

Mr Grant Hehir
Auditor-General of Australia
Australian National Audit Office
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Dear Mr Hehir

1. SUBJECT/RECOMMENDATION:

That the Australian National Audit Office undertake a performance audit of the procedures, and validity of the methodology, used by the Australian Bureau of Meteorology in the construction of the official historical temperature record for Australia. The terms of reference to include:

- Consistency with its own policies;
- Reliability of methodologies;
- Objectives and terminology, to ensure public expectations are consistent with the final product.

2. ISSUES:

Surface air temperatures, as measured at weather stations across Australia, are routinely remodeled through a process of homogenization by the Bureau to correct for perceived non-climatic variables. After the remodeling of approximately 100 individual temperature series, various area weightings are applied to these individual series, then the average annual temperature is calculated for each state and territory, the entire continent, and used to report climate change. Issues of concern are the process of homogenization, the choice of stations, the way the homogenized data series are combined, and whether this provides an accurate representation of the historic temperature record for Australia.

Of particular concern, the same combination of stations are not used for the entire period of the record. For example, while there is a continuous maximum temperature record for the relatively hot location of Wilcannia in western New South Wales that extends back to 1881, the Bureau only adds Wilcannia into the mix of stations used to calculate annual mean temperatures from 1957. In the case of Oodnadatta in South Australia, officially the hottest place in Australia, data from this weather station has only been used in the calculation of the average annual temperatures for South Australia, and Australia, since 2012. Furthermore, the official record for Australia only begins in 1910, which corresponds with an early dip in surface temperatures.

The determination of homogeneity, which influences how each individual temperature time series is remodeled, is made relative to temperatures at comparative stations. This is standard practice in climate science, and a worked example is provide for Rutherglen as a case study in Section 4. Adjustments for perceived discontinuities are then propagated backwards in time. In particular, early minima are generally adjusted down, this has the effect of making the present appear hotter.

Homogenization, and in particular the propagation of adjustments back in time, represents an altogether different category of change to correcting for transcription errors, or equipment failure, as practiced in traditional quality control. Furthermore, the adjustments are rarely made in accordance with the Bureau's own policies as detailed in CAWCR Technical Report No. 049, which state that adjustments should be supported by metadata indicating a site move or equipment change, and that sites affected by an Urban Heat Island are not incorporated into the official record.

The veracity of the temperature record is of critical importance as many government and private decisions and expenditures are based on this primary dataset. My analysis of the temperature data suggests that the information provided by the Bureau to government may be incorrect.

3. BACKGROUND:

On 20th December 2010 a formal request was made to the Australian National Audit Office for a review of the data and algorithms that contribute to the formal assessments of climate change in Australia. This request compiled by Perth-based science communicator, Joanne Nova, and colleagues, was accompanied by five appendices providing 61 pages of information detailing discrepancies and errors.

The audit didn't proceed, however, because the Bureau immediately replaced what was then known as the 'High Quality Network', the focus of Nova and colleagues' submission, with what was ostensibly a new dataset and methodology, the current 'Australian Climate Observations Reference Network –Surface Air Temperatures (ACORN-SAT)'.

The Bureau also then commissioned its own peer review of methods used in the development of ACORN-SAT. This review concluded that the Bureau uses 'World's Best Practice', and recommended the establishment of a Technical Advisory Forum to review and provide advice on the ongoing development and operation of ACORN-SAT.

The Technical Advisory Forum was not established until late 2014, following a series of article in *The Australian* newspaper querying the nature of adjustments made to individual temperature

series in the development of ACORN-SAT; specifically the series from Rutherglen in Victoria, Bourke in New South Wales, and Amberley in Queensland.

The term 'Forum' implies the opportunity for public and open discussion. The Technical Advisory Forum, however, never meet to exchange information with the many critics of the Bureau's handling of historical temperature data. Rather the Technical Advisory Forum meet for one day in March 2015. The agenda from the first meeting showed that the day was spent either being briefed by, or in discussions with, staff from the Bureau. Their report published in June 2015, followed the agenda of the March meeting, and concerned itself with:

- The extent of the public availability of ACORN-SAT information;
- Developments since the 2011 peer review; and
- The scientific integrity and robustness of the climate record and homogenization process.

Of further concern, the first report from this Technical Advisory Forum confounds homogenization as practiced by climate scientists, with standard quality assurance techniques. Furthermore, it is clear from the report that the Technical Advisory Forum never worked through a single example of homogenization. If it had done this it would have become clear, that contrary to assumptions implicit in this report:

- Changes to individual temperature series in the development of ACORN-SAT are *not* principally concerned with removal of systematic error, and
- Uncertainty generally increases, rather than decreases, with the homogenization of the raw data in ACORN-SAT.

Concerned with claims the Bureau was exaggerating estimates of global warming, former Prime Minister Tony Abbott's own department proposed setting up an investigation late in 2014. Environment Minister Greg Hunt acknowledged on ABC Lateline on 25th September 2015, that he "killed" the idea explaining to journalist Tony Jones that he was confident the Bureau used, "hard science, hard data, literally millions of points of information through our satellite and local monitoring." The Bureau, in fact, *does not* rely on satellite data in the development of the official historical temperature record for Australia. ACORN-SAT is based entirely on homogenized surface temperature records from approximately 104 weather stations.

4. RUTHERGLEN CASE STUDY/EXAMPLE OF HOMOGENIZATION:

It is possible to change the trend in any time series by making specific adjustments to individual values, and then propagated these backwards to the beginning of the record. This technique has been applied to the raw data from Rutherglen, and a majority of the other temperature

time series that comprise ACORN-SAT. It is justified on the basis that it is part of the quality control process, and that it is necessary to correct for discontinuities in the raw data.

Control charts are routinely used for quality control, not within climate science, but within many other disciplines that analyse time series data. The technique does have much potential application to climate science, and has been used to find discontinuities, and correct the same, in temperature series from Cape Otway lighthouse, as published in a recent volume of the international climate science journal *Atmospheric Research* (volume 166, pages 141-149).

The Bureau of Meteorology *does not* use control charts to find, or correct, discontinuities. Rather it uses a technique that relies on ‘comparative stations’, and unique algorithms, which are not available for public scrutiny. Until the series of articles by journalist Graham Lloyd the list of ‘comparative stations’ was not publically available. A list was published in August 2014, following requests from Mr Lloyd. One of the comparative stations that the Bureau lists, as used to ‘correct’ the temperature series at Rutherglen, is Beechworth as shown in Figure 1.

Beechworth is approximately 40kms south east of Rutherglen. There is a minimum and maximum temperature series for this location from January 1908 until June 1986. The mean is calculated as the average of the minima and maxima. When monthly minima from Beechworth are run through a control chart we see that there is a step-change, a discontinuity, in 1977, as shown in Figure 2.

Rutherglen	82039	Min	01/01/1974	Statistical*	-0.57	74034	82053	82002	72097
Rutherglen	82039	Min	01/01/1966	Statistical*	-0.63	82053	82002	<u>82001</u>	72150
Rutherglen	82039	Max	01/01/1950	Statistical*	0.63	82053	72023	<u>82001</u>	82002
Rutherglen	82039	Max	01/01/1938	Statistical	-0.59	82053	72023	<u>82001</u>	82002
Rutherglen	82039	Min	01/01/1928	Statistical	-0.49	82053	82002	72023	<u>82001</u>

Figure 1. Extract from ‘ACORN-SAT Station Adjustment summary’ showing the temperatures adjusted (third column), date from which all adjustments are applied (fourth column), and stations used for statistical comparison (columns 8-17). 82001 is the Bureau’s station number for Beechworth.

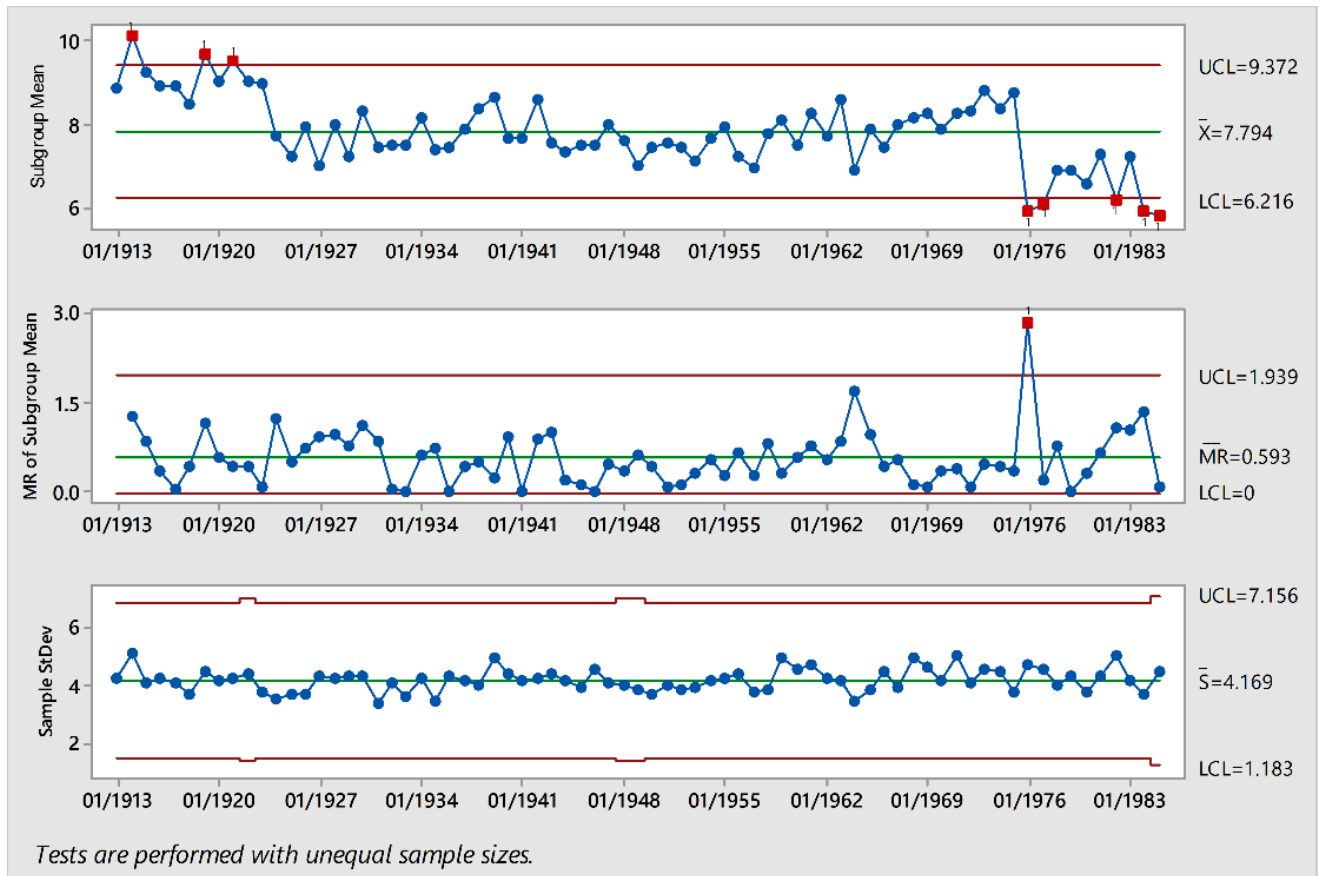


Figure 2. I-MR-R/S control chart showing measured raw minimum temperatures as recorded at Beechworth (1913-1985). Top chart shows the annual mean minimum temperatures for Beechworth, middle chart shows the moving range of the subgroup (annual) mean, bottom chart shows the standard deviation of the subgroup mean.

The discontinuity corresponds with a documented site move for Beechworth, recorded as occurring in 1977. This change appears to have caused a step-down in the annual minima from 1977 (top chart), and a corresponding exceedance of the upper control limit for the moving range (middle chart). It would be appropriate to make adjustments/homogenize the temperature series to account for this discontinuity associated with a real physical cause.

When the equivalent series for Rutherglen is run through a control chart, Figure 3, we see that the mean annual minimum temperature (top chart) fluctuates within three standard deviations (defined by the upper and lower red lines) from the overall mean. The moving range of the subgroup mean (middle chart), and the sample standard deviation (bottom chart) are also generally in control for the period of the record. This suggests that *if* there had been any site moves or equipment changes they have *not* significantly perturbed the historical record.

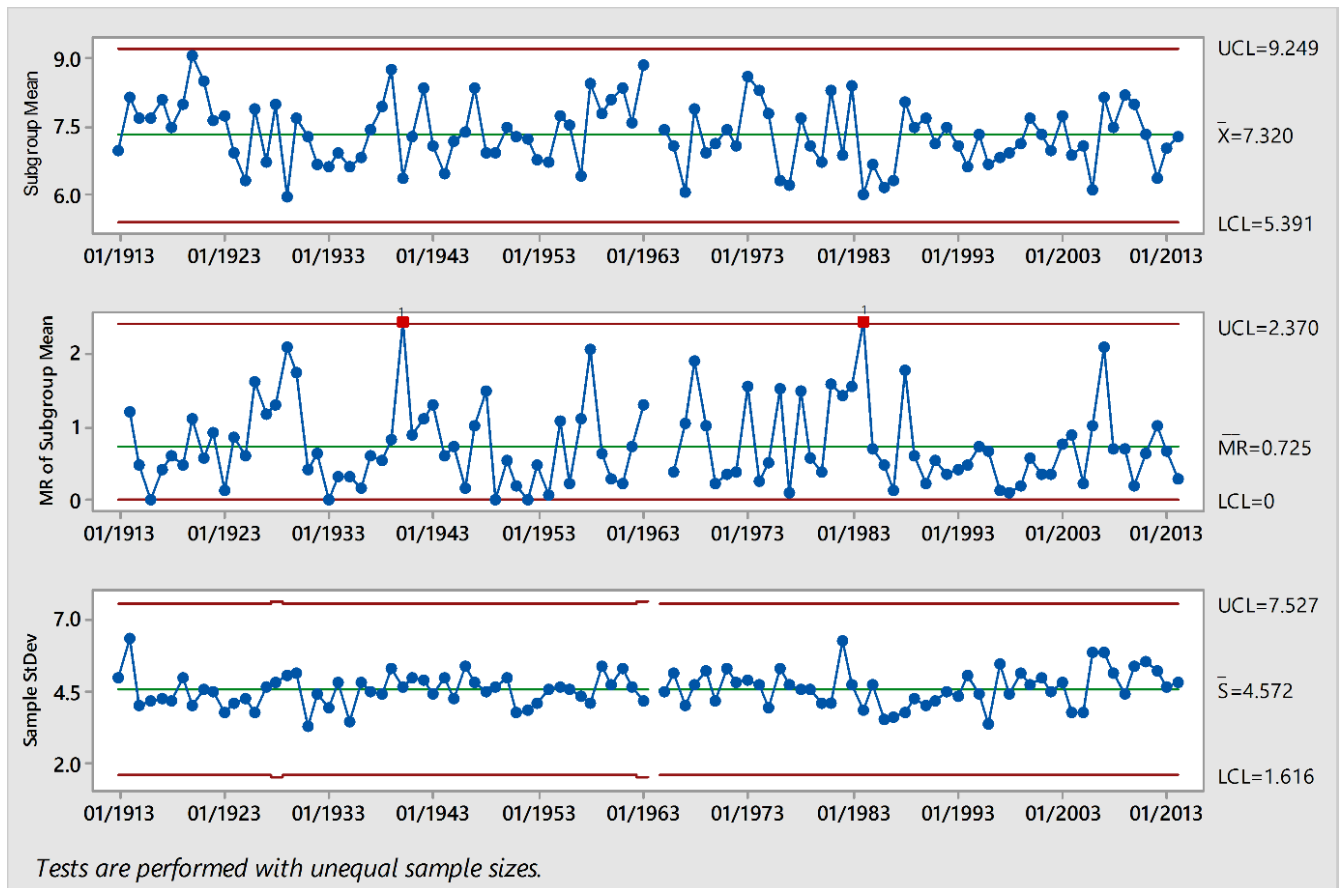
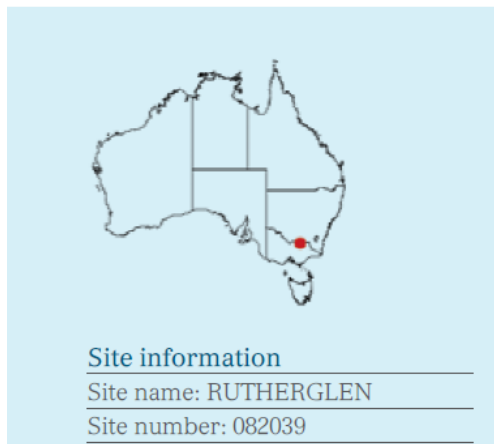


Figure 3. I-MR-R/S control chart showing measured raw minimum temperatures as recorded at Rutherglen (1913 - 2014).

Following the series of articles in *The Australian*, the Bureau claimed in August 2014 that there had been a site move at Rutherglen. Pages of documentation were provided, but none provided actual evidence for a site move. In the official Bureau ACORN-SAT catalogue published in 2012, it clearly states, in accordance with the available metadata, that there has never been a site move at Rutherglen, Figure 4.

Rutherglen



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 4. The official catalogue, published by the Bureau in 2012, clearly states there have been no sites moves at Rutherglen.

To summarize thus far, the Bureau uses a 'comparative station', Beechworth, with obvious discontinuities in its record, to 'correct' the temperature record at Rutherglen which has no discontinuities.

It is unclear whether the Bureau realizes that there are discontinuities in the Beechworth record, because it is unclear whether any quality control is undertaken of 'comparative sites'. Beechworth and other comparative sites listed in Figure 1 are not part of ACORN-SAT and not considered 'high quality'. It could be that the Bureau uses only the five years from the Beechworth record that occur immediately before the purported discontinuity at Rutherglen in 1974, in accordance with policy. This in-turn begs the question of why Bureau policy considers a 5-years period in a low quality dataset adequate for the purposes of homogenization, when 30 years is normally considered the minimum necessary to establish/understand a climatic trend.

Scrutiny of the ACORN-SAT dataset for Australia, and the list of associated comparative sites, shows that this dubious technique is routinely applied by the Bureau. This same technique is applied by other organisations, including NASA's Goddard Institute for Space Studies, which develops global temperature datasets. The method is defended on the basis it has passed peer review and is the 'World's Best Practice'.

In summary, even though all temperatures from Rutherglen were recorded in a Stevenson screen which is an accepted standard, there are *no* documented site moves (Figure 4), and *no* discontinuities (Figure 3), the Bureau nevertheless makes changes to the minimum temperature series as recorded at the Rutherglen Research Station.

The extent of the changes depends on which Bureau document is consulted. The Bureau does *not* publish important methodological information in the peer-reviewed literature, and so it can make changes at whim, apparently without consequence.

The official summary as published in August 2014 (Figure 1) indicates that three ‘adjustments’ are made to the minimum temperature series for Rutherglen cooling the past by a total of 1.69 degree Celsius. This has the effect of changing a slight cooling trend of 0.35 degree Celsius per century in the raw data for Rutherglen, into dramatic global warming of 1.73 degree Celsius per century in the official record. The adjustments for Rutherglen now published at the Bureau website omit the drop-down in all temperatures prior to 1928. Net cooling based on the revised adjustments indicate statistically significant warming of 1.59 degree Celsius per century for Rutherglen.

5. PROPONENT:

I have a BSc and PhD from the University of Queensland. I am a Senior Fellow with the Institute of Public Affairs, Melbourne, and Founder of the Climate Modelling Laboratory, Noosa. My recent peer-reviewed publications concerning climate science and temperature records include:

Marohasy, J. and Abbot, J. 2015. Assessing the quality of eight different maximum temperature time series as inputs when using artificial neural networks to forecast monthly rainfall at Cape Otway, Australia, *Atmospheric Research*, Volume 166, Pages 141-149. doi: 10.1016/j.atmosres.2015.06.025.

Abbot J. and Marohasy J. 2015. Using artificial intelligence to forecast monthly rainfall under present and future climates for the Bowen Basin, Queensland, Australia, *International Journal of Sustainable Development and Planning*, Volume 10, Issue 1, Pages 66 – 75.

Abbot J. and Marohasy J. 2015. Using lagged and forecast climate indices with artificial intelligence to predict monthly rainfall in the Brisbane Catchment, Queensland, Australia, *International Journal of Sustainable Development and Planning*. Volume 10, Issue 1, Pages 29-41.

Abbot J. and Marohasy J. 2014. Input selection and optimisation for monthly rainfall forecasting in Queensland, Australia, using artificial neural networks. *Atmospheric Research*, Volume 138, Pages 166-178.

Abbot J. and Marohasy J. 2013. Barriers to Accessing Environmental Information under Australian Freedom of Information. *Public Law Review* 24, 10-16.

Abbot J. and J. Marohasy, 2012. Accessing information under Australian freedom of information legislation: a case study involving climate change. *Environmental Law and Management*, Volume 24, Issue 3, Pages 114-118.

Abbot J., and J. Marohasy, 2011. Application of artificial neural networks to rainfall forecasting in Queensland, Australia. *Advances in Atmospheric Sciences*, Volume 29, Number 4, Pages 717-730. doi: 10.1007/s00376-012-1259-9 .

Abbot J. and J. Marohasy, 2010. Accessing information relating to climate change: the case of Irish oaks tree rings. *Environmental Law and Management*, Volume 22, Issue 4, Pages 172-181.

Abbot J. and J. Marohasy, 2010. Accessing environmental information relating to climate change: a case study under UK freedom of information legislation. *Environmental Law and Management*, Volume 22, Issue 1, Pages 3- 12.

Yours Sincerely

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