1932, 1956, 1957, 2000	2003
74062	Leeton	01/1913–12/1975	733	491	59.9		
81084	Lemnos	01/1965–01/1996	326	898	26.6		
80043	Numurkah	02/1908–06/1977	636	588	52.0		
082039	Rutherglen	11/1912–12/2014	1210	14	98.9		1998
81049	Tatura (119 km)	01/1965–06/2015	600	624	49.0		
74106	Tocumwal	12/1970–07/2015	529	695	43.2		
72150	Wagga Wagga, Airport* (130 km)	01/1942–06/2015	876	348	71.6	None	1996
74114	Wagga Wagga, Research Centre	01/1948–07/2003	622	602	50.8		
72151	Wagga Wagga, Post Office*	05/1871–12/1950	456	768	37.3	1925, 1928, 1943	None
73127	Wagga Wagga, Agriculture Institute	04/1913–12/1975	525	699	42.9		
82053	Wangaratta	01/1901–05/1987	876	348	71.6		
82056	Wodonga	03/1954–05/1968	171	1053	14.0		

Table 3. Metadata and other relevant statistics for Rutherglen and comparative sites. Sites marked with asterisk are also ACORN-SAT locations. The amount of information available varies by site. Extensive searches of Bureau online databases have only been made for the eight sites with long continuous records that correspond with the apparent sites moves at Rutherglen. These sites, and Rutherglen, are in boxes that have been shaded blue.

I sought out all relevant metadata for all these sites, including the length of the available record, the equipment used to measure temperatures and any site moves (Bureau of Meteorology 2015a; Bureau of

Meteorology 2012; Torok 1996). This information is shown in Table 3, as well as the distance from Rutherglen for the sites with longer records.

Some of the 27 sites (in Table 3) have very short records, with many of them missing months. I went on to quantified uncertainty for those sites where there is a continuous record of at least 30 years that overlaps with the period of the record for Rutherglen with the discontinuities identified by the Bureau (i.e. 1966 and 1974).

According to the official ACORN-SAT station catalogue (Bureau of Meteorology 2012): 'there have been no documented site moves [at Rutherglen] during the site's history.' Contradicting this information, the September 2014 advisory (Bureau of Meteorology 2014b) indicates there were possibly site moves within the grounds of the agricultural research station in 1966 and 1974. This advisory also indicates that from the 1960s there is a large amount of missing data at Rutherglen. Interestingly, while there is a large amount of missing *daily temperature* data at the Bureau website (Bureau of Meteorology 2015a), the rainfall record is complete for this same period. In addition, the monthly temperature record is much more complete than the daily record. There are a total of 14 *months* missing from the maximum temperature series: August 1928, April 1963, and all months for 1964. There is a total of 13 months missing from the minimum temperature series: April 1963, and all months for 1964.

I did infill where there were missing values for the analysis in Section 4.1. I used the mean for the relevant month calculated from the entire data-set. This infilling has not changed the ranking of individual years, or the temperature trends, but it does mean that the resulting temperature series are of practical value for my work forecasting rainfall using artificial neural networks where complete series are needed as input (e.g. Abbot and Marohasy 2012; Abbot and Marohasy 2014; Marohasy and Abbot 2015; Marohasy and Abbot 2016). No infilling occurred of either the raw or homogenised series used to generate the results in Section 4.2, which compares raw with homogenised values.

3.3 Regression of raw and homogenised series against comparative sites

A range of statistical models have been applied to Australian maximum and minimum temperature series to determine fit relative to comparative sites; estimate trends in the data-sets; and to maximise the predictive power with respect to missing observations (Fawcett et al. 2012, p. 27). The quadratic model was found to be the best fit, and superior to a linear regression (Fawcett et al. 2012). This model is thus used in this study.

Given current assumptions in climate science, the ACORN-SAT ‘high-quality homogenised temperature series’ (Jones et al. 2009) for Rutherglen would be expected to be a better match for series at other sites within south-east Australia, relative to the original raw measured temperatures at Rutherglen. This hypothesis was tested through quadratic regression of Rutherglen raw measured series and Rutherglen homogenised series against comparatives sites.

4. Results

This study was undertaken in two parts. Initially I compared raw versus homogenised minimum temperatures: this was the focus of a manuscript submitted to *Atmospheric Research* in 2015 and is the focus of Part 2 of this results section (see Section 4.2). The raw temperature series were recently updated to February 2016, and the reanalysis included the calculation of rankings for the annual mean, minima, maxima and summer maxima as detailed in Part 1 of this results section. The key difference between the values in Tables 1 and 4, is that the former are based on data only to the end of 2014, while Table 4 includes data to the end of February 2016.

4.1 Part 1: Climate variability and change

Mean annual raw temperatures as measured at Rutherglen show no overall statistically significant trend. The linear regression is calculated as +0.09°C per century with large confidence intervals at -0.24 and +0.42 (Table 4). There is significant inter-annual variability, with distinct peaks in 1914, 1938, 1961 and 2007 and 2009 as shown in Figure 1 (Section 1). The hottest years in this record are 1914 and 2007 (tied at 15.8°C), followed by 2009, 1938, 1919, 1961, 1921, 2014, 1930 and 1920.

Series	Period	Mean (°C)	Standard error	Variance	Slope (°C/100 years)	95% confidence intervals	Number data points
Mean	1913–2015	14.53	0.050	0.25	+0.09	-0.24, +0.42	103
Minima	1913–2015	7.31	0.068	0.48	-0.34	-0.79, +0.12	103
Maxima	1913–2015	21.8	0.0758	0.591	+0.52	+0.03, +1.00	103
Summer Maxima	1912/13–2015/16	30.5	0.123	1.57	+0.42	-0.40, 1.20	104

Table 4. Mean with standard error and variance, as well as slope of the linear trend (°C/century) with 95% confidence intervals (two-sided), for the annual minimum, maximum and mean temperature series from Rutherglen for the period 1913 to 2015, and for the summer maxima (December, January and February) for the period December 1912 to February 2016. Calculations are based on annual values. Missing monthly values (14 for TMax and 13 for TMin) were infilled using the mean for that month calculated from the entire dataset (November 1912 to February 2016) before annual statistics were calculated.

The measured raw minimum temperatures at Rutherglen show a cooling trend of -0.34°C per century, but again with significant inter-annual variability as shown in Figure 7. The average annual departure from the overall mean minimum of 7.3°C is 0.56°C (Table 4). The coldest years were 1929, 1984 and 1967 with a mean annual minimum temperature of 6°C.

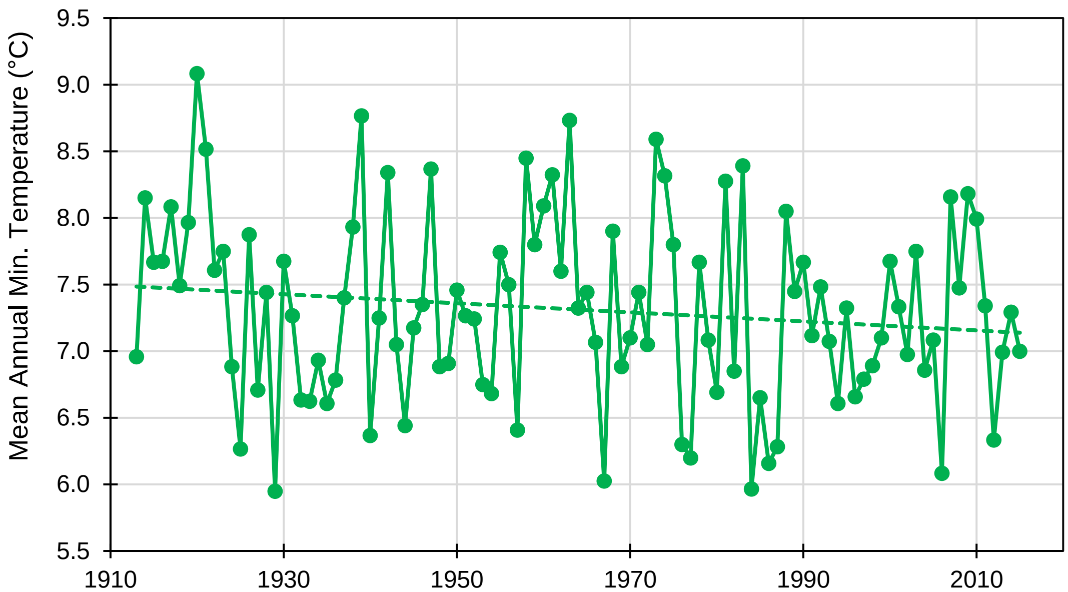

Figure 7. Mean minimum of annual raw temperatures as measured at Rutherglen, 1913 to 2015.

Maximum annual raw temperatures show warming of +0.52°C per century (Table 4). The hottest three years, tied at 23.4°C, are 1914, 2006 and 2007, as shown in Figure 8. Mean annual departure from the overall mean maximum of 21.8°C is 0.61°C.

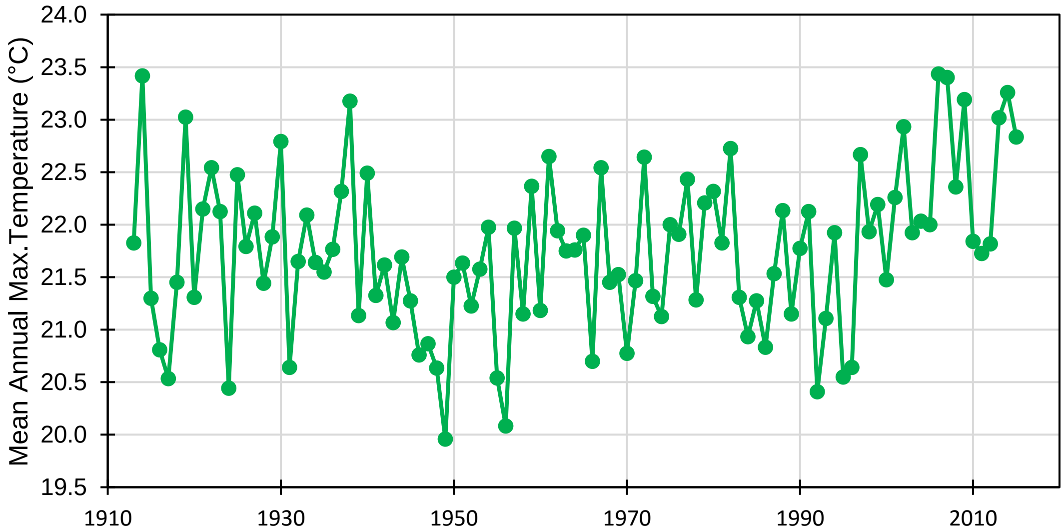

Figure 8. Mean maximum of annual raw temperatures as measured at Rutherglen, 1913 to 2015.

When the maximum temperature is plotted just for the summer months (December, January and February) for the period December 1912 to February 2016, it is evident that the summer of 1938–1939 was relatively hot at Rutherglen as shown in Figure 2 (See Section 1). The average maximum temperature during this summer was 33.5°C, which is a departure of 3°C from the overall mean annual summer temperature at Rutherglen of 30.5°C (Table 4). The next hottest summers were 1980–81 and 2013–14. While much has been made in the mainstream media of this recent summer (2015–16) being exceptionally hot in Australia, it actually ranks 13th overall considering the Rutherglen data.

4.2 Comparing raw and homogenised values

4.2.1 Comparing maximum and mean temperatures

The ACORN-SAT adjustments to the temperature maxima are both positive (addition of 0.39°C and 0.62°C to all values prior to 1965 and 1950, respectively) and negative (subtraction of 0.62°C from all values before 1938). While the net effect is a slight increase in the mean homogenised (ACORN-SAT) maximum temperature for Rutherglen, there is no change to the standard errors or variances, as shown in Table 1 (See Section 1, Summary). The adjustments do, however, change the trend from one of warming to cooling as shown in Figure 9 (compare top green and yellow lines); but neither trend is statistically significant.

The relatively large adjustments to the temperature minima in the creation of the homogenised ACORN-SAT series – illustrated by the difference between the bottom blue (homogenised) and bottom green (raw) series as shown in Figure 9 – result in a statistically significant warming trend in mean temperatures of 0.7°C per century (Table 1). This is because the mean is calculated from the temperature minima and maxima. The homogenisation process for the temperature minima, and its justifications, are discussed in detail in the following three subsections concerned with quantifying uncertainty and quadratic regression.

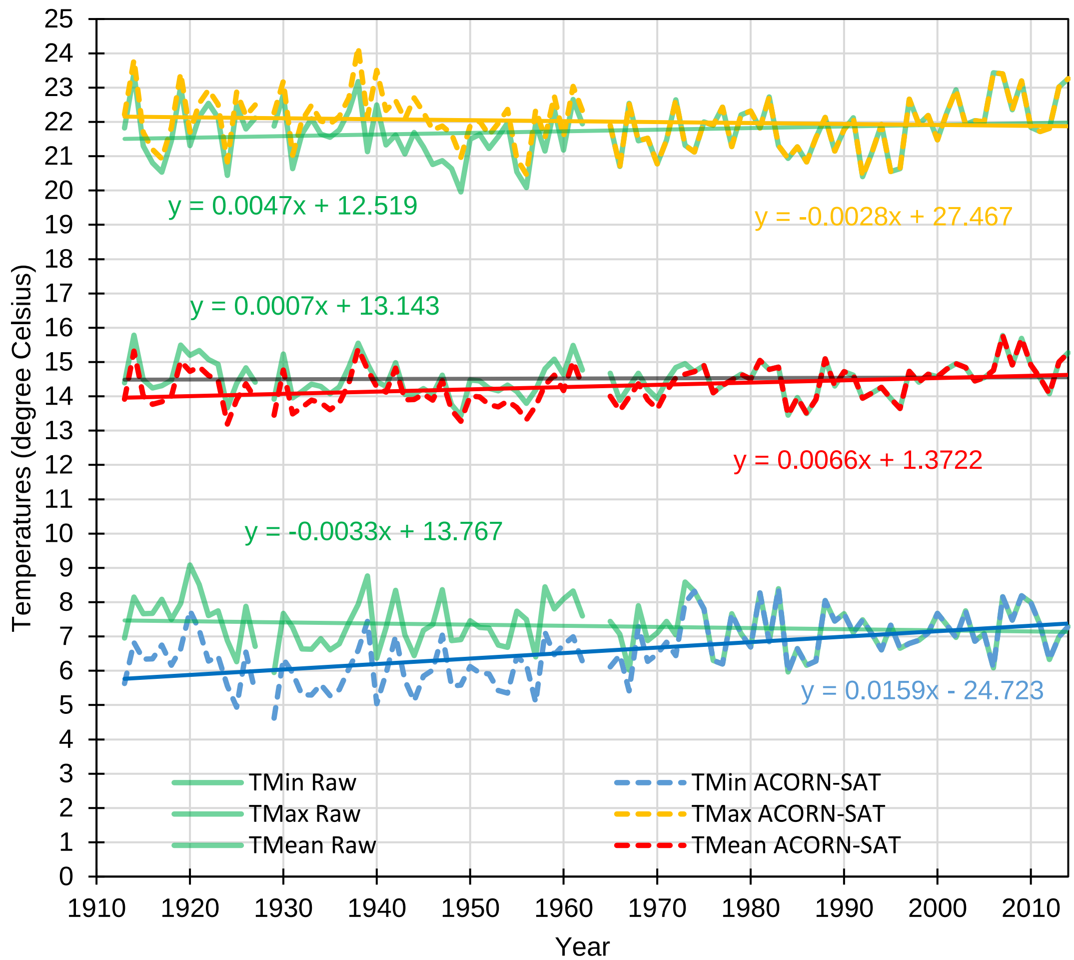

Figure 9. Mean of the annual raw maximum (top), mean (middle), and minimum (bottom) temperatures, and also mean of the annual homogenised (ACORN-SAT) minimum, maximum and mean for Rutherglen, 1913 to 2014. The annual raw values are plotted in green; while the homogenised temperature maxima, mean and minima are plotted in yellow, red and blue, respectively.

4.2.2 Within- and between-year variations in minimum temperatures

The mean minimum temperature for Rutherglen, based on raw (un-homogenised) monthly values (n=1210) for the period January 1913 to December 2014, is 7.32°C± 0.13, Table 1. Excluding the years where there are missing values (1963, 1964), and using the remaining annual means (n=99), this value is 7.30°C ± 0.07 (Table 1). The standard error is reduced when annual values, as opposed to monthly values, are used (Table 1). Whether using annual or monthly values the slope of the linear regression is -0.3°C per century, and is not statistically significant (p>0.05) (Table 1).

Homogenisation of this raw measured minimum time series in the creation of the official ACORN-SAT series involves subtracting 0.61°C and 0.72°C from all values before 1974 and 1966, respectively (Bureau of Meteorology 2014b). This reduces the mean minimum temperature for Rutherglen to 6.6°C ±0.13 and 6.6 ±0.09°C when calculated from monthly and annual values, respectively, as shown in Table 1. While the annual average temperature is reduced, both the standard error and also the variance are increased (Table 1). Most remarkably, the slope of the linear regression changes from slight cooling to statistically significant warming (Table 1).

When the raw, and also homogenised, ACORN-SAT temperature time series are plotted using I-MR-R/S control charts, as shown in Figures 10 and 11, it becomes evident that while there is very little effect on the moving range of the subgroup mean and standard deviations, homogenisation has significantly lowered the subgroup mean for the early component of the homogenised ACORN-SAT series. This is most evident through a comparison of the top charts in Figures 10 and 11. A consequence is displacement of the subgroup mean for the year 1929 by more than three standard deviations below the centre line, as shown in Figure 11 (top chart). Clearly, homogenisation has had the opposite effect to that intended in theory. To be clear, homogenisation of the Rutherglen temperature minima (using the ACORN-SAT methodology) has created a discontinuity – an exceedance of the lower boundary.

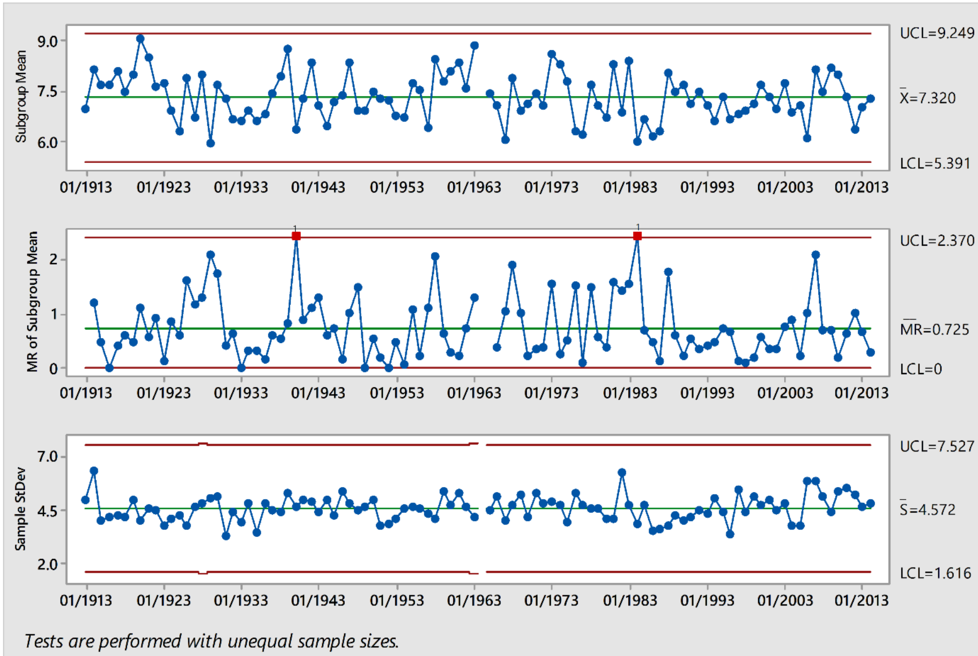

Figure 10. I-MR-R/S control chart showing mean minimum of annual raw temperatures as measured at Rutherglen (1913–2014). The subgroup means (top chart) represents the means of the monthly data for that year eliminating the within-subgroup component of variation (i.e. the seasons), thus tracking process location (i.e. annual temperature change). The moving range (MR) of the subgroup mean (middle chart) tracks between year variations. The sample standard deviation (bottom chart) plots process variation using the within-subgroup (i.e. within each year) component of variation.

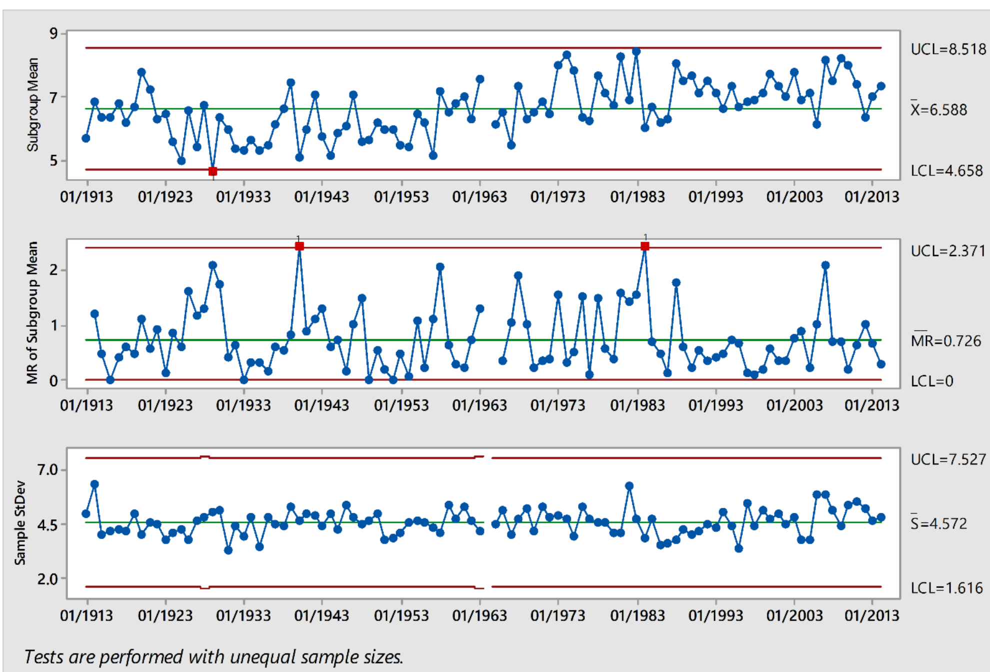

Figure 11. I-MR-R/S control chart showing mean minimum homogenised values as incorporated into ACORN-SAT (1913–2014). The subgroup mean shown (top chart) represents the means for each year eliminating the within-subgroup component of variation (i.e. the seasons), thus tracking process location (i.e. annual temperature change). The moving range (MR) of the

subgroup mean (middle chart) tracks between year variations. The sample standard deviation (bottom chart) plots process variation using the within-subgroup (i.e. within year) component of variation.

The Bureau claim to have detected a discontinuity at 1966 and 1974 (Bureau of Meteorology 2014b). The presence of such a discontinuity in a temperature series when run through an I-MR-R/S control chart typically manifests as a step-change (see Figures 12, top chart at 1976). There is, however, no step-change evident in the location of the subgroup mean in the raw minima temperature as measured at Rutherglen (Figure 10, top chart). This would indicate that the raw Rutherglen temperature minima are homogenous: the minimum temperature series have no breakpoints.

There is no significant change in the standard deviation of the sample (bottom chart, Figure 11) or the moving range of the subgroup mean (middle chart, Figure 11) at 1966 or 1974 following homogenisation. Yet a change would be expected if adjustments – the homogenisation process – had actually corrected for transcription or other errors, which had genuinely created discontinuities in the raw minimum temperature series. The moving range of the subgroup mean does exceed the upper control limit in 1940 and 1984, suggesting significant variability between years (Figures 10). This uncertainty, however, is unaffected by homogenisation (Figure 11).

4.2.3 Within- and between-year variations in minimum temperatures from comparative locations

Analysis of the available data for the 27 comparative sites, as listed in Table 3, indicates that there are only eight sites with continuous monthly data for a period of at least 30 years that overlap with the years with apparent breakpoints (1966 and 1974) as reported for Rutherglen by the Bureau.

Many of the 27 sites potentially used by the Bureau to homogenise the raw measured data from Rutherglen have short records with many missing months, or no record for the critical period (Table 3). For example, the first listed site, Adelong, has 30 years of continuous monthly data between 1920 and 1950, but months are missing for the critical period from 1966 through to 1974. There is a total of only 195 months for the second listed site, Albury Pumping Station, and a total of 1029 months missing (Table 3). In contrast, the sites of Echuca and Hay have almost complete records for the entire period, with only one month missing within the period January 1913 to December 2014 (Table 3).

Of the eight sites with continuous data for the relevant period of the Rutherglen record, the minimum temperature series for Benalla, Deniliquin and Echuca show statistically significant cooling trends based on average annual values (Table 1). The trend is still significant for Echuca when calculated from monthly values (Table 1). Hay (number 75031) is the only comparative site with a long and continuous record and also a statistically significant warming trend (Table 1). Temperatures at Hay were measured in Miller Street, within the town centre, and are likely to be Urban Heat Island (UHI)[8] effected.

When the raw minimum temperature series for each of these eight sites are passed through a control chart, it is evident that Beechworth, Hay and Wagga Post Office have significant exceedance of the control limits suggesting intrinsic quality issues with the individual temperature series (Figures 12, 13 and 14). The other five minimum temperature series – Benalla, Deniliquin, Echuca, Wagga Airport and Tatura – when passed through a control chart, show no obvious discontinuities. The subgroup means, moving range of the subgroup mean, and sample standard deviations are generally within three standard deviations from the relevant mean.

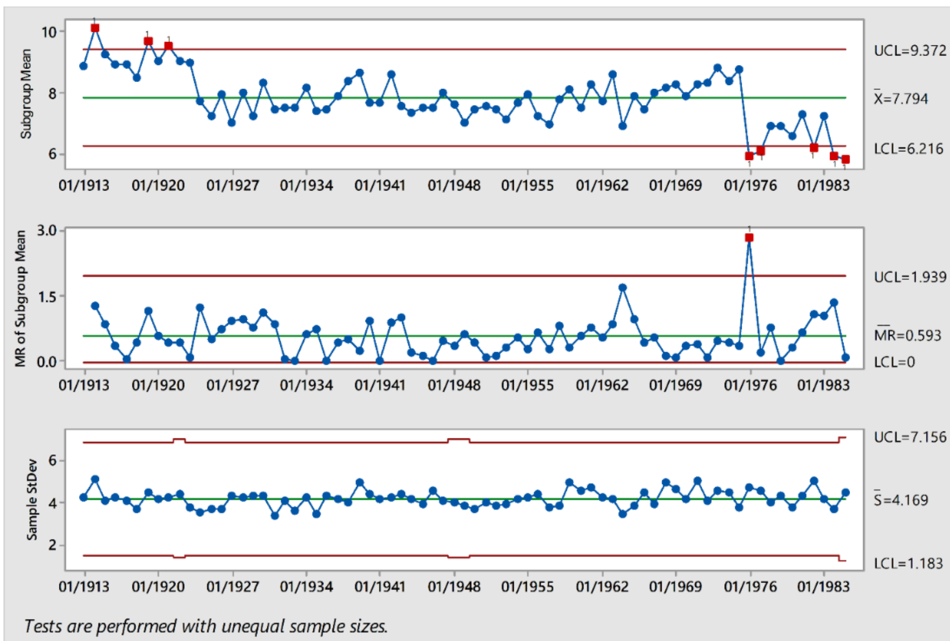

Figure 12. I-MR-R/S control chart showing mean minimum of annual raw temperatures as measured at Beechworth (1913–1985). The subgroup mean shown (top chart) represents the means for each year eliminating the within-subgroup component of variation (i.e. the seasons), thus tracking process location (i.e. annual temperature change). The moving range (MR) of the subgroup mean (middle chart) tracks between year variations. The sample standard deviation (bottom chart) plots process variation using the within-subgroup (i.e. within year) component of variation.

[8] An urban heat island (UHI) is an area that is significantly warmer than its surrounding rural areas due to the modification of land surfaces and waste heat generated by energy usage. As a population centre grows, it tends to expand its area and increase its average temperature.

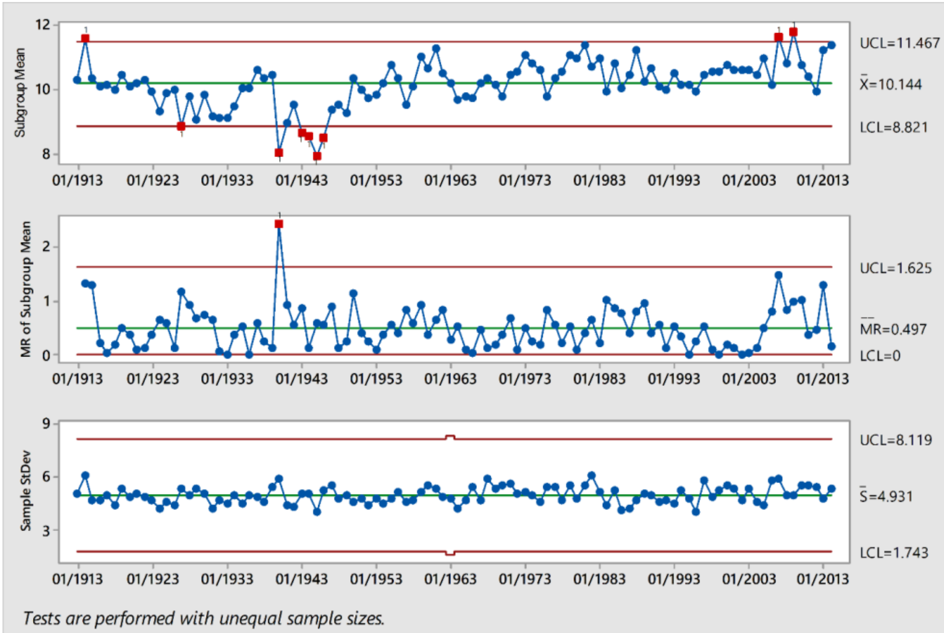

Figure 13. I-MR-R/S control chart showing mean minimum of annual raw temperatures as measured at Hay (1913–2014). The subgroup mean shown (top chart) represents the means for each year eliminating the within-subgroup component of variation (i.e. the seasons), thus tracking process location (i.e. annual temperature change). The moving range (MR) of the subgroup mean (middle chart) tracks between year variations. The sample standard deviation (bottom chart) plots process variation using the within-subgroup (i.e. within year) component of variation.

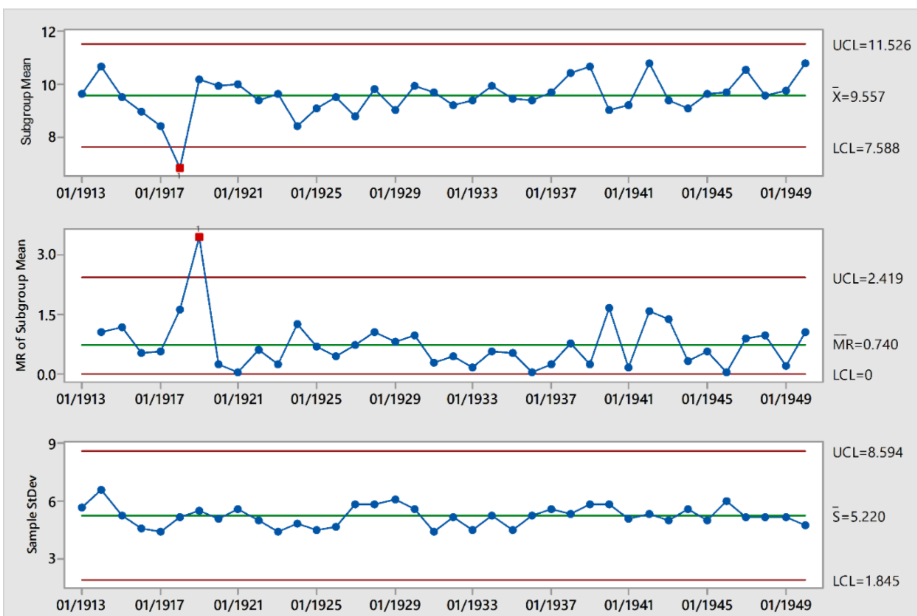

Figure 14. I-MR-R/S control chart showing mean minimum of annual raw temperatures as measured at Wagga Wagga Post Office (1913–1950). The subgroup mean shown (top chart) represents the means for each year eliminating the within-subgroup component of variation (i.e. the seasons), thus tracking process location (i.e. annual temperature change). The moving range (MR) of the subgroup mean (middle chart) tracks between year variations. The sample standard deviation (bottom chart) plots process variation using the within-subgroup (i.e. within year) component of variation.

The I-MR-R/S control chart for Beechworth, shown in Figure 12, shows breakpoints in 1924 and 1976. There is a documented site move at Beechworth in 1977 (Table 3), which may be related to the step-down in the annual minima from 1976 (top chart, Figure 12), and a corresponding exceedance of the upper control limit for the moving range (middle chart, Figure 12).

The temperatures for Hay have been recorded within the township; it is likely that there was some temporary change in the immediate surroundings of the weather station during the period corresponding to World War II's war effort (1939 to 1945). Exceedance of the upper control limit at Hay (Figure 13) coincides with an equipment change in 2006 (Table 3). The record for the Wagga Post Office shows a discontinuity in 1918 (Figure 14).

4.2.4 Quadratic regression against Rutherglen's measured and homogenised minimum temperatures

A quadratic regression model (alpha <0.05) was used to determine whether the measured or homogenised data for Rutherglen was a better fit with the five comparative sites of Benalla, Deniliquin, Echuca, Wagga Airport and Tatura. These are the sites with long and continuous records that show no breakpoints.

Considering the data for Deniliquin, the quadratic regression model fit with Rutherglen's raw values is 94.98%, but only 92.76% with Rutherglen's ACORN-SAT after homogenisation. At Echuca, the result was 95.69% versus 92.60%; Benalla, 94.67% versus 93.24%; and Wagga Wagga airport, 96.20% versus 95.22%. The homogenised ACORN-SAT was only a marginally better fit for the Tatura time series at 96.71% versus 96.34%.

5. Discussion

5.1 Erroneously changing the magnitude and direction of a temperature trend through homogenisation

Climate change is often reported as an increase in land surface temperatures of 0.8°C globally since 1880 (e.g. Lawrimore, Menne, Gleason, Williams, Wuertz, Vose & Rennie 2011). In Australia, the trend is typically reported as an increase of 0.9°C since 1910: maximum temperatures warming at a rate of 0.8°C per century, and minimum temperatures at a rate of 1.1°C per century (Bureau of Meteorology & CSIRO 2014). These trends are derived from the compilation of homogenised, weighted, and then gridded surface temperature recordings from weather stations, such as Rutherglen.

It is stated that there is a high degree of consistency in these datasets (Brohan et al. 2006; Fawcett et al. 2012, Hansen et al. 2001; and Van Wijngaarden 2014), which, it is claimed, indicate that there was warming until 1940, followed by stasis or some cooling to 1965, and then more warming. However, considering homogenised data only for Australia, Torok and Nicholls (1996) and Trewin (2013) have stated that temperatures showed no significant trend until about 1950, after which there has been dramatic warming.

Della-Marta, Collins and Braganza (2004) and Nicholls (2006) state there is significant regional variability in Australian temperatures, but what they report is *not* consistent. For example, with reference to minimum temperatures, Nicholls (2006) concludes there has been cooling in 'some parts of the north-west (strong in summer) and along the south coast of Western Australia (in most seasons)'. Della-Marta et al. (2004) indicate that only maximum temperature trends for north-east Australia show cooling trends since 1910, with a warming trend evident in *all* minimum temperatures.

Meanwhile, Fawcett (et al. 2012) and Trewin (2012, 2013) report cooling in minimum temperatures at specific locations around south-east Australia. Of particular relevance to this study, these authors have attributed the cooling trend in the temperature minima to 'rapid land-use change' associated with the development of widespread irrigated agriculture. Specifically, Fawcett et al. (2012) identified five locations with cooling trends in the temperature maxima from 1911 to 2010, and two for minima. Fawcett et al. (2012) states 'the anomalous trend' at Mildura was a consequence of the development of widespread irrigated agriculture in that region in the period from 1920 to 1945. Trewin (2012) reported that temperatures at the irrigation centre of Griffith decreased by 0.3°C to 0.4°C relative to other locations outside the irrigation area.

Further to the south, particularly the area to the west of Rutherglen in the vicinity of Deniliquin, was once associated with dry-land sheep production; the area is now associated with rice production. The Hume dam was completed in 1936 and the Snowy Mountain hydroelectricity and irrigation scheme came online in 1974. It was in 1974 that the Bureau claims it can find a discontinuity in the Rutherglen temperature series.

The Snowy Mountains scheme is the largest engineering project in the history of Australia. The Yarrawonga weir is the point where there is the greatest diversion of water from this scheme. The Mulwala canal and Yarrawonga main channel (Figure 6) now supply water to more than 800,000 hectares (nearly 2 million acres) of irrigated farmland (Murray–Darling Basin Authority 2015). This ponded water provides a possible physical mechanism to explain the long-term cooling trend in this region in the temperature minima: evaporation removes latent heat from the surface from which evaporation occurs, and is the physical basis of industrial and domestic cooling systems, and also of sweating.

Within this longer-term cooling trend in the temperature minima, there is considerable inter-annual variation at Rutherglen and neighbouring sites, with a high level of synchrony between sites as shown in Figure 3.

There is an extensive literature noting that low rainfall in this region is often accompanied by anomalous high air temperatures (Lockhart, Kavetski & Franks 2009; Franks 2013). Cooler years occur when there is moisture in the environment with much of the sun's energy used in evaporation, with limited heating of the surface. However, when soil moisture content is low – and also when rivers, creeks, and billabongs, have dried-up – nearly all the incoming radiation is converted into heating the surface. These are hotter years – occurring during periods of drought. This is consistent with temperature spikes corresponding with extreme drought years, and troughs in wetter years. For example, the first spike in 1914 (Figure 3), was a year of exceptional low rainfall in the state of Victoria, as shown in Figure 15. The recent jump up in the temperature minima at Rutherglen, which occurred between 2006 and 2007 (Figure 7), also corresponds with exceptionally low rainfall in 2007 (Figure 15).

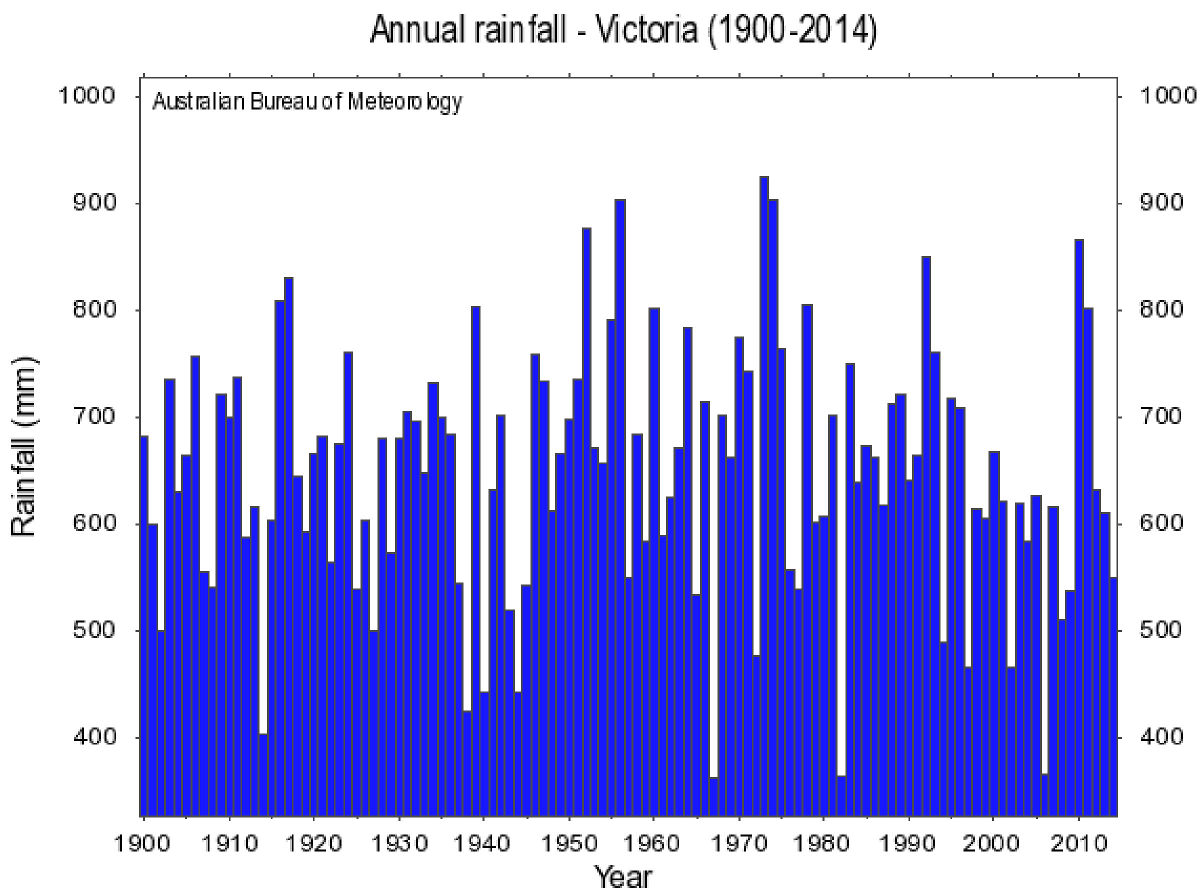

Figure 15. Annual rainfall Victoria, south-east Australia, 1900–2014. Source: Australian Bureau of Meteorology.

Interest in climate change specifically at Rutherglen followed a series of articles by Graham Lloyd in *The Australian* newspaper beginning in 2014. The Bureau was asked to justify the remodelling of the minimum temperatures as measured at Rutherglen, which one of these articles showed had changed a cooling trend into warming. Rather than acknowledging the significant inter-annual variability and the development of irrigated agriculture in the vicinity of Rutherglen, the Bureau claimed site moves and the need for consistency with nearby sites as justification for the adjustments which it claimed were part of a quality assurance process (Bureau of Meteorology 2014b). Yet we now know that Rutherglen's nearest neighbouring weather stations, which have long and continuous temperature series, generally show cooling in their temperature minima: this is evident in Figure 3.

The Bureau supported its faux claims with a chart (see Appendix 2, Figure D) showing raw minimum temperatures as measured at Rutherglen, with remodelled temperatures from the neighbouring sites of Wagga, Deniliquin and Kerang. The Bureau then stated the adjustments were made to the Rutherglen minimum temperature series to achieve consistency with trends at these neighbouring sites (Wagga, Deniliquin and Kerang).

The idea that historical temperature data can be changed to make it consistent with measurements from neighbouring sites would have once been considered scientifically absurd; it is now standard practice in climate science. Furthermore, that the timing, magnitude and direction of the adjustments are determined relative to comparative sites that have already been remodelled, would have once been considered fraud. That this is now apparently accepted practice suggests that climate science has embraced a postmodernist philosophy. Indeed, this is exemplified through the practice of homogenisation.

Homogenisation is a two-step process (Trewin 2013). After breakpoints are identified –in the case of the Rutherglen temperature minima in 1966 and 1974 (Table 2) – adjustments may be made either up or down. This depends on temperature trends at neighbouring sites. In the case of Rutherglen, it is unclear why the 23 sites and three locations listed in the Bureau's advisory (Bureau of Meteorology 2014b) were chosen for comparison – as comparative stations.

Rutherglen is a rural site, while the temperature series from several of the comparison sites – for example Hay (Miller Street) and Wagga (post office) – are from urban environments. Studies in the United States and China indicate that the Urban Heat Island effect (UHI) can potentially introduce a warming bias of up to 0.3°C per decade in temperature trends (Karl, Diaz & Kukla 1988; Balling & Idso 1989; Wang, Zeng & Karl 1990). The UHI effect is particularly pronounced in large cities on calm, clear nights where temperatures can be up to 6°C higher than in surrounding rural areas (Barry & Chorley 1992). It should thus be of considerable concern that the Bureau routinely uses stations known to be affected by UHI to homogenise rural and remote locations. For example, an inner-city Melbourne site (Bureau No. 086071) is listed as a comparative site for the lighthouse at Cape Otway (Bureau No. 090015), as detailed in Marohasy and Abbot (2015).

A solution is to do away with the use of comparative sites – remodelled or UHI-effected – altogether when assessing the integrity of temperature time series as part of quality assurance. In this study I have shown that control charts provide a technique for both detecting discontinuities, and also for quantifying uncertainty *independently* of temperature series at comparative sites.

If comparatives sites are to be used at all, this should only occur after the intrinsic quality of individual temperatures series have been determined through the use of control charts. For example, in demonstrating through the use of control charts that the raw data at Beechworth contains systematic errors, divergence from measurements at Rutherglen can be expected, and explained.

The ACORN-SAT Technical Advisory Forum has recommended that the effect of homogenisation on the standard error be reported (Commonwealth of Australia 2015). In the case of Rutherglen, I have shown that homogenisation has reduced the minimum temperature from 7.3°C to 6.6°C while increasing the standard error from $\pm$0.07 to $\pm$0.09. If homogenisation corrects for systematic errors, then the standard error of the annual means would likely be smaller after adjustments. Furthermore, if homogenisation is undertaken to make a temperature series more consistent with neighbouring stations, then the quadratic regression model would be a better fit with the homogenised temperature series, which it is not.

An important philosophical principle in traditional science states that *no* more things should be presumed to exist than are absolutely necessary. It is often referred to as 'Ockham's Razor' after an English Franciscan friar and philosopher, William of Ockham (c. 1285–1349). Indeed, if there is no evidence of systematic errors in the raw temperature measurements then there is no need to make any adjustments. There would certainly be no scientifically justifiable reason to remodel the temperature series at Rutherglen relative to series:

- known to contain a UHI effect
- series with discontinuities, or
- that have already been remodelled to show a warming trend.

In this study I have shown that the Bureau makes all three errors in its homogenisation of the Rutherglen temperature minima.

5.2 Making adjustments in the wrong direction, for real outliers caused by bushfires

Homogenisation of historic temperature series, and the worldwide obsession with how many fractions of a degree Celsius temperatures may have risen or fallen as a consequence of increasing atmospheric concentrations of carbon dioxide, has diverted attention away from natural climate cycles. In the case of Rutherglen, these may be driven by rainfall variability and they may involves shifts of several degrees Celsius between successive years and successive summers. For example, the summer of 1938–39 was

2.2°C hotter than the average maximum temperature during the ten most recent summers at Rutherglen, and a full 3°C hotter than the average maximum summer temperature at Rutherglen for the entire period of the record (1912-2016).

Indeed, the historic maximum temperature record for Rutherglen shows very significant inter-annual variability (Figure 8). Yet, according to the popular literature, Australia will have lost all its iconic sites (the Great Barrier Reef, Kakadu, Alpine environments) and also its agricultural productivity, and the majority of its animal and plant species, if there is 3°C of warming (e.g. Hogarth 2007). This popular perception of climate change derives from a revisionist approach to historical temperatures which is dependent on records that have been homogenised or otherwise remodelled – as discussed in more detail in Appendix 1.

At Rutherglen, the summer of 1938–1939 occurred during a period of extended drought in the Murray Darling catchment (Helman 2009). In January 1939 intense bushfires burnt across the state of Victoria. There are reports of ash from these fires falling as far away as New Zealand (Victorian State Government 2015). An area of two million hectares to the immediate south and east of Rutherglen burned; whole townships were destroyed and many lives were lost (Franklin 2009).

Seventy years later, on 7 February 2009, it happened all over again. According to journalist Roger Franklin (2009) lamenting the terrible loss of life and complete destruction to so-many natural environments:

> Every time Victoria burns it is the same, especially the weather. It is always hot with a vicious northerly bringing the desert's dryness, parching the air and playing midwife to the flames. Then, inevitably, comes a southerly change – winds that make fronts of what were flanks and send a much greater destruction raging in entirely new directions. Like the weather, the dates can also be fixed. While the official fire season extends from November through to March, it is the last half of January, and the first weeks of February when the cruellest fires always rise and roar.
>
> Yet Victoria and Victorians on Black Saturday [7 February, 2009] appear to have absorbed none of history's harsh lessons. If you were to go by area burnt, the inferno of 2009 was far from the broadest spate of fires Victoria has seen. Black Friday, 1939, consumed twice as much countryside, but less than half as many lives. For all the theorising and inquiring and po-faced post-mortems, the toll this time says we are losing ground.
>
> And the next time? Unless the wind changes in the corridors of power there will be a next time, and the trend says it will be worse. Much worse.

Franklin goes on to make the case that there were inadequate warning systems in place, communication breakdowns, bush left unburnt for years, and a lack of leadership. The situation may also be worse in years to come because of confusion regarding the relationship between temperature and fire hazard. This is because warnings are issued based on temperatures, humidities, wind speeds, and estimated fuel loads. The Bureau publishes a Fire Danger Indices (Bureau of Meteorology 2016) and explains that values (risks) are very sensitive to small changes in temperature. But when running models to develop this indices and understanding the past behaviour of bushfires at a particular location, should a fire authority and government scientist input homogenised ACORN-SAT temperatures (which are considered 'high quality'), or the measured raw values from that location (which the Bureau claims have not been quality controlled)? For example, if we consider daily maximum temperatures at Rutherglen for the Black Friday bushfire of 13 January 1939, the measured (raw) value is 42.2°C. This value is a full 5.4°C cooler than the ACORN-SAT (homogenised) value for the same site for the same day, which is 47.6°C!

Franklin (2009) wrote that when considering the likely impact of a bushfire it is important to consider the historical record – but which record? He states that in Melbourne on 13 January 1939 it was 45.6°C. In fact, the official ACORN-SAT value for Melbourne on that day is 46.1°C.

As previously explained, homogenisation is a two-step process. With respect to the temperature maxima at Rutherglen, the Bureau have identified a statistically significant discontinuity in 1938–1939. It is somewhat peculiar that the Bureau does not recognise this exceptionally hot period as likely associated with the drought, compounded by bushfires. It is then a nonsense for the Bureau to make adjustments so that the period of the bushfires is even hotter, as shown in Figure 9 (see top series: yellow versus green series).

Scrutiny of maximum temperatures for the summer months from the beginning of the record in December 1912 to February 2016 would indicate that the summer of 1938–1939 was an outlier as shown in Figure 2. Outliers often have their purposes: they can provide some indication of the possible range of conditions for which government and industry should have a contingency plan. But the Bureau seems unable to understand the relevance of this apparent 'breakpoint'; they describe it as a statistical anomaly and as a justification for changing the historical temperature record.

6. References

Abbot, J & Marohasy, J 2012, 'Application of artificial neural networks to rainfall forecasting in Queensland, Australia', *Advances in Atmospheric Sciences*, vol. 29 no. 4, pp. 717_730.

Abbot, J & Marohasy, J 2014, 'Input selection and optimisation for monthly rainfall forecasting in Queensland, Australia, using artificial neural networks', *Advances in Atmospheric Sciences*, vol. 138, pp. 166–178.

Balling, RC & Idso, SB 1989, 'Historical temperature trends in the United States and the effect of urban population growth', *Journal of Geophysical Research*, vol. 94, pp. 3359–3363.

Barry, RG & Chorley, RJ 1992, *Atmosphere, Weather and Climate*, 6th edn, Methuen, London.

Boretti, A 2013, 'Statistical analysis of the temperature records for the Northern Territory of Australia', *Theoretical and Applied Climatology*, vol 114, iss. 3, pp. 567–573.

Boulanger, M, Johnson, ME & Luko SN 2012, 'Reviews of standards and related material: statistical standards and ISO', *Quality Engineering*, vol. 24, pp. 94–101.

Brohan, P, Kennedy, JJ, Harris, I, Tett, SFB & Jones, PD 2006, 'Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850', *Journal of Geophysical Research*, vol. 111, iss. D12.

Bureau of Meteorology 2012, 'The Australian Climate Observations Reference Network – Surface Air Temperature' (ACORN-SAT), Commonwealth of Australia, Melbourne.

Bureau of Meteorology 2014a, 'ACORN-SAT Station adjustment summary', Commonwealth of Australia, Melbourne, viewed 8 August 2015 <http://www.bom.gov.au/climate/change/acorn-sat/documents/ACORN-SAT-Station-adjustment-summary.pdf>.

Bureau of Meteorology 2014b, 'ACORN-SAT Station adjustment summary' – Rutherglen (as at 24 September 2014), viewed 8 August 2015, <http://www.bom.gov.au/climate/change/acorn-sat/documents/station-adjustment-summary-Rutherglen.pdf>.

Bureau of Meteorology 2015a, 'Climate Data Online', viewed 8 August 2015. <http://www.bom.gov.au/climate/data/>.

Bureau of Meteorology 2015b, ‘Long-term temperature record, Australian Climate Observations Reference Network – Surface Air Temperature’, Commonwealth of Australia, Melbourne. http://www.bom.gov.au/climate/change/acorn-sat/ .

Bureau of Meteorology & CSIRO 2014, ‘State of the Climate 2014’, Commonwealth of Australia, Melbourne.

Bureau of Meteorology 2016, ‘Maximum Fire Danger Index Maps’, viewed 8 August 2015, <http://www.bom.gov.au/vic/forecasts/fire-map.shtml>.

Commonwealth of Australia 2015, ‘Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT): Report of the Technical Advisory Forum, June 2015’, viewed 8 August 2015, <http://www.bom.gov.au/climate/change/acorn-sat/documents/2015_TAF_report.pdf>.

de Freitas, CR, Dedekind, MO & Brill, BE 2014, ‘A reanalysis of long-term surface air temperature trends in New Zealand’, *Environmental Modeling and Assessesment*, vol. 20, iss. 4, pp. 339–410.

Della-Marta, PM, Collins, D & Braganza, K 2004, ‘Updating Australia's high-quality annual temperature dataset’, *Australian Meteorological Magazine*, vol. 53, iss. 2, pp. 75–93.

Easterling, DR’& Peterson, TC 1995, ‘A new method for detecting undocumented discontinuities in climatological time series’, *International Journal of Climatology*, vol. 15, iss. 4, pp. 369–377.

Fawcett, RJB, Trewin, BC, Braganza, K, Smalley, RJ Jovanovic, B & Jones, DA 2012, ‘On the sensitivity of Australian temperature trends and variability to analysis methods and observation networks, CAWCR Techical Report No. 050’, The Centre for Australian Weather and Climate Research, Bureau of Meteorology, Melbourne.

Franklin, R 2009, *Inferno: The Day Victoria Burned*, The Slattery Media Group, Melbourne.

Franks, S 2013, ‘Climate change: in search of a signal’, *IPA Review*, vol. 65, pp. 16–21.

Gibbons, JD 1986, ‘Tests of randomness’, *Encyclopedia of Statistical Sciences*, 3rd edn, John Wiley & Sons, New York.

Hansen, JE, Ruedy, R, Sato, M, Imhoff, M, Lawrence, W, Easterling, D, Peterson, T & Karl, T 2001, ‘A closer look at United States and global surface temperature change’, *Journal of Geophysical Research*, vol. 106, iss. D20, pp. 23 947–23 962.

Helman, P 2009, ‘Droughts in the Murray Darling Basin since European Settlement, Griffith Centre for Coastal Management, Research Report No 100’, Griffith University, Brisbane.

Hogarth, M 2007, *The 3rd Degree: Frontline in Australia’s Climate War*, Pluto Press Australia, Melbourne.

Horton, R 2015, ‘What is medicine’s 5 stigma’, *The Lancet*, vol. 385, no. 9976, p. 1380, 11 April.

International Organization for Standards 2015, ‘ISO/TC 69/SC 4 – Applications of statistical methods in product and process management’, viewed 15 August 2016, <http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_tc_browse.htm?commid=49774>.

Jones, DA, Wang, W & Fawcett, R 2009, ‘High-quality spatial climate data-sets for Australia’, *Australian Meteorological and Oceanographic Journal*, vol. 58, pp. 233–248.

Karl, TR, Diaz, H & Kukla, G 1988, ‘Urbanization: Its detection in the United States Climate Record’, *Journal of Climate*, pp. 1099–1123.

Lawrimore, JH, Menne, MJ, Gleason, BE, Williams, CN, Wuertz, DB, Vose, RS & Rennie, J 2011, ‘An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3’, *Journal of Geophysical Research*, vol. 116.

Lewis, SC & Karoly, DJ 2014, ‘The role of anthropogenic forcing in the record 2013 Australia-wide annual and spring temperatures’, Bulletin of American Meteorological Society, vol. 95, iss. 9, pp. 31–41.

Lloyd, G 2014, ‘Climate records contradict Bureau of Meteorology’, *The Australian*, 27 August, viewed 18 August 2015, <http://www.theaustralian.com.au/national-affairs/climate/climate-records-contradict-bureau-of-meteorology/story-e6frg6xf-1227037936046?sv=fa17786900e7b252d4c06a48f2c99577#mm-premium>.

Lloyd, G. 2014, ‘“More time” to find Rutherglen temperature record’, *The Australian*, 4 September, viewed 18 August 2015, <http://www.theaustralian.com.au/news/nation/more-time-to-find-rutherglen-temperature-record/story-e6frg6nf-1227046989433?sv=c2ef0e890802dbe6c7ee553c9b0ce857#mm-premium>

Lockart, N, Kavetski, D & Franks, SW 2009, ‘On the recent warming in the Murray-Darling Basin: Land surface interactions misunderstood’, *Geography Research Letters*, vol. 36, iss. 24.

Marohasy, J, Abbot, J., Stewart & Jensen, D 2014, 'Modelling Australian and global temperatures: what's wrong? Bourke and Amberley as case studies', *The Sydney Papers Online*, Issue 26, <http://jennifermarohasy.com/wp-content/uploads/2011/08/Changing_Temperature_Data.pdf>.

Marohasy, J & Abbot, J 2015, 'Assessing the quality of eight different maximum temperature time series as input when using artificial neural networks to forecast monthly rainfall at Cape Otway, Australia', *Atmospheric Research*, vol. 166, pp. 141–149.

Marohasy, J & Abbot, J 2016, 'South East Australian maximum temperature trends, 1887–2013: An evidence-based reappraisal', *Evidence-Based Climate Science*, 2nd edn, Easterbrook, D (ed.), Elsevier S&T Books, Washington.

Murray–Darling Basin Authority, 2005, Yarrawonga Weir. Accessed 18th August 2015, http://www.mdba.gov.au/what-we-do/managing-rivers/river-murray-system/dams-weirs/yarrawonga-weir

Nicholls, N, Tapp, R. Burrows, K & Richards D 1996, 'Historical thermometer exposures in Australia', *International Journal of Climatology*, vol. 16, iss. 6, pp. 705–710.

Nicholls, N 2006, 'Detecting and attributing Australian climate change: a review', *Australian Meteorological Magazine*, vo. 55, iss. 3, pp. 199–211.

Peterson, TC, Easterling, DR, Karl, TR, Groisman, P, Nicholls, N, Plummer, N, Torok, S, Auer, I, Boehm, R, Gullett, D, Vincent, L, Heino, R, Tuomenvirta, H, Mestre, O, Szentimrey, T, Salinger, J, Førland, EJ, Hanssen-Bauer, I, Alexandersson, H, Jones, P & Parker, D 1998, 'Homogeneity adjustments of *in situ* atmospheric climate data: a review', *International Journal of Climatology*, vol. 18, iss. 13, pp. 1493-1517.

Ryan, TP 1989, *Statistical methods for Quality Improvement*, 3rd edn, John Wiley & Sons, New York.

Stockwell, DRB & Stewart, K 2012, 'Biases in the Australian high quality temperature network', *Energy & Environment*, vol. 23, iss. 8, pp. 1273–1294.

Taylor, WA 1991, *Optimization & Variation Reduction in Quality*, McGraw-Hill, New York.

Torok, SJ 1996, 'The development of a high quality historical temperature data base for Australia' (PhD Thesis), University of Melbourne, p. 1996.

Torok, SJ & Nicholls, N 1996, 'A historical annual temperature dataset for Australia', *Australian Meteorological Magazine*, vol. 45, 251–260.

Trewin, B 2012, 'Techniques involved in developing the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) dataset, CAWCR Technical Report No. 049', Bureau of Meteorology, Commonwealth of Australia, Melbourne.

Trewin, B 2013, 'A daily homogenized temperature data set for Australia', *International Journal of Climatology*, vol. 33, iss. 6, pp. 1510–1529.

Victorian State Government 2015, 'Black Friday 1939', viewed 1 July 2016, <http://www.depi.vic.gov.au/fire-and-emergencies/managing-risk-and-learning-about-managing-fire/bushfire-history/black-friday-1939>.

Van Wijngaarden, WA 2014, Arctic temperature trends from the early nineteenth century to the present', *Theoretical and Applied Climatology*, vol. 122, iss. 3, pp. 567–580.

Wang, WC, Zeng, Z & Karl, TR 1990, 'Urban Heat Islands in China', *Geophysical Research Letters*, vol. 17, iss. 12, pp. 2377–2380.

Zhang, L, Ren, G, Ren, Y, Zhang, A, Chu, Z & Zhou, Y 2013, 'Effect of data homogenization on estimate of temperature trend: a case of Huairou station in Beijing Municipality', *Theoretical and Applied Climatology*, vol. 115, iss. 3, pp. 365–373.

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Appendix 1

Homogenisation: In practice and theory

Blair Trewin oversees development of Australia's official homogenised temperature dataset (known as ACORN-SAT). Trewin works at the Australian Bureau of Meteorology[9] and has written that:

'If a temperature data set is to be used for monitoring climate change it is important that it be homogeneous; that is, changes in the temperatures as shown in the data set reflect changes in the climate, and not changes in the external (non-climatic) conditions under which the observations are made.'

Trewin[10] goes on to explain that it may thus be necessary to make adjustments to individual temperature series for changes in instruments, and to enable data from two or more different weather-recording stations to be combined to provide a longer composite temperature record. Temperature time series from 109 of the 112 weather-stations that comprise ACORN-SAT have adjustments made to them. In the case of Rutherglen, for example, one of these adjustments involves the subtraction of 0.61°C from the actual measured values for all data prior to January 1974 back to the beginning of the record.

In theory, homogenisation is undertaken to ensure temperatures are an accurate reflection of change for that place: accepting the limitations of any measurement. In reality, however, homogenisation is used to extensively remodel data. This study details the case for Rutherglen. Temperature minima at Rutherglen are *not* an isolated example of homogenisation changing the direction of the temperature trend from one of cooling to warming. For example, cooling of 0.16°C per century in the measured temperature minima at Dubbo (NSW) is changed into warming of 2.26°C per century through homogenisation (an increase of 2.42); and the temperature minima at Brisbane (Queensland) is changed from cooling of 0.68°C to warming of 1.57°C per century (an increase of 2.25). Warming in the temperature minima at Carnarvon (Western Australia) is increased from 0.18°C per century to 2.20°C (an increase of 2.02).

These are not trivial changes; they involve an artificial increase in warming of more than 2°C. This is more than double the reported overall increase in temperatures for Australia since 1910 of 1°C. The changes at Dubbo, Brisbane and Carnarvon may be justified, but there is no easy way to verify this, because the Bureau does not detail its methodology or its reasoning for changes to individual temperature series. Furthermore, in the case of Rutherglen, the actual number of adjustments and the magnitude of these adjustment, as published online by the Bureau, changed between August and September 2014 without any explanation or justification.

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[9] Blair Trewin was the lead developer of the Bureau's current long-term Australian temperature data set, ACORN-SAT. He was the scientific coordinator of the World Meteorological Organisation's annual Global Climate Statement in 2010 and 2011, and is a member of the WMO's Expert Team on Climate Change Detection and Indices, and Task Team on Definitions of Extreme Weather and Climate Events. He is also the current President of the Australian Meteorological and Oceaonographic Society, and editor of the Australian Meteorological and Oceanographic Journal.

[10] Trewin, B 2013, 'A daily homogenized temperature data set for Australia', *International Journal of Climatology*, vol. 33.

The Bureau assures the Australian public that the differences between raw and homogenised data-sets are small. For example, in advice to journalist Graham Lloyd in 2014, and in a Fact Sheet previously available on the internet,[11] this point is made by charting the entire homogenised ACORN-SAT dataset with the 'unadjusted (AWAP) gridded Australian average temperature', as shown in Figure A.

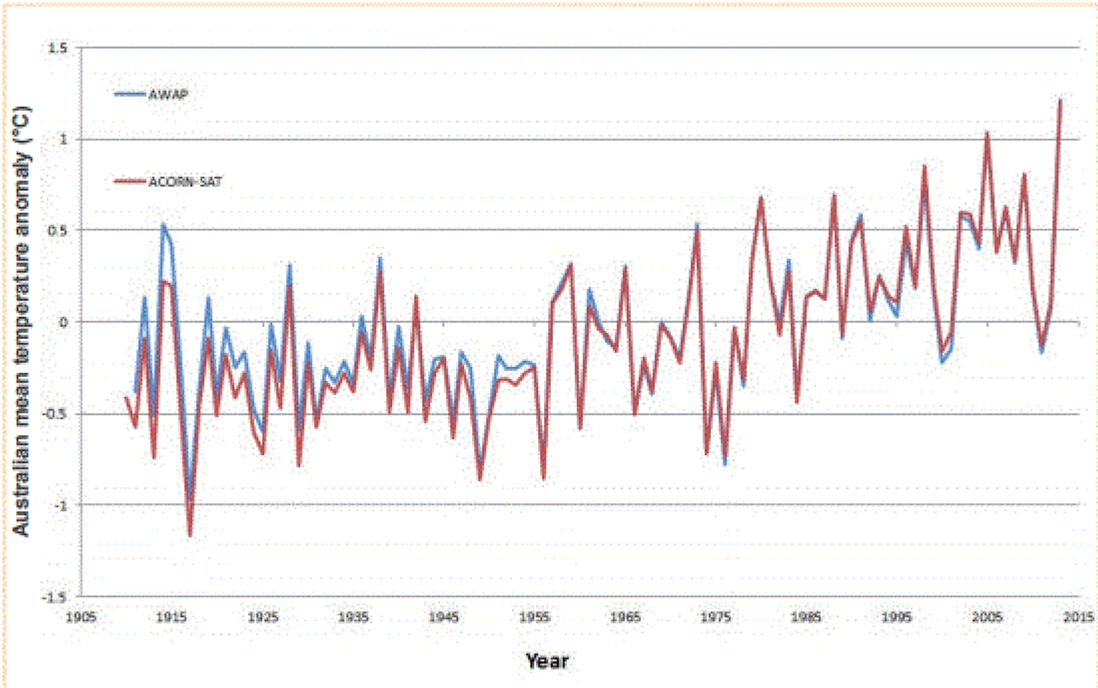

Figure 1: Comparison of two different Bureau of Meteorology temperature records for Australia. The Blue line is the unadjusted (AWAP) gridded Australian average temperature. The red line is the homogenised (ACORN-SAT) temperature for Australia.

Figure A. The blue line in the chart has been generated from un-homogenised temperature series subsequently adjusted through the application of the Barnes Successive Corrections Method, three-dimensional smoothing spines, and the iterative Barnes algorithm as described in Jones et al. (2009).

The impression from this chart is that the 'unadjusted' and the 'homogenised' data-sets are virtually identical. However, both the blue (unadjusted) and the red (homogenised) lines actually represent remodelled values. The chart and accompanying text are deceptive because in the case of the blue line (labelled unadjusted), the remodelling is actually *more* extensive: with the purpose of converting measurements from individual locations into values that represent points on a grid that have a resolution of approximately 5 km by 5 km. The complicated methodology (involving the application of an area weighting and much more) is explained in a technical paper by David Jones.[12] The same weather stations

[11] Bureau of Meteorology 2014, 'Scientific integrity and robustness of Australian climate record', http://jennifermarohasy.com/bom-scientific-integrity-factsheet/ (this document was once available at the Bureau's website but has since been removed).

[12] Jones, DA et al. 2009, 'High-quality spatial climate data-sets for Australia', Australian Meteorological and Oceanographic Journal, vol. 58.

have *not* been used in each year, and values have been recalculated using a smorgasbord of different algorithms depending on factors such as altitude, as detailed in the paper by Jones.

While two very different methods have been used to remodel the raw temperature data in the development of the blue and red lines shown in Figure A, both reconstructions were overseen by David Jones at the Bureau.

When the maximum temperature series from all 1655 Australian stations listed in the US Global Historical Climatology Network (GHCN) dataset are simply combined and the yearly average plotted – without any adjustments for equipment changes or any area weighting – it is apparent that it was much hotter in Australia during the late 1800s, as shown in Figure B. All data was used, including temperature series from capital cities that are UHI effected.

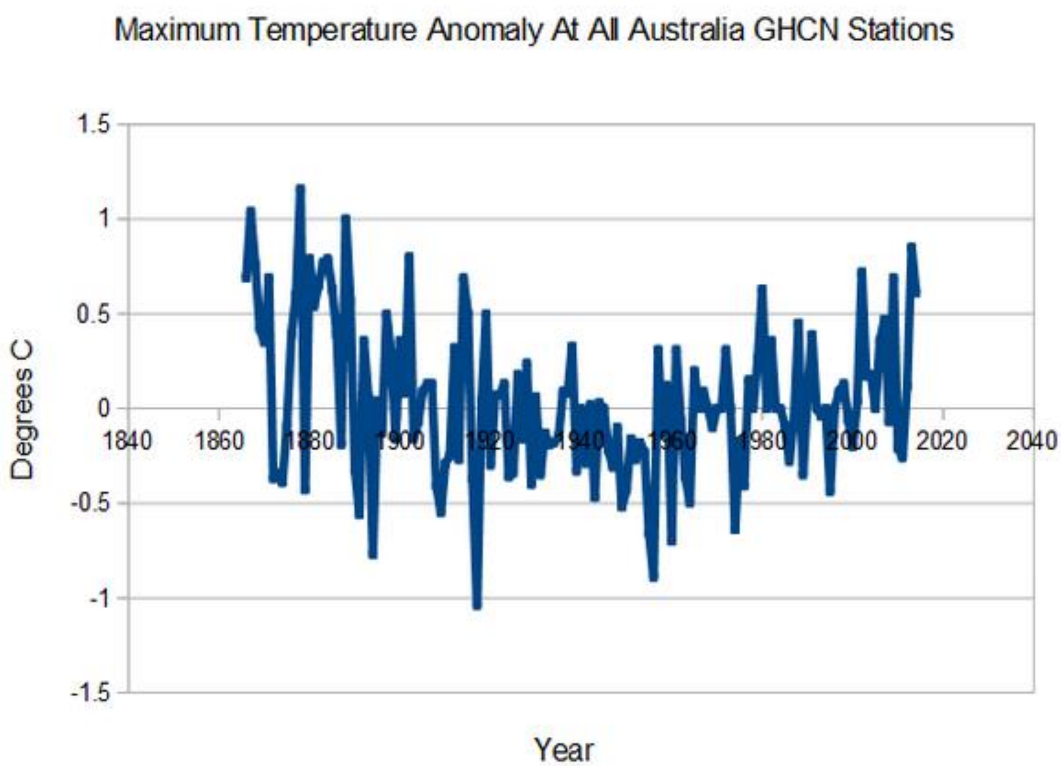

Figure B. There are 1655 Australian stations in the GHCN (Global Historical Climatology Network) database that include temperature data. The database, which includes maximum temperatures, is located here:<ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/all/>, with the station list at the bottom. This chart was created by averaging the daily data for each month at each station over the lifespan of the station to generate a monthly mean, and then calculating anomalies from the monthly mean. The numbers are the average anomaly across all stations for all records during a year. For more information, see <http://jennifermarohasy.com/2014/09/go-boldly-and-smash-all-preconceptions-steve-goddard/>.

I would not use this reconstruction (Figure B), however, to draw conclusions about the historical temperature profile for Australia, because some of 'the heat' in the early part of this record can be attributable to the use of non-standard equipment. I discuss this issue, and show how to make appropriate adjustments to the temperature series at Cape Otway lighthouse, in a recent paper coauthored by John Abbot and published in *Atmospheric Research*.[13] It will not be possible to show an accurate historical temperature reconstruction for the entire Australian continent until many individual temperature series are carefully analysed for such discontinuities using standard quality control techniques, and as appropriate adjustments made – with these changes properly justified and documented. I have begun this task with funding from the B. Macfie Family Foundation.

When temperatures are compared for thirty year blocks using exactly the same 84 sites, and only since 1911 (i.e. since standard equipment was in place), the average rise in temperatures across Australia is 0.3°C.[14] This analysis by Chris Gilham, indicates that the raw mean minimum temperature for Australia has only increased by 0.1°C since 1911, and was static or has cooled in NSW, Victoria and Western Australia. When capital cities are removed from the mix, and a comparison made of only regional weather stations, Gilham shows that average nightly minimum temperatures are now cooler in NSW, Victoria and Western Australia.

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[13] Marohasy, J & Abbot, J 2015, 'Assessing the quality of eight different maximum temperature time series as input when using artificial neural networks to forecast monthly rainfall at Cape Otway, Australia', *Atmospheric Research*, vol. 166.

[14] Gilham, C 2015. 'Two-thirds of Australia's warming due to adjustments – according to 84 historic stations' http://joannenova.com.au/2015/04/two-thirds-of-australias-warming-due-to-adjustments-according-to-84-historic-stations/

Appendix 2

The politics of the homogenisation of Rutherglen: a postmodernist approach to science

On 24 June, 2015, *The Australian* newspaper published an opinion piece by Maurice Newman entitled, ‘Climate is right for a probe into the Bureau of Meteorology’. The article stated:

> WEATHER bureaus are a protected species. Often criticised, their workings remain a mystery to most of us. They continue to escape close scrutiny.’
>
> In an op-ed in Britain’s *The Telegraph* (December 19, 2010), the mayor of London, Boris Johnson, blamed much of the city’s pre-Christmas transport chaos on the Met Office. The Met had predicted 1°C to 1.5°C warmer temperatures. The reality was the coldest December in 100 years.
>
> ‘Is it really true no one saw this coming?’ Johnson asked.
>
> Well, no. He identified Piers Corbyn of Weather Action, a private weather forecaster, and went on: ‘He has no telescope or supercomputer. Using a laptop, huge quantities of publicly available data and a first-class degree in astrophysics, he gets it right, again and again.’
>
> Perhaps a predisposition to man-made global warming accounts for the Met Office’s failure to predict abnormally harsh winters in Britain? After all, its chairman for two full terms was Robert Napier, a global warming activist and former head of WWF UK. The Met’s leaning came to light in leaked emails and revelations from Russian scientists. It and the Climatic Research Unit of the University of East Anglia were shown to have systematically contorted data past and present to achieve the desired warming direction. The frustrated CRU climatologist-programmer, Ian ‘Harry’ Harris, admitted to struggling with the complex computer programs and conceded he would do what the CRU usually did, ‘allow bad databases to pass unnoticed and good databases to become bad’.
>
> The leaked emails also informed us of Australia’s collusion in the warming hype. There was an email from Phil Jones referring to Australia ‘inventing’ the December 1995 monthly value, and there was reference to Australian scientists who ‘would like to see the section on variability and

extreme events beefed up if possible'. The head of climate monitoring and prediction services at the Bureau of Meteorology boasted about a policy that 'snows' sceptics.

Doctoring data, or throwing inquirers off the track, to deliver an outcome is unscientific and unacceptable at any time. Yet in climate science there seems to be a culture of toleration. In 2009, John Theon, retired chief of NASA's Climate Processes Research Program, testified to a US Senate inquiry that 'scientists have manipulated the observed data to justify their model results'.

Fast forward to today. This newspaper's environment editor, Graham Lloyd, published information that raises questions about the quality of Australia's temperature records. In a series of articles, Lloyd published details about the Bureau of Meteorology's data 'homogenisation', the practice that involves the mixing, matching and deletion of temperature records and that seemed to create its own discontinuities. The bureau claims to observe world's best practice. Perhaps. But homogenisation practices globally are under challenge, so conformity provides little comfort. If temperature manipulation can happen somewhere, why not elsewhere?

In response to *The Australian*'s report, the BoM quietly released a 'nothing to see here' summary of the impact of temperature adjustments at 112 locations around Australia, with the list of reference stations used for comparison. The stated reasons for homogenisation seem arbitrary. Words like 'merge', 'move' and 'statistical', provide little understanding of the thinking behind each decision or the reason stations were chosen. Colonial records are dismissed, notwithstanding the existence of Stevenson screens and the undoubted diligence of record keepers pre-1910. To the layman, the list of so-called 'nearby' stations used to homogenise data raises questions of suitability. Is Bathurst's jail really an appropriate site to include for homogenising Bourke's records?

As a member of the World Meteorological Organisation, the BoM is inevitably caught up in global warming politics. After all, it was the WMO that partly established the Intergovernmental Panel on Climate Change, and it remains an anthropogenic warming propagandist.

The BoM is a large and expensive agency, employing 1700 people and costing more than $300 million a year to run. The importance of its database and the reliability of its forecasts go well beyond direct operating costs and daily bulletins. As the bureau says, 10 per cent of Australia's GDP is weather sensitive. This makes its input to public policy potentially valuable. But it must first dispel suspicions of a warming bias. The memory of Climategate and its casual approach to Celsius conversion lingers. It should explain why homogenisation consistently turns cooling trends to warming and why pre-1910 records were dropped and, with them, the extreme heatwaves of the Federation drought.

The record is error-ridden. Even to an amateur, the latest information dump prompts more questions than answers. The concerns about Rutherglen raised by Lloyd as to why a 0.35°C cooling became a 1.73°C warming still have no satisfactory explanation. No supporting documentary evidence, algorithms or methodology have been produced, leaving the unfortunate impression that temperature records were falsified.

As Einstein warned, 'Whoever is careless with the truth in small matters cannot be trusted with important matters.' Indeed, those who doubted the reliability of the 'high-quality' records that were abandoned for the 2011 ACORN-SAT data are unlikely to find much comfort in the latest release. But it's not only temperatures where doubts exist.

In 2008, David Stockwell, a niche ecological modelling expert, found: 'The most worrying failure was that simulations (CSIRO/BoM models) showed increases in droughted area over the last century in all regions, while the observed trends in drought decreased in five of the seven regions identified.'

Lending its name to clearly partial scholarship only increases concerns that the bureau puts climate change advocacy ahead of scientific rigour and transparency. Trust in our national climate records is critical. Yet, the more we see, the more we question. Now is not the time for a tame review. For the sake of public policy and the BoM's reputation, the air must be cleared.

Nothing short of a thorough government-funded review and audit, conducted by independent professionals, will do.

Maurice Newman chairs the Prime Minister's Business Advisory Council. These views are his own.

Following publication of this article, the Bureau of Meteorology lodged a complaint with the Australian Press Council. It claimed that the issue of temperature adjustments at Rutherglen had been thoroughly dealt with in an advisory dated 24 September 2014. As a consequence of this complaint, *The Australian* newspaper was directed to publish the following links to the Bureau's website at the online version of the article by Newman:

- www.bom.gov.au/climate/change/acorn-sat/rutherglen/rutherglen-station.shtml
- www.bom.gov.au/climate/change/acorn-sat/#tabs=Adjustments
- www.bom.gov.au/climate/change/acorn-sat/#tabs=Methods .

The critical document is the advisory:

- http://www.bom.gov.au/climate/change/acorn-sat/documents/station-adjustment-summary-Rutherglen.pdf .

It makes four key claims:

- The Rutherglen raw temperature series is a combination of several data series.
- Changes in site location or conditions have caused breakpoints/discontinuities in the raw data as measured at Rutherglen.
- These breakpoints/discontinuities can be detected using statistical methods.
- The trend in the raw minimum temperature series from Rutherglen that shows cooling is very different from the series at neighbouring sites which show warming.

Let's consider these four claims in turn.

1. ***Is the temperature series as measured at Rutherglen a combination of several data series?***

According to Bureau convention[15] the term 'site' is used to denote a specific observation station, while 'location' is used in the case of ACORN-SAT to denote an homogenised composite of one or more sites. It is Bureau policy, in accordance with practice recommended by the World Meteorological Organization, that any significant site relocation results in a new station number. Yet Rutherglen has always been referred to by a single station number: 082039. This is in contrast, for example, to the nearby location of

[15] Fawcett, RJB et al. 2012, 'On the sensitivity of Australian temperature trends and variability to analysis methods and observation networks', CAWCR Technical Report No. 050

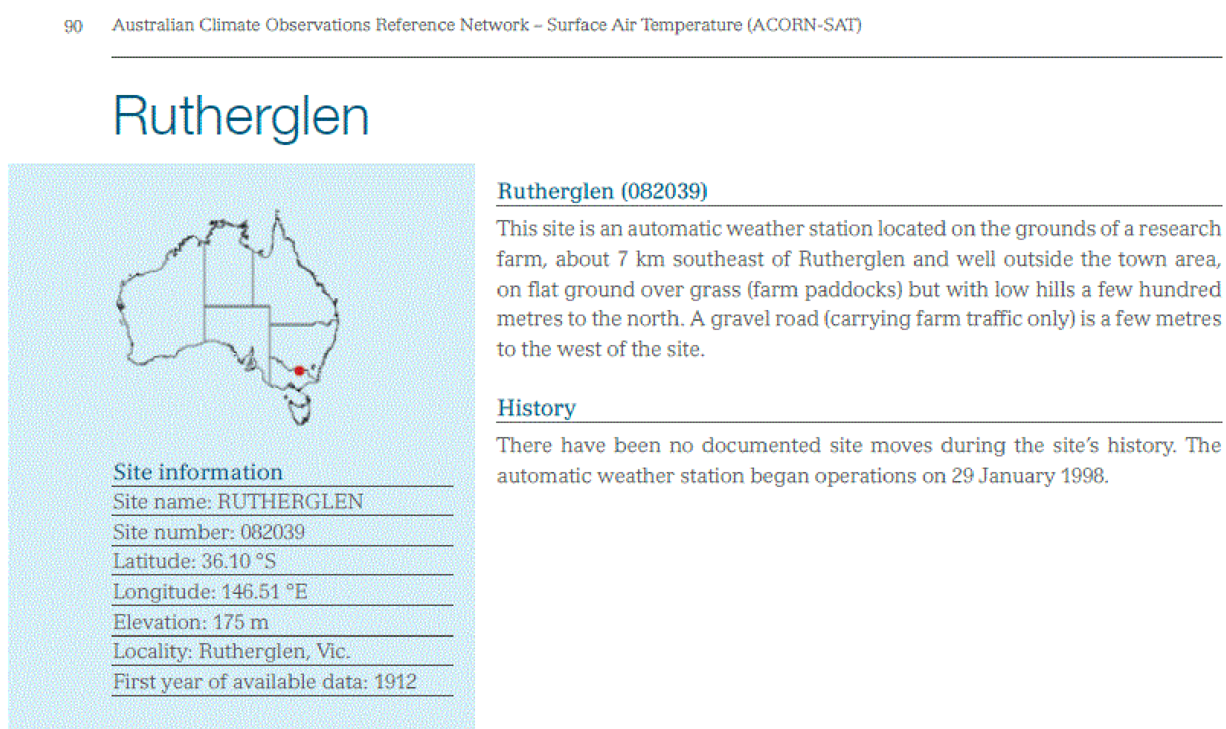
Deniliquin that we know is a composite of the post office (number 074128), and the airport (number 074258).

2. *Was the weather station at Rutherglen ever moved?*

In the advisory of 24 September 2014, and also in correspondence with Graham Lloyd from *The Australian* newspaper, the Bureau have stated that:

> Rutherglen: the major adjustments in minimum temperature data are in 1966 and 1974. Both were detected through comparisons with neighbours. The nature of the change is consistent with the site moving from a location near the main experimental farm buildings (which are on a small hill) to its current location on low-lying flat ground (minimum temperatures are normally higher on slopes than on flat ground or in valley bottoms).

This claim is not supported by any documentary evidence for such a move. Furthermore, the official ACORN-SAT Bureau catalogue, published in 2012, clearly states, 'there have been no documented sites moves during the site's history', as shown in Figure A.



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

Rutherglen

Site information

Site name: RUTHERGLEN

Site number: 082039

Latitude: 36.10 °S

Longitude: 146.51 °E

Elevation: 175 m

Locality: Rutherglen, Vic.

First year of available data: 1912

Rutherglen (082039)

This site is an automatic weather station located on the grounds of a research farm, about 7 km southeast of Rutherglen and well outside the town area, on flat ground over grass (farm paddocks) but with low hills a few hundred metres to the north. A gravel road (carrying farm traffic only) is a few metres to the west of the site.

History

There have been no documented site moves during the site's history. The automatic weather station began operations on 29 January 1998.

Figure A. Extract from official ACORN-SAT Station Catalogue, published by the Bureau of Meteorology in 2012

3. Which statistical tests were used to detect the breakpoints associated with the site moves?

In 14 different places in the two-page advisory, the Bureau states that 'statistical methods' were used to detect the site moves which created breakpoints. But at no time are the breakpoints illustrated, or is the statistical method explained, nor the level of statistical significance stated.

Of particular concern, the breakpoints identified by 'statistical methods' in the September advisory, are not consistent with the breakpoints identified also using 'statistical methods' in an adjustment summary released just one month earlier, in August 2014. Extracts from the two documents, both published by the Bureau of Meteorology, are shown in Figures B and C.

Rutherglen	82039	Min	01/01/1974	Statistical*	-0.57		74034	82053	82002	72097	82100	74106	81049	81084	72023	82001	Site moved at least once between 1958 and 1975
Rutherglen	82039	Min	01/01/1966	Statistical*	-0.63		82053	82002	82001	72150	74114	80015	74039	74062	74128	75032	1955-59 used as reference
Rutherglen	82039	Max	01/01/1950	Statistical*	0.63		82053	72023	82001	82002	75028	75031	80043	72000	72150	80015	1949 inspection report said site was overgrown, possibly cleared?
Rutherglen	82039	Max	01/01/1938	Statistical	-0.59		82053	72023	82001	82002	75028	75031	80043	72000	80015	82016	
Rutherglen	82039	Min	01/01/1928	Statistical	-0.49		82053	82002	72023	82001	75028	74009	80043	80015	74110	82016	

Figure B. Extract from ACORN-SAT station adjustment summary, first published in August 2014. There are two breakpoints in the maxima and three in the minima, including a breakpoint in 1928. <http://www.bom.gov.au/climate/change/acorn-sat/documents/ACORN-SAT-Station-adjustment-summary.pdf>.

Rutherglen station temperature adjustments

Station name	Station number	Temperatures adjusted	Date (adjustment applied to all data prior to this date, unless stated)	Cause	Impact of adjustment (°C)	Seasonal (if applicable)	Comparative stations										Notes
Rutherglen	82039	Min	1/1/1974	Statistical	-0.61		74034	82053	82002	72097	82100	74106	81049	81084	72023	82001	Station documents suggest likely move c. 1974
Rutherglen	82039	Min	1/1/1966	Statistical	-0.72		82053	82002	82001	72150	74114	80015	74039	74062	74128	75032	Station documents suggest likely move c. 1966
Rutherglen	82039	Max	1/1/1965	Statistical	0.39		82053	72023	82001	82002	75028	75031	80043	72000	72150	80015	Station documents suggest likely move c. 1966
Rutherglen	82039	Max	1/1/1950	Statistical	0.62		82053	72023	82001	82002	75028	75031	80043	72000	72150	80015	Site reported as overgrown at 1949 inspection
Rutherglen	82039	Max	1/1/1938	Statistical	-0.62		82053	72023	82001	82002	75028	75031	80043	72000	82016	80015	

Figure C. Extract from ACORN-SAT station adjustment summary, published in September 2014. There are three breakpoints in the maxima, including a breakpoint in 1965, which did not exist in the adjustment summary for Rutherglen issued just a month earlier. <http://www.bom.gov.au/climate/change/acorn-sat/documents/station-adjustment-summary-Rutherglen.pdf>.

Furthermore, the breakpoints shown for the temperature minima and maxima do not occur in the same years, yet if they were the consequence of a site move there should be correspondence.

4. Are temperature trends at Rutherglen different from trends at neighbouring sites?

The September advisory claims that temperature minima, as measured at Rutherglen, are different from temperature trends at other sites in the region. This is purportedly illustrated in Chart 3, reproduced here as Figure D.

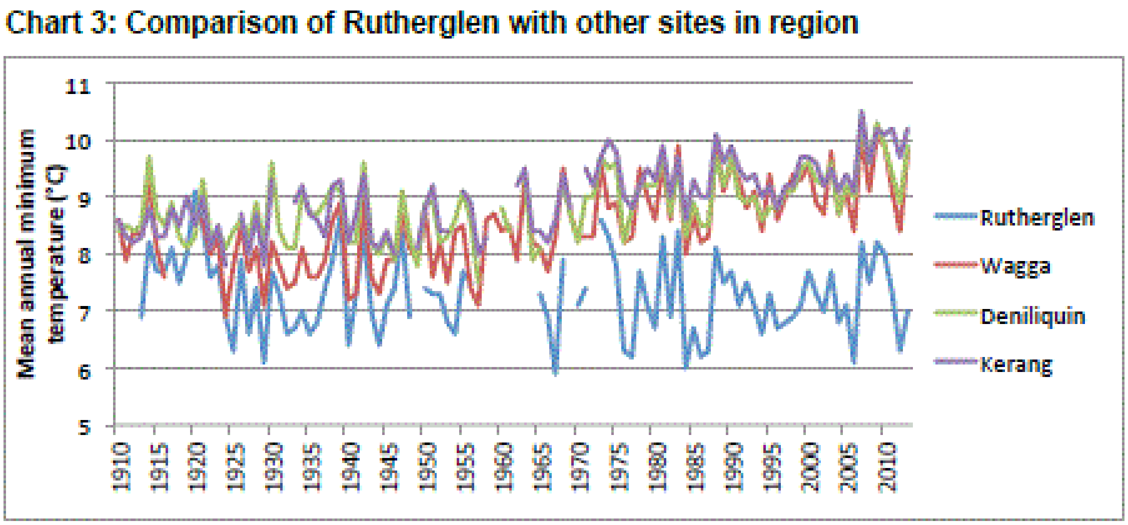


Figure D. This chart from the September 2014 advisory shows the raw temperatures as measured at Rutherglen with homogenised values from Wagga, Deniliquin and Kerang.

In fact, the raw data from Rutherglen is compared with *homogenised* data from the nearby locations of Wagga, Deniliquin and Kerang in Chart 3 (Figure D) – not the equivalent raw data.   This is *not* acknowledged in the legend or caption to Chart 3, but is mentioned in the text of the advisory.

The Bureau has used mathematical modelling, and perhaps an infusion of values, to justify this preference for virtual (homogenised data) over observational (raw) data. The Bureau is implicitly taking a postmodernist approach by using this contrived evidence to justify the remodelling of temperature minima at Rutherglen.

Uncorrected prepublication manuscript. Please cite this article as: Marohasy, J., Temperature change at Rutherglen in south-east Australia, New Climate (2016), http://dx.doi.org/10.22221/nc.2016.001

Appendix 3

Peer review

This study is based on a shorter manuscript that was peer reviewed by physicist, and former Dean of Science at James Cook University, John Nicol, in August 2015. Dr Nicol sent an 800-word critique on 1 September 2015 that began:

> I have now put together a few basic comments on the structure and minor detail of your paper which may or may not be of any help to you. I believe I now have a reasonable understanding of the many nuances associated both with homogenization in general and your very specific and carefully constructed comments on the situation of the messing, by the Bureau, with the Rutherglen data. From what you have presented, no one can doubt that the process undertaken by the Bureau is a fiddle disguised as science and that the use of the measurements from distant sites to 'correct' the original data, for which there is no evidence of failed recordings, is, to be very kind, quite wrong.

Dr Nicol went on to make some specific recommendations which were incorporated into a manuscript subsequently submitted for publication to the journal *Atmospheric Research* also in early September 2015. This manuscript was sent to two reviewers by the journal's editor, José Luis Sánchez.

The first reviewer replied:

> The paper under revision discusses the application of the Shewhart control charts, an application mainly of engineering statistics, for the control and homogenization of climatic time series, namely temperature records of Rutherglen, Australia. This is a new application that appears to be promising. The manuscript is very well organized; the methodology is clearly explained and the results and discussion sections do not have any obscure and ambiguous points. Therefore I recommend this paper for publication, after some minor editorial corrections.

The second reviewer, however, advised against publication including for the following two 'major reasons':

> 1. The basic premise of this new approach (the first paragraph of the abstract) is incorrect from a climatic perspective. Most of your work is analysing annual averages, although you do additionally mention the monthly and daily values on which the annual values are based. At the annual timescale (and less well at the other timescales), the variability (changes from year to year) at a single site will be strongly related to variations at neighbouring sites. Therefore it makes no sense to not refer to what is happening at neighbouring sites. Series from neighbouring sites should look like one another. The BoM ones do.

> 2. The Bureau has produced an Australian average based on 112 series. What I'm also asking you to do is to repeat this without Rutherglen. I'm confident that this will make absolutely no difference to the Australian average.

These faux criticisms expose two core problems with homogenisation as practiced in climate science: that, first, it is acceptable to remodel a temperature series if it does not accord with neighbouring sites; and second, this remodelling has no significant effect on the resulting national average temperature. In response to these misguided statements from the second reviewer I will quote from a private email received from a professor at the University of Sydney. This email was received in September 2014, and was written in response to public comment that I had made concerning the Bureau's routine homogenisation of historical temperature records.

> As any one of my 45 or so research students will tell you, I have always emphasized the need to retain all raw data, unless there is a specific reason to reject it as low quality. Outliers have their reasons. Therefore I strongly approve your current critique opposing automatic 'homogenization' of temperature records where there is disagreement. The idea that temperature records should be adjusted because they disagree with neighbouring stations is scientifically absurd. It just means that you are losing key information while destroying the future value of the dataset.

It would seem, however, that primarily on the basis of the 'scientifically absurd' recommendations from the second reviewer, my paper was rejected by the journal *Atmospheric Research*. In particular, I received an email from Donna Tucker, a professor at the University of Kansas, on 23 November, 2015, writing on behalf of the editor, Dr Sánchez. In this email Professor Tucker *incorrectly* stated that both reviewers were recommending against publication of my work. She concluded: 'For your guidance, I append the reviewers' comments below. If you wish you can revise the manuscript taking seriously into account the comments of the reviewers. If you resubmit it I will probably send it to the same reviewers.'

Uncorrected prepublication manuscript. Please cite this article as: Marohasy, J., Temperature change at Rutherglen in south-east Australia, New Climate (2016), http://dx.doi.org/10.22221/nc.2016.001