On the quality of Australia's temperature data

Dr. Bill (WH) Johnston.

(Former NSW Department of Natural Resources Senior Research Scientist.)

The issue is: if data are faulty, conclusions based on them are also faulty.

Data downloaded from the Bureau of Meteorology, for former NSW Department of Natural Resources Research Centres at Cowra and Wagga Wagga (Bureau sites 63023 and 74114) are examined.

Issues in Rutherglen's data (82039) are touched-on and discussed in a wider context.

(Cowra is 180km north of Wagga Wagga; Rutherglen is 130 km south. Annual rainfall is about the same but summer rainfall increases from south to north.)

The Author was based at Wagga Wagga Research Centre from 1971 to 2000 and observed the weather on a rotating basis until about 1980. He had projects co-located at Cowra and collaborative links with Rutherglen, but is less familiar with operation of the Rutherglen site.

This essay is about data that are in the public domain not organisations, sites or people. History can't be re-written and at the time observations commenced, observers had no inkling their data, originally collected to describe the weather would be used to track climate warming.

The question is: are the datasets useful for estimating unbiased trends?

The met-lawn at Cowra has always been across the road from the office. The road and buildings were there when records started. A new brick building was completed 40m south of the met-lawn in 1997.

Before 1977 the Wagga Wagga meteorological lawn also did not move.

The site was consistent and ambient heat-loads on the instruments constant. A shed, car park and brick office building were constructed in the 1940's.

A double-mass-curve study in 1976 found near-by trees reduced wind-run relative to Wagga Wagga airport. The site was relocated about 300 m west, to a better-exposed position in 1977.

Ambient heat is the background heat-signature against which day-to-day temperature is measured. Provided nothing changes, it's a constant loading. If it changes and data are affected, the change shows-up as a shift in the data's mean level. Several statistical tests are used to detect and analyse time-wise shifts.

The met-lawn at Rutherglen has probably moved several times.

From Torok (1996)[1] based on notes in the Bureau's files:

Rutherglen 82039 and 82038
01/1914: Composite site move.
09/1924: First correspondence.
05/1939: Screen opens to west.
12/1949: Long grass around site.
05/1975: Good site, no changes.

Evidently there was a site move in 1914 and a composite dataset developed using data from the town Post Office, which is ~7km distant. It seems the site was not audited before 1924.

---

[1] Torok SJ (1996). *The development of a high quality temperature database for Australia.* PhD Thesis. School of Earth Sciences, University of Melbourne, 1996.

In its early years three datasets are possibly involved: the Post Office PO (82038) 1903 to 1921, Viticulture (82085) 1903 to 1927 and Rutherglen Research (82039) 1913 to 2015. There is likely a site-move after the Bureau got involved (1924); at least one re-orientation (~1939) and another unconfirmed but probable move around 1968. From the ACORN Catalogue[1]: "There have been no documented site moves during the site's history."

What is congruent data?

- **Their measurable *qualities* are uniform over time.**
- **They are homogeneous. Their trajectory is unaffected by changes at sites, site moves or deterioration (Stevenson screen decay for example). Such consistency is important for trend analysis.**
- **They are part of a 'data-package' that describes a site. Congruent data are related to other elements such as rainfall, dry-bulb temperature, evaporation etc.**

As they are less noisy, annual data calculated from daily values are used in this study.

Qualities include data counts; decimal-fraction frequencies (% of total numbers); counts and ratios of extremes (data greater than 95th and less than 5th day-of-year (1-366) percentiles); inter-year ranges and within-year standard deviations and variances. Such data about the data (*metadata*) affect their usefulness for an intended purpose.

For example, it's important to know about missing data (data counts/yr). They may affect seasonal averages and trend. They also cause uncertainty in analysing for extreme temperatures.

The Cowra site started observing in 1943. Daily data from the Bureau are available from 1965.

Precise data has a decimal-fraction frequency of 10%/yr. Cowra Tmin is observed reasonably precisely in ^{o}F to 1972 (Figure 1). However, after 1972 whole and ½-degrees are over-observed.

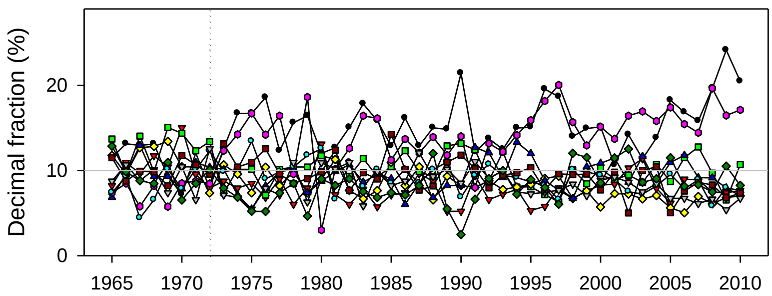

Figure 1. Cowra Tmin (and Tmax) was mainly measured in whole and ½-degrees after 1973 (black diamonds and pink circles). This affects the accuracy of detecting extreme values but doesn't necessarily impact on trends. (The vertical dotted line indicates metrication.)

Other metrics are that missing days increase after 1990 because observations are not made on weekends. For Tmin within-year variance stepped-down in 1984 and up in 1997.

Tmax stepped-up in 1979 (+0.63^{o}C, P = 0.02) and 1997 (+1.04^{o}C, P < 0.01); Tmin in 1979 (+0.59^{o}C, P < 0.01).

This indicates data are acted-on by some external forcing and are possibly not homogeneous. Naïve trends could be affected.

[1] Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) Station Catalogue. (Bureau of Meteorology 2012).

Local rainfall is useful for checking temperature data.

- Ignoring heat-storage in the landscape, which is cyclical; the local energy balance partitions heat loss between evaporation, which is cooling when the local environment is moist; and sensible heat transfer to the atmosphere (advection) during the day and radiation at night, which is warming when the environment is dry. Thus the longer it's dry, the hotter it gets.

  Rainfall is (should-be) linearly related to temperature, especially Tmax, but independent of it.

- If the local heat-load changes, forcing a significant base-level shift, the relationship is still linear but is offset by the impact of the change.

- If data become grossly disturbed or dislocated from the site (for example, if it were fabricated, or implanted from somewhere else), variation around the relationship increases, data become random to each other and statistical linearity is lost. (Rainfall seasonality may also impact on this, but is not considered here.)

So, linearity is expected; and we need a statistic that indicates how good (bad) the relationship is.

R^2 (the proportion of total variation accounted for by the relationship) adjusted for the number of terms in the model (R^2_{adj}), is commonly used.

(Analysis is done in R (https://www.r-project.org/), using the Rcmdr (R commander) package (http://www.rcommander.com/).)

Composite analysis of Cowra's average annual data is shown in Figure 2 and summarised in its caption.

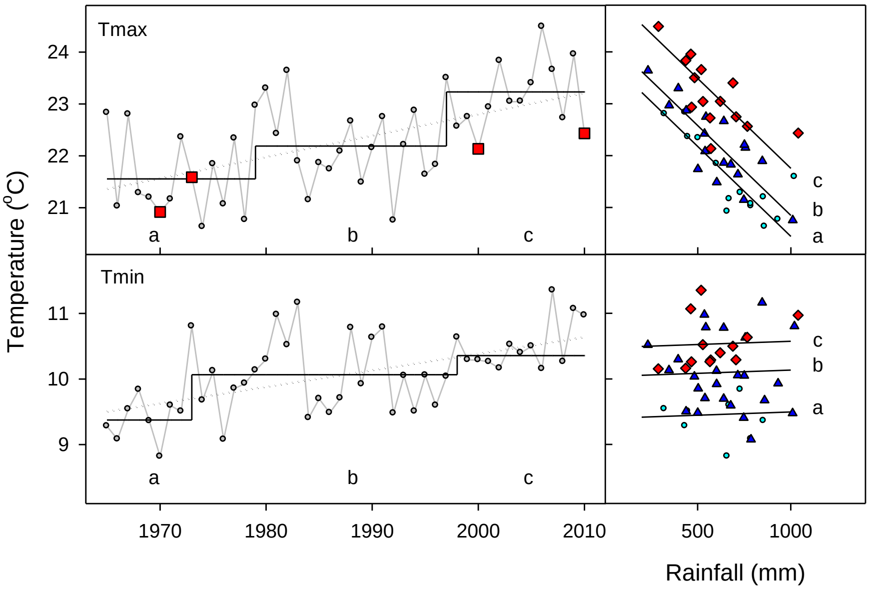

Figure 2. Cowra's annual average Tmax and Tmin increase with time (dotted line). Tmax weighted by within-year variance to improve precision, increases by 0.4°C/decade (R^2_{adj} = 0.332); Tmin by 0.2°C/decade (R^2_{adj} = 0.296). Relationships seem highly significant (P < 0.001).

Tmax trend includes step-changes in 1979 (+0.63°C; P = 0.02) and 1997 (+1.04°C; P < 0.001); and Tmin trend in 1973 (+0.69; P < 0.001) and 1998 (+0.29°C; P = 0.04). Due mainly to missing data, highlighted Tmax data may be faulty.

On the right, Tmax declines as rainfall increases: overall, including faulty data by –0.35°C/100 mm rainfall (R^2_{adj} = 0.484); excluding faulty data by -0.42°C/100mm (R^2_{adj} = 0.580) and factored by step-changes (excluding faulty data), by –0.30°C/100mm (R^2_{adj} = 0.779). Tmax lines are statistically parallel. Tmin varies randomly with rainfall, so there is no association.

Step-change group means (subscripted a, b and c) are significantly different (P <0.001) (Turkey contrasts). For Tmin there are no within-group time or rainfall trends. (Ignoring faulty Tmin data makes no difference.)

The main points are that local rainfall naïvely explains 48.4% of overall Tmax variation; 58.0% when four suspect-years are ignored; and 77.9% when data step-changes are also accounted for.

Lines are parallel, so rainfall has the same effect within groups. Step-change group means are significantly different (21.56°C $\pm_{S.D.}$ 0.75; 22.20°C $\pm_{S.D}$ 0.75; and 23.18°C $\pm_{S.D}$ 0.66).

Step-changes are caused by changed instrument sensitivities or heat-loadings in 1979 and 1997.

The cause of the 1979 shift is unknown, but it could be a replaced thermometer or refurbishment or re-orientation of the Stevenson screen.

The new building is on the southern side of the met-lawn, which is the prevailing direction of winter-weather. It's heat signature (including operation of its air-conditioner) caused ambient heat to increase and temperature to step-up around 1997.

Importantly, with step-changes and rainfall accounted-for, there is no residual time-trend.

At Wagga Wagga Research Centre, changes in precision that reflect differences between observers (Figure 3) are unrelated to data-trends.

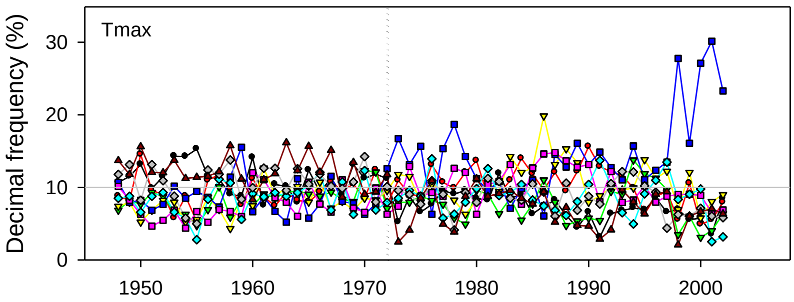

Figure 3. Wagga Wagga Research Tmax decimal frequency. Whole-degrees C are over reported from 1972 (metrication – vertical dotted line) until 1980 and after 1998, reflecting differences between observers.

Despite the exposure change in 1977 there's no Tmax step-change or Tmax time-trend (Figure 4).

Changes in Tmin in 1967 (+0.66°C, $P < 0.01$) and 1992 (-0.77°C, $P = 0.02$), which could be related to screen refurbishment or re-orientation cancel each other out, are unrelated to the move and don't affect time-trend, which is not significant anyway.

Missing data are an issue. Plotting them with rainfall indicates most are on-scale (Figure 4). Those that are not are: 1957, 1960, 1961 and 1998 (Tmax) and 1957, 1960, 1968 and 1999 (Tmin).

So did the 1977 site-move affect Wagga Wagga's data?

The short answer is no.

Annual rainfall explains 63.2% of the variation in Tmax; zero in Tmin.

Factored by the move, there is no evidence of group-mean differences, or of differences with rainfall between sites. There is no between-site interaction.

So the case is closed. Despite missing Tmax and Tmin data, Wagga Wagga Research Centre's data are homogeneous, congruent with local rainfall and un-trending in time.

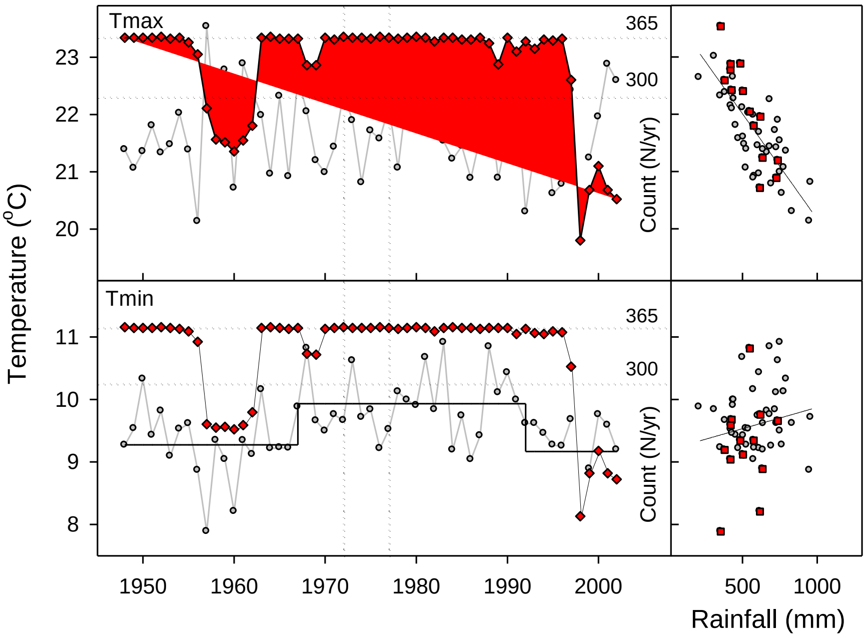

Figure 4. Composite analysis of Wagga Wagga Research Centre Tmax and Tmin. Vertical dotted lines indicate metrication in 1972 and the re-location in 1977. Missing data between 1956 and 1962; in 1968 and 1969; and after 1996 are problematic. However, only a few are outliers in the rainfall domain (right) (red squares). Ignoring them made no difference to trends in the time- or rainfall-domains and had little impact on R^2_{adj}.

The Bureau acknowledges the history of the Rutherglen site is poorly known.

As indicated earlier, Rutherglen's data are compiled up to 1924 and there have been possibly three undocumented site moves.

There are also non-random patches of missing data that may influence trend and significant step-changes indicative of site moves or other problems (Figure 5).

It's also problematic that Rutherglen's Almos automatic weather station (AWS), which supplanted thermometer data after November 1996, is biased-high (Figure 5).

The instrument over-ranges (spikes) near the limits of its sensor's quadratic calibration. Being housed in a small screen it may also sense fleeting parcels of warm air that thermometers don't detect. The problem mainly affects Tmax and is evidenced by an abrupt up-shift in Tmax data after 1996.

AWS bias sets-up false trends.

The homogenisation process embeds the problem also in Rutherglen's ACORN Tmax series. This is because most comparator data are also reported by AWS, which also over-range. (The corresponding ACORN Tmax up-step is 0.72°C.)

With suspect data (shown in Figure 5) removed and rainfall as the independent variable (and accounting for within-year variance), Tmax estimated by the AWS is significantly higher (+0.68°C) compared with thermometer data. R^2_{adj} = 0.629; lines are parallel and rainfall reduces Tmax by -0.24°C/100 mm. The offset is caused by the instrument not the climate.

There is an expected linear relationship between Tmax and rainfall (Figure 2 and Figure 4).

However, like for Ceduna S.A. (18012), due to bias, Rutherglen's AWS Tmax runs out-of-range in dry warm years.

It's suspicious that despite near-average rainfall in 2013 and 2014, Tmax is much higher than the 95% bootstrapped confidence intervals of the LOWESS curve. (LOWESS is a type of non-linear non-parametric regression usually used to indicate curvature.)

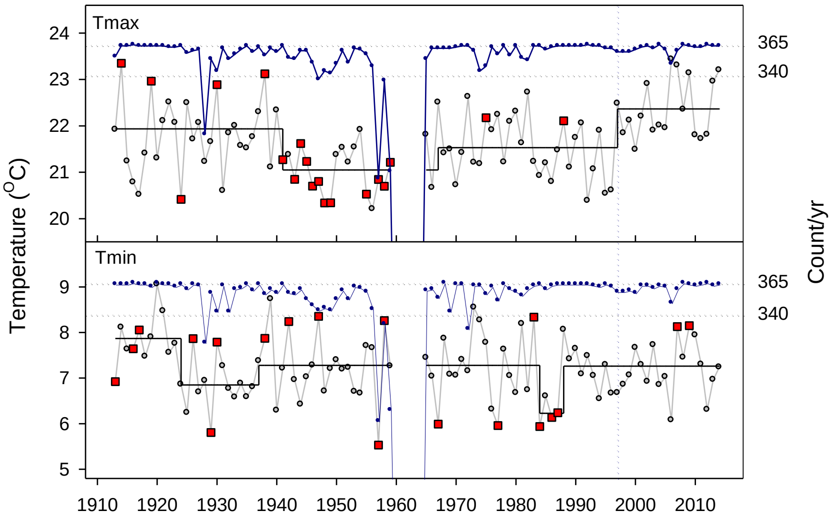

Figure 5. Step changes in Rutherglen's raw data are indicative of site moves and other data problems. Highlighted data are detected as faulty. Transition to the automatic weather station in 1996 (vertical line) caused an abrupt Tmax increase of 0.75°C relative to previous thermometer data.

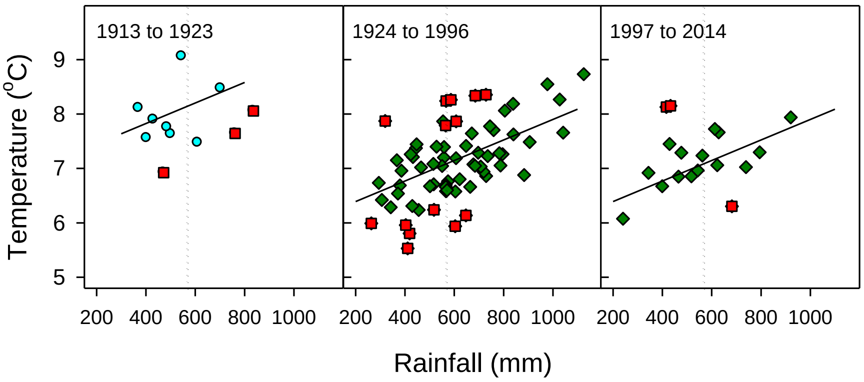

Figure 6. Tmin increases with rainfall at Rutherglen and other southern temperate/Mediterranean sites because wet years are cloudy; foggy-winter-days more frequent and rainfall is more winter-dominant than at Wagga Wagga and Cowra.

Groups are defined by Tmin step-changes; their group-means are different; regression lines are parallel; some outliers (red squares) are due to missing data others may be faulty. (Median rainfall (566 mm) is indicated by the vertical dotted line.)

Bias occurs across the Bureau's AWS network.

Another ACORN site, Ceduna is 1,250 km from Rutherglen.

Because its much drier, its AWS Tmax response to rainfall is flatter; it's also non-linear. Relative to LOWESS confidence bands, Ceduna's years of above-median rainfall (2005, 2013 and 2015) are also suspiciously hotter.

Both sites AWS data are warmer than comparable Tmax thermometer data averaged up to 1996 when AWS became primary instruments.

Discussion.

Like Wagga Wagga airport (72150) and Bathurst Agricultural Institute (63005), Rutherglen is an homogenised ACORN-SAT (Australian Climate Observations Reference Network – Surface Air Temperature) site used to calculate Australia's warming.

Without accounting for local rainfall, Cowra's daily data with its faux-trend is used to homogenise Bathurst. Wagga Wagga Research's un-trending dataset is used to homogenise Wagga Wagga airport and Rutherglen.

Also without adjusting for rainfall, Wagga Wagga airport and Rutherglen's ACORN data are used to homogenise other ACORN sites. Much potential exists in the process, for homogenisation to implant problems to other data, especially data not adjusted for rainfall and which are homogenised at daily time-steps.

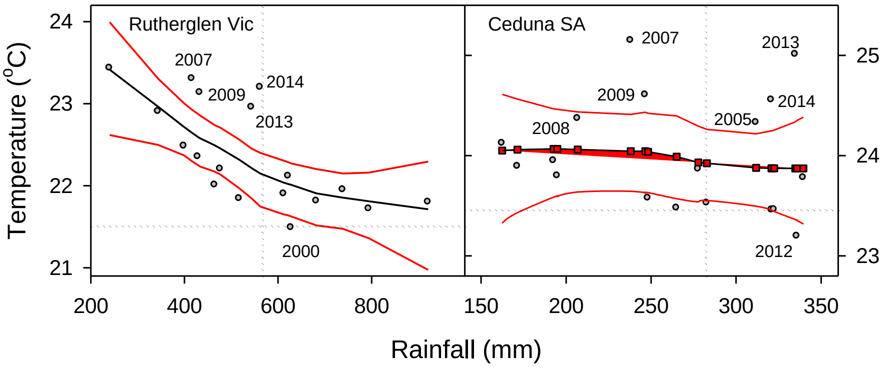

Figure 7. Relationship between temperature and rainfall for Rutherglen and as a contrast, Ceduna's AWS (post 1996). A non-parametric LOcally WEighted Scatterplot Smoothing (LOWESS) curve (smoothing parameter 0.8) fitted with a bootstrapped 95% confidence intervals track curvature. Dotted lines are pre-AWS average Tmax (21.7°C and 23.5°C) and each site's median rainfall (566 mm and 282 mm). Indicated out-of-range values are suspiciously high relative to the distribution of other data in those years.

- At Cowra and Wagga Wagga Research Centres and Rutherglen, no residual trends remain after site and instrument changes and rainfall are accounted-for.
- The Bureau discards many historical records. Consequently the history of many sites is poorly known or not known at all. This is reflected by data-changes that are not specifically attributable and is also evidenced by poor or vague site documentation in the ACORN catalogue. Rutherglen is an example.
- Step-changes are due to changes in ambient conditions. It is these that cause inhomogeneties.

  Data for many former Royal Australian Air Force sites; for example, Amberley, Broome, Mt. Gambier, Wagga Wagga and Laverton (Vic.) show evidence of undocumented site moves around the time the Bureau took-over meteorological operations from the RAAF in the 1950's.
- Presuming rainfall doesn't change, analysing step-change effects in the rainfall domain provides convincing evidence of their influence on temperature trajectories.

  For instance: similar to the Tmin step-change in Norfolk Island's data in 1948 (Figure 8), which is also undocumented; an up-step at Alice Springs airport in 1956 (not shown) aligns with extensions to the Bureau's Aeradio Office that the Bureau don't know about. (Tenders sought by the Department of Works in Darwin appeared in newspapers in 1955).

  It challenges the concept of 'worlds best practice' that ACORN is so poorly researched and documented.
- Undocumented site changes identified by data step-changes are also found early in records for Hobart and Adelaide Observatory. There are also multiple faults in Bridgetown Post Office's (WA) temperature record.
- ACORN is relentlessly marketed as 'peer-reviewed' and 'worlds best practice'. It's a feeble concept when peer-reviewers avoid looking at data or sites.

  For instance, ACORN's data are collected almost exclusively by AWS. While Rutherglen's met-lawn is probably well maintained to preserve its consistency, the ACORN site at Bridgetown (WA) is over-grown with weeds (Figure 9).

World-best-practice is not sticking expensive sensitive gear in a paddock and forgetting it's there. Peer-reviewers are only interested in processes; they don't audit data or sites, which is where the problems are.

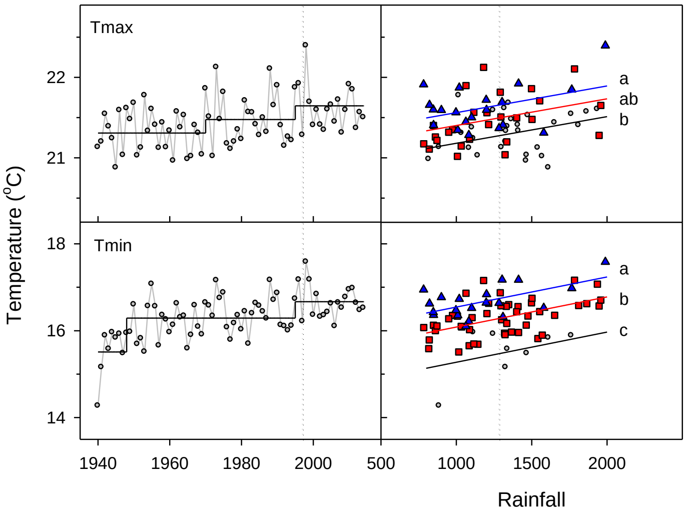

Figure 8. Like Rutherglen, Norfolk Island's automatic weather station over-reports upper-range temperatures (Tmax +0.17°C, *P* = 0.07; Tmin + 0.38°C, *P* <0.001). This causes the instrument to be biased-high relative to the thermometer record, which ended in 1996. There is a Tmin step-change, likely caused by an undocumented site move after the site was taken over by the Bureau from the Royal New Zealand Air Force in 1948 (+0.78°C, *P* <0.01), and a Tmax step-change in 1970 (+0.17°C, *P* = 0.03); both are undocumented.

Grey-circles represent the first data group; red-squares, the intermediate group; blue triangles are AWS data. Lines with unique subscripts (a, b, c) are statistically dissimilar. (Lines a and b are uniquely dissimilar in Tmax; all lines are dissimilar in Tmin.) Data are raw averages and have not been screened for outliers.

Figure 9. The raingauge at Bridgetown (WA) ACORN-AWS site is submerged by weeds (13th September 2015). What hope is there that data are not compromised? Numerous problems, including data infilling are identified in the Post Office record too.

- It's hard to find sites where AWS-instruments are not biased-high like at Rutherglen (Figure 5), Ceduna (Figure 7) and Norfolk Island (Figure 8).
- In addition to sites already mentioned; AWS-bias occurs in data for Sydney airport, Sydney Observatory, Cape Leeuwin, Hay, Melbourne Regional Office, Geraldton airport (WA),

Deniliquin, Mildura, Ballarat airport, Wilsons Promontory, Cape Otway, Bourke, Montague Island, Loxton, Gabo Island and Trangie (ag), to mention some that are analysed.

- Data for 'record-hot' years at many places is *highly* unusual, and needs urgent explanation (Figure 7).
- Relationships between local temperature (especially Tmax) and local rainfall are also useful for detecting incongruent data. For instance, Tmax data from 1981 to 1993 at Bridgetown are random with respect to rainfall; thus probably imported from somewhere else, or made-up!

(Some sites, like Cape Otway can be diagnosed using derived metadata, such as counts of high and low extremes (Figure 10).)

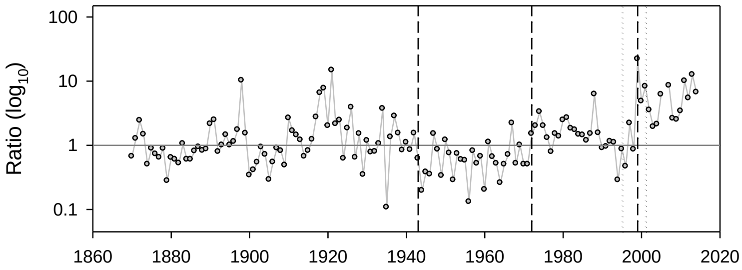

Figure 10. Cape Otway's AWS markedly over-reports upper-range temperatures. Data are log_{10}Tmax count ratios of upper to lower extremes. Vertical dashed lines indicate other inhomogeneties. The AWS was installed in 1994 and replaced in 1995. Similar problems are evident across the Bureau's network.

Conclusions.

Temperature data in Australia are not up to the task of tracking climate warming. Most datasets have multiple problems that are not smudged-away by homogenisation.

A confounded issue is that AWS-bias infects raw data, homogenised data, and comparisons between networks (ACORN *vs.* AWAP). Bias is therefore undetected by station comparisons.

There is evidence also that data for manually observed stations (Gunnedah, Moruya PS and Kerang for instance) are adjusted by the Bureau to agree with the AWS network.

Bias is transferred; it reinforces trends, extremes and trends in extremes that are due to the instrument, possibly the politics, but demonstrably not the climate.