Welcome to the back of Bourke where they make the weather warmer.

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Main points.

Record temperatures at Bourke are due to site and instrument changes not the climate.

- Maximum temperature (Tmax) is higher after 1996 because the weather station moved to the airport where daily temperatures above 21°C in town are up to 0.5°C warmer; extremes are even hotter. Minimum temperatures (Tmin) cooler than 19°C in town are up to 2°C cooler at the airport because airport data are not affected by artificial warming. So while summer days are warmer after 1996, winter nights are cooler.
- Poor site control affects day-to-day measurements and temperature extremes. While watering was a problem at the post office, nearly 1,000m^2 of land was ploughed adjacent to the airport automatic weather station in 2013, which causes Tmax extremes to increase.
- Homogenisation, which aims to adjust for site and instrument changes, is bound not to work if site changes are not known or ignored and if faulty data are used as comparators. As Bourke is one of the key 112 ACORN-SAT[2] sites used to track Australia's warming it's important to understand all aspects of the data.

Part A. Site changes affect measurements.

Daily weather observations started at the telegraph office in April 1871 but data before 1879 are too haphazard to be useful. After the telegraph office burnt down in November 1874 observations were made at another site before moving to the new post office in Oxley Street in 1880 (Figure 1). A 230-litre Stevenson screen installed in 1908 moved at least once and would have been refurbished before it was replaced (and probably moved out of the way of a building) in 1964, then repainted in 1983. Vegetation problems (shading etc.) were noted from the 1940s and the lawn around the screen was also watered. The post office record ends on 14 August 1996.

Figure 1. The Stevenson screen (possibly with a copper or iron roof) and anemometer pole occupy a 10 m wide strip that was added to western (right) side of the post office land-title in 1891. (1920 photograph courtesy of the National Library of Australia.) The second storey was added to the original 1880 building in 1889.

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[1] Former NSW Department of Natural Resources Research Scientist.

[2] Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) Station catalogue, Bureau of Meteorology Melbourne, Australia.

Manual (thermometer) observations commenced using another 230-litre screen beside a dusty track behind the cottage near the airport terminal in November 1994 and ceased in January 1999. An automatic weather station (AWS), which used a single electronic temperature probe housed in a 60-litre screen to record daily maximum and minimum temperature (Tmax and Tmin) was established in an enclosure 700m north of the terminal on 3 December 1998. The AWS reported whole-degrees until 2002.

In this analysis post office and manually observed airport data were joined on 1 November 1995 and with AWS data from 1 February 1999 to make a seamless record. Missing data is a problem for the AWS, which seems unreliable or poorly serviced (Figure 2). (It failed temperature field performance checks four times between December 1998 and October 2015; the probe was replaced twice and although a dry bulb thermometer was not removed until November 2012 there is no comparative spot-data.)

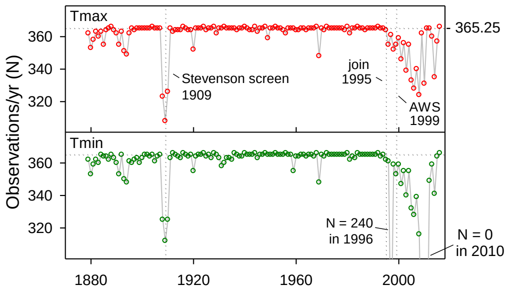

Figure 2. Less than 330 Tmax observations/yr are available in 1888, 1908, 1909, 1910, 1909, 2006 and 2008 and those years are ignored in the analysis. AWS data after 1999 were often faulty or culled for being out-of-range.

To determine if the climate has warmed or if other factors are involved, site and weather changes affecting Tmax are investigated[1] separately. Rainfall changes (average rainfall stepped-down abruptly from 443mm to 290 mm in 1898; increased 103mm in 1947 and declined 96 mm/yr in 2001) are confounded with site-changes in the top panel in Figure 3 and linear regression is used to filter variation caused by rainfall (side panel) from site-change effects embedded in residuals. Step-changes in re-scaled residuals[2] are detected statistically and changepoints are aligned with known site factors afterwards (bottom panel).

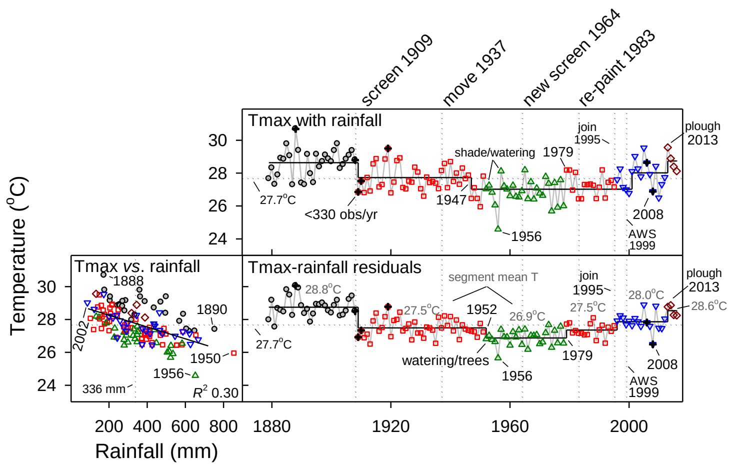

Figure 3. Step-changes in raw Tmax (top) track both site and rainfall changes. Tmax depends on rainfall (side panel; symbols correspond with data segments) but due to un-accounted for changes the naïve relationship is imprecise and explains only 30% of Tmax variation. Step-changes in residuals reflect site changes alone[1]. Average Tmax is the same for the second and 4th segments (red squares) but is different for others (pre-Stevenson screen; cooling due to shading and watering; the move to the AWS, and from 2013 after the periphery of the AWS-site was ploughed. Segment means (grey) are median-rainfall adjusted values derived from multiple linear regression (see following text). (Solid symbols identify data with fewer than 330 observations/yr that were ignored.) Average Tmax (27.7°C) and median rainfall (336 mm/yr) are indicated.

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[1] Observed Tmax is disaggregated, firstly, by removing variation due to rainfall [described by the linear regression equation (Tmax = 29.0 – 0.0036.Rainfall)]; and, secondly, by analysing re-scaled residuals (variation that is unexplained by rainfall) for abrupt step-changes (shifts) in the mean using an independent statistical method.

[2] Zero-centred residuals are re-scaled by adding back-on grand-mean Tmax.

Finally, the effect of site changes and rainfall on Tmax is analysed simultaneously[1]. Rainfall and step-changes (shown for each segment in Figure 4) explain 74.2% of Tmax variation (*vs*. 30% for rainfall alone); rainfall reduces Tmax 0.38°C/100 mm and except for data after 2013, median-rainfall adjusted segment-means after 1909 are different. (The mean after 2013 is higher by 0.66°C but several more years of ploughing is needed for the change to be significant.) Importantly, after step-changes and rainfall are accounted-for no residual time-trend is attributable to CO_2, the climate, or anything else.

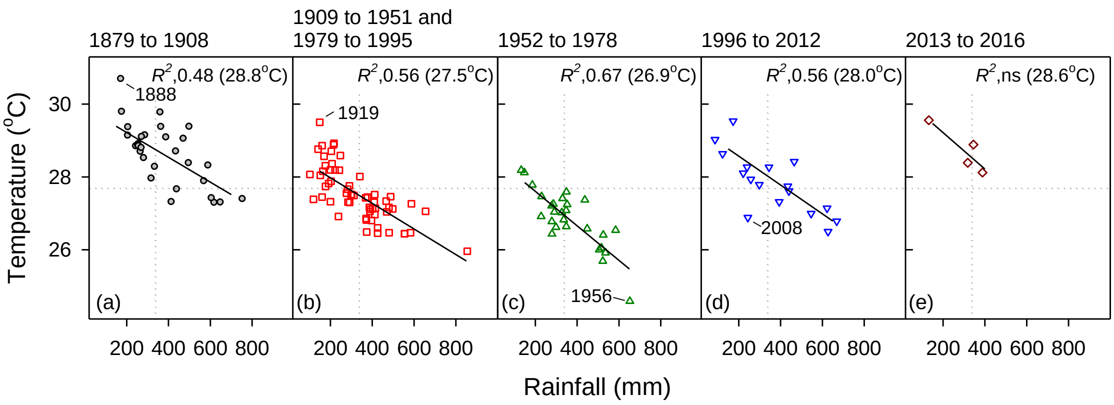

Figure 4. Free-fit Tmax-rainfall relationships for segments defined in the lower panel of Figure 3. Individual goodness-of-fit (R^2_{adj}) and median-rainfall adjusted segment means (in parenthesis) are indicated. Lines are parallel; (a) and (e) means are the same so those lines are coincident. Lack of correlation (ns) in (e) is due to too-few data points.

Comparing temperatures in town and at the airport.

The overlap between when the airport site opened in 1994 and the post office closed in 1966 (about 630 data-days) allows datasets to be compared. Both sites use 230-litre screens and were manually observed so differences are related to site conditions (urban *vs*. airport).

Cumulative distribution functions (CDF) calculated over identical temperature scales visualise the likelihood of daily values within temperature bandwidths and are conveniently thought of as smoothed frequency histograms. Similar heat signatures result in similar distributions; otherwise distributions shift relative to each other or their peaks are different. The hypothesis that distributions (and medians) are the same (P_{same}) is tested statistically.

While CDF's visualise how a disturbance affects the *shape* of data distributions, percentile differences[2] show the *nature* of the change – which parts of the distribution are affected. Values than the 5th and greater than the 95th percentiles (low and high extremes respectively) define the 'tails' – or outliers to the overall distribution and are particularly relevant for comparing the relative frequency of extremes through time and trends in extremes and for analysing site-related impacts.

Upper-range Tmax temperatures are skewed higher at the airport than in town where lawns and gardens are cooled by watering (Figure 5). Within error bandwidths (assumed to be ± 0.2°C) both sites record 20°C on a 20°C day, but when it's 33°C in town it is 33.5°C at the airport and on days when it's close to 40°C in town it is up to a whole degree hotter at the airport. Tmin at the airport in winter is up to 2 or even 3°C cooler, probably because night-time temperatures in town is warmed by urban effects: air-conditioners and wood-burning stoves; also, bitumen and bricks and mortar store heat during the day and exchange it with the local atmosphere at night prolonging night-time warmth.

Urban cooling of Tmax (due to watering and shade) and warming of Tmin (night-time advection and heat storage in the urban environment) result in site-related temperature bias.

[1] Multiple linear regression (Tmax ~ $Site_{factor}$ + rainfall) done using R.

[2] Percentiles are daily values ranked by 1%-frequency intervals; thus 1% of daily temperatures are less than the 1st percentile; 2% are less than the second and so on; the 25th percentile is also called the 1st quartile and the 50th is the median.

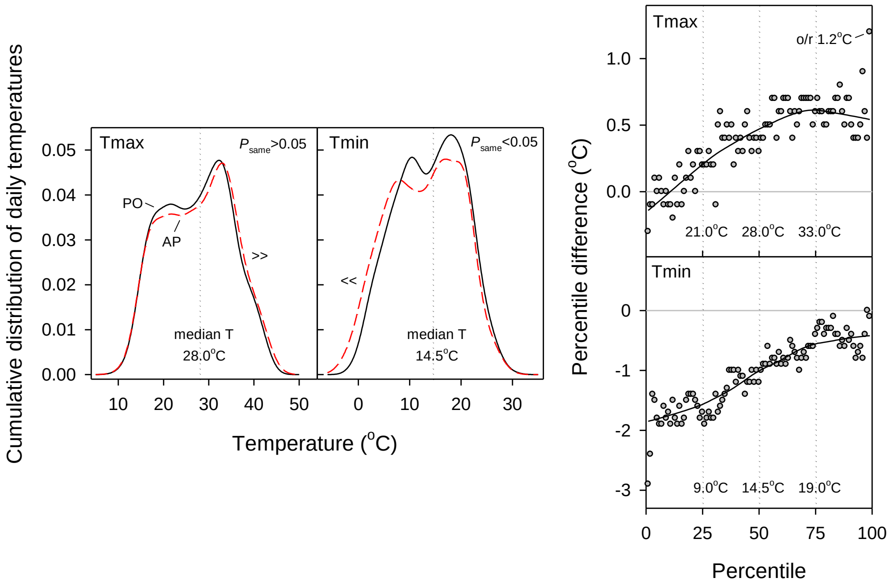

Figure 5. Cumulative distribution functions (CDF) show the *shape* of Tmax and Tmin data distributions across same-scaled temperature ranges (bottom axis). Relative to the post office (PO, solid black line) there is a slight warm-shift in Tmax (>>) and a pronounced cool-shift in Tmin (<<) in airport data (AP, red dashed line). For Tmax the difference overall is not significant (P_{same} >0.05; Kolmogorov-Smirnov test for equal distributions) and medians (27.8°C *vs*. 28.1°C) are the same (Mann-Whitney test of central tendency). However, Tmin distributions and medians (14.4 *vs*. 13.2) are different (P_{same} <0.05).

Overlap percentile differences (right hand panels) (AP minus PO percentiles) show Tmax is warmer at the AP on days when PO temperatures exceed about 20°C. The difference increases with temperature, indicating systematic site-related bias. The highest airport temperature during the overlap (44.7°C on 9 November 1995) is over range (o/r) by 1.2°C and is probably spurious (miss-observed or transcribed) (reflectance of the screen might be affected by dust for instance). Airport Tmin is up to 0.5°C cooler in summer and up to 2°C cooler in winter.

Effect of ploughing around the AWS at the current site

Under dryland conditions evaporation of rainfall results in local cooling and any practice that increases or reduces water use by plants (evapotranspiration) also causes artificial cooling or warming. While watering the lawn at the post office increased evapotranspiration and artificially cooled Tmax (Figure 3) ploughing around the AWS at the airport before September 2013 reduced it and caused warming (Figure 6).

Predicting Tmax relative to rainfall and subtracting the prediction from measured values estimates the magnitude of the 'ploughing' effect (Table 1). If they continue to plough around the site the average difference (0.27°C) will become entrenched as a significant offset.

Table 1. Actual and predicted[1] Tmax and their differences (Delta- the 'ploughing' effect). O/r is °C over-range relative to the upper 95% prediction interval (PI_{95}). So, in 2013, Tmax is higher than predicted (by rainfall) by 0.79°C; which exceeds PI_{95} by 0.51°C. (Note data for 2013 to 2016 are excluded in the underlying analyses.)

Year	Rainfall (mm)	TmaxObs/yr (N)	Tmax (°C)	Predicted Tmax (°C)	Tmax Delta (°C)	O/r (°C)	PI_{95} (±°C)
2013	132	360	29.56	28.77	0.79	0.51	0.57
2014	345	335	28.89	28.34	0.55	0.29	0.52
2015	318	357	28.38	28.06	0.32	0.07	0.50
2016	389	366	28.12	27.79	0.33	0.08	0.50

Surface energy balance accounts for surface energy fluxes according to the first law theorem that energy is conserved[2]. Average annual solar exposure[1] at Bourke is 7290 MJ/m²/yr. Evaporation of average rainfall

[1] Calculated in R using the *lsmeans* package.

[2] First law of thermodynamics: net energy = latent heat flux + atmospheric flux (advection) + ground-heat flux.

(336 mm) removes 823 MJ/m^2/yr of available energy (11.3%) from the environment as latent heat. Additional rainfall (or watering) increases evaporation, reduces heat advection and cools Tmax; while ploughing does the opposite: deep-rooted perennial plants that transpire water are lost; evapotranspiration is less, advection increases and Tmax is higher.

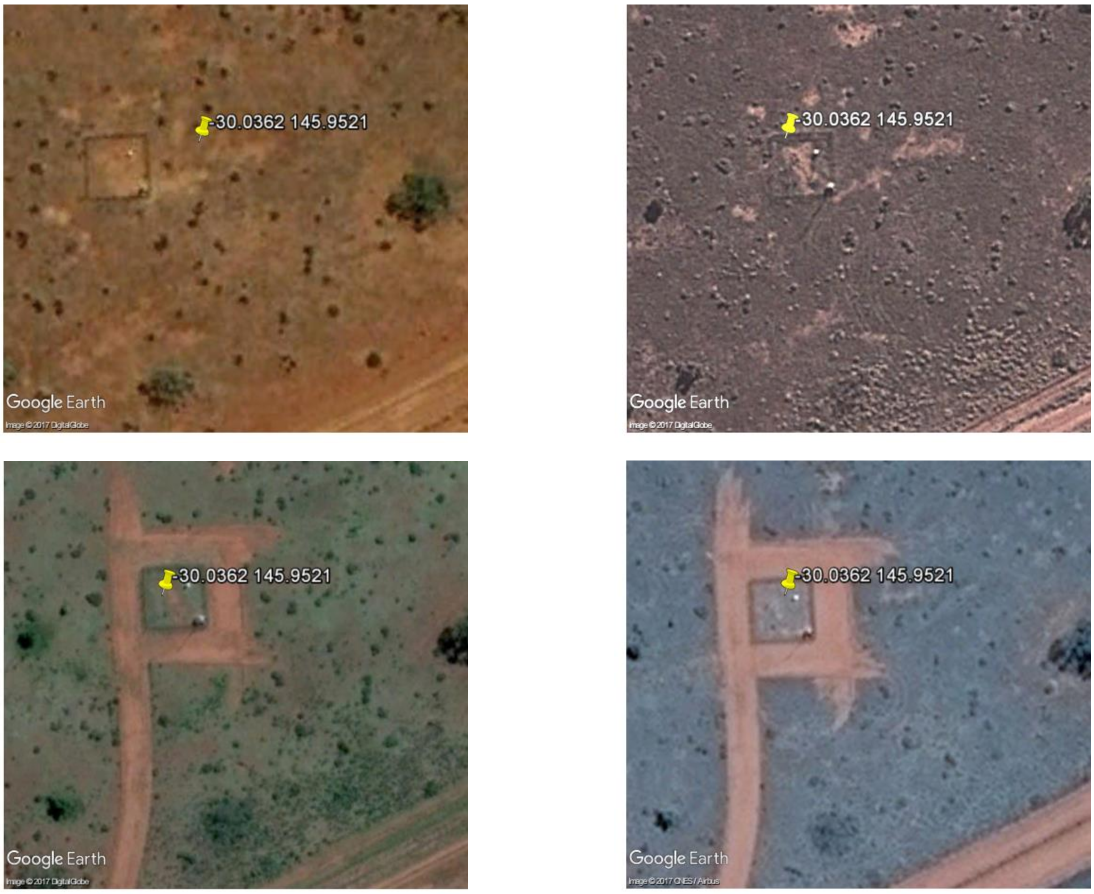

Figure 6. Bourke airport AWS (clockwise from upper left) in February 2007, May 2010, September 2013 and September 2015 (Google Earth Pro). Reduced evaporation caused by cultivation increases local warming in the vicinity of the screen. (The area of cultivation estimated using Google Earth Pro measuring tools is four times that of the enclosure (966m^2 *vs*. 225m^2).

Discussion.

Tmax measures the heat advection component of the local energy balance, which is directly related to factors affecting evapotranspiration. Thus under dryland conditions, the drier it is the hotter it gets. Poor site control such as watering/shading, which increases evapotranspiration, or ploughing which reduces it, causes Tmax to cool (or warm) artificially. Rainfall and non-climate factors (moving to the airport then to the neglected 60-litre AWS screen) explain all of the warming in Tmax.

Cooling at night is mainly *via*. long-wave (emitted) radiation and cool-air drainage. Advection of heat stored in the urban environment during the day to the local atmosphere at night and other sources of heating (air conditioning and wood-burning heaters) warm Tmin artificially relative to the non-urban situation at the airport. Effects on temperature are due to the environment surrounding where it is measured. There is residual trend indicating the climate has warmed and no other factor is influential.

The climate has not changed and there is no measurable warming trend. Both Tmax and Tmin consist of non-trending segments defined by step-changes related to site changes.

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[1] Solar exposure is the energy falling on a horizontal surface estimated from satellite measurements allowing for cloudiness and albedo (reflectance). (Average MJ/m^2/day multiplied by 365.25 = MJ/m^2/year.)

Part B. Homogenisation of Bourke temperature data.

Estimation of temperature trends and climate-change effects requires that conditions under which observations are made remain consistent (or homogeneous). Thermometer exposure changed at the at the post office when the Stevenson screen was installed in 1908; also in 1937, 1964 and 1983; shade and watering was a problem from 1947; post office and airport data were joined in 1995, the AWS and small screen took-over in 1999; then in 2013 the site is ploughed-around. Artefact changes create trends that are unrelated to the climate.

Homogenisation aims to adjust for site and instrument changes that affect measurements but the process[1] is deeply flawed. Two key weaknesses are:

- **Faulty or incomplete metadata[2] is used to identify changepoints in the first instance.** Metadata for individual datasets is frequently incomplete (influential changes are not documented) or misleading (some changes happen that don't affect data). For example, moving the screen in 1937 did not impact on data; an aerial photograph shows replacing the screen in 1964 probably involved moving out of the way of a new building but because the place was watered there was no detectable temperature step-change.
- **Comparative methods are inherently biased.** As most comparator datasets are not homogeneous their selection based on correlation with the target is likely to choose sites having parallel faults.

The first iteration of homogenised Bourke post office data (1879 to 1993) was the *high quality* dataset developed in 1996[3] (HQ_1). A second homogenisation (also in 1996) resulted in another *high quality* series (HQ_2), which was extended several times eventually to include the period 1910 to 2012. The composite dataset (from 1910) was homogenised again by ACORN-SAT, which replaced HQ in 2012.

Site and instrument changes only happen once. However, different homogenisations apply different adjustments at times that don't coincide (Figure 7). For instance, the Tmax-residual step-change in 1952 was adjusted by HQ_1 in 1965; by HQ_2 in 1954 and ACORN-SAT in 1953; but no adjustments were made for the data up-step in 1979 (Figure 3). The residual data step-change due to the join in 1996 was 0.50^{o}C; HQ_2 and ACORN-SAT merged in November 1994 and applied an adjustment of 0.35^{o}C. Also, ACORN-SAT reported that the screen at the post office moved in May 1937 and applied a slight Tmax adjustment (0.02^{o}C), whereas other homogenisations of the same data ignored or didn't know about the move.

Homogenisation uses up to 10 correlated datasets (Figure 8) to adjust (smooth or change the trajectory of) raw data. Adjustments are also applied retrospectively relative to the present; thus hot temperature in the past may be cooled and *vice-versa*. **The fallacy, which applies to all datasets homogenised using comparative methods is that unexplained changepoints are attributed to the climate by default.** Furthermore, homogenisation is applied *a priori* – changes in data are not detected first and their cause researched after as is the case for evidenced-based (*post hoc*) research; instead, changes implied (or not) by metadata are imposed on the data at the outset. So despite obvious deficiencies in the method whatever trend or change emerges is claimed to reflect the climate.

Sites in Figure 8 that have been individually researched (Charleville, St George, Inverell, Tibooburra, Wanaaring, Walgett, Gunnedah, Cobar, Dubbo, Bathurst, Broken Hill and Wagga Wagga) all show evidence of site and instrument related changes, which affect data (some have moved, telephone exchanges were built in post office yards; some have been refurbished, some have missing data, 60-litre Stevenson screens have replaced 230-litre ones, AWS have replaced thermometers etc.). (Appendix 1 gives specific examples.)

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[1] Trewin B. (2012) "Techniques involved in developing the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) dataset". CAWCR Technical Report No. 049

[2] Metadata describes the data. For instance, timing of site moves and changes in instruments is identified (or not) by metadata. Effects of influential changes are embedded in the data-stream either as a significant change in the mean; or other metric such as variability (variance), range, and year-to-year difference or relative to another co-related factor.

[3] Torok S.J., 1996. The development of a high quality historical temperature data base for Australia. PhD thesis, School of Earth Sciences, Faculty of Science, The University of Melbourne, Australia. [Availabe online at http://minerva-access.unimelb.edu.au/handle/11343/39449]

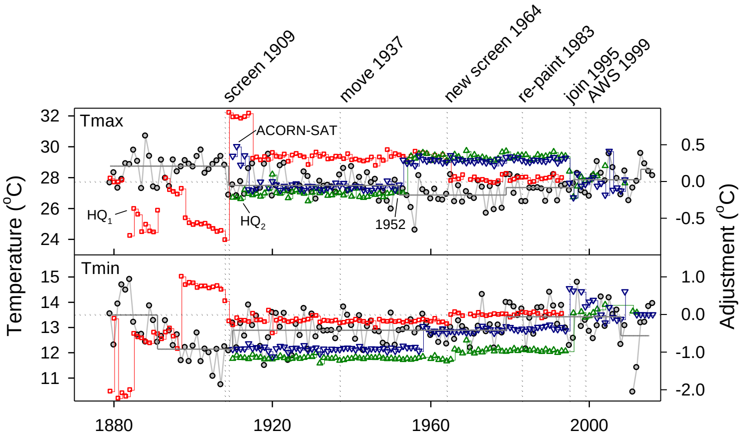

Figure 7. Homogenisation adjustments of the Bourke post office and airport composite temperature series (grey circle; horizontal line) (calculated as homogenised minus raw data) are shown on the right axis: HQ_1 (red squares from 1879), HQ_2 (green triangles from 1910 to 2012), and ACORN-SAT (blue inverted triangles from 1910 to 2016). Data are homogenised relative to the present and the adjustments scale is centred relative to the most recent segment (indicated by the dotted line).

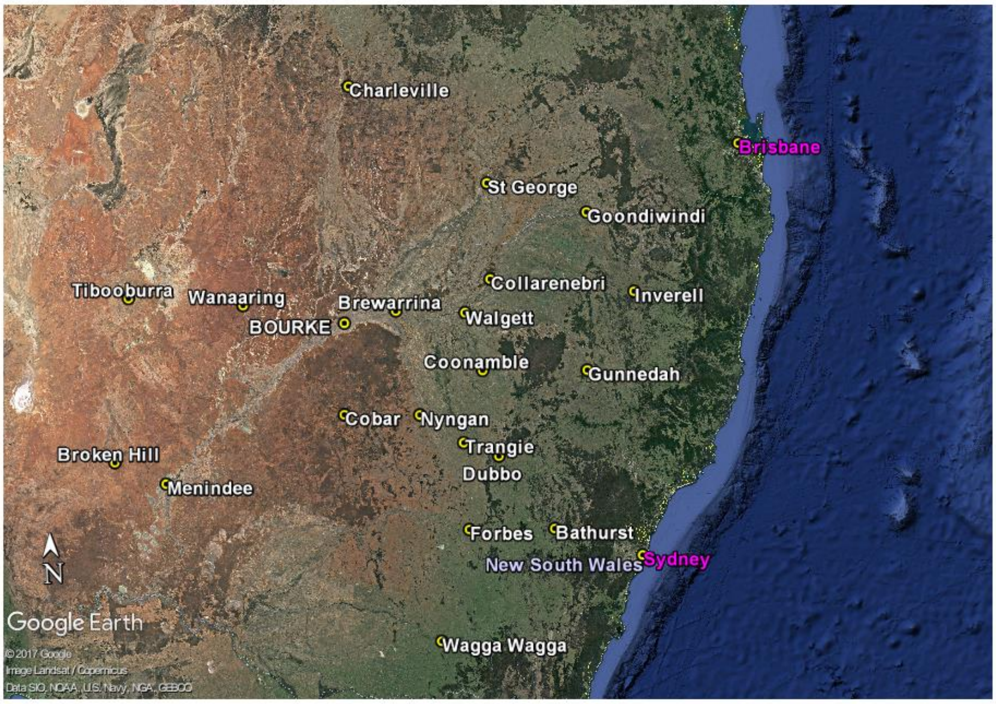

Figure 8. Datasets used to homogenise Bourke temperate data for site inhomogeneties. The distance from Bourke to Charleville is 410 km and to Wagga Wagga is 580 km. (Map courtesy of Google Earth Pro.)

Furthermore, those that are ACORN-SAT sites have been adjusted using other ACORN-SAT data that are faulty. For instance, faulty Sydney Observatory data are used to adjust Cobar, Walgett, Gunnedah and Bathurst, which in-turn are used to adjust Bourke. Also, Moruya Heads and Canberra airport (which are homogenised using Sydney Observatory) are also used to adjust Bathurst and Dubbo; Gunnedah is used for Inverell and Dubbo; and Dubbo for Tibooburra. (Bourke, Broken Hill and Birdsville are also used to adjust Tibooburra; and those four datasets together with others that are faulty, are used to adjust Alice Springs).

Discussion and conclusions.

Bourke is just another ACORN-SAT dataset whose data embed site-related inhomogeneities and where homogenisation changepoints are applied arbitrarily. Resulting trends don't reflect the climate. As uncorrected faults are propagated across the network by the process, homogenisation is biased, has no scientific or statistical merit and should be abandoned.

Appendix 1.

Blowing the whistle - using Google Earth Pro to view recent site changes.

Recent weather station changes can be viewed using time-lapse satellite images available from Google Earth Pro; which is free to download and use (to avoid third-party add-ins, only download from https://www.google.com/earth/download/gep/agree.html).

Paste latitude and longitude into the search bar separated by a single space; for Bourke it is -30.0362 145.9521 then zoom down and scroll through images. (It is useful if: under Tools-Options-Navigation; choose "Do not automatically tilt while zooming" and "Gradually slow the earth when rotating or zooming".) To open the time-bar showing available images double-click the image date in the lower-left box.

Changes at some Australian weather stations that can be explored using time-lapse Google Earth Pro satellite imagery (paste coordinates into the search bar directly from the Table). (Bolded sites are ACORN-SAT.)

Weather station site and issue		Latitude and Longitude
Widening and sealing of Beech and Elm streets within metres of the Stevenson screen at the back of the **Barcaldine** post office (a) before it moved beside a dusty track at the airport (b). At **Marble Bar** the AWS is also beside a dusty track (c). At **Camooweal** it is between a bitumen-paved car park and an intermittently watered sports oval (d).	(a) (b) (c) (d)	-23.5544 145.2883 -21.1756 119.7497 -22.9117 139.9039 -19.9225 138.1214
Herbicide is used to kill-off vegetation at **Richmond airport (Qld)** (a). The cluttered yard at **Marree (SA)** evidences poor site control (b); the replacement AWS is beside the fuel dump at the airport (c). Surrounds of the AWS at **Learmonth (WA)** appear sprayed-out before December 2002 (d). The area affected increased by more than 2 Ha between October 2014 and the latest image (October 2015).	(a) (b) (c) (d)	-20.7289 143.1425 -29.6481 138.0637 -29.6589 138.0686 -22.2406 114.0967
Location of the 1966 site at Mt Isa (a) *vs*. after it moved to the met-office in 1975 (b).	(a) (b)	-20.6644 139.4908 -20.6778 139.4875
The AWS at **Oodnadatta** beside a dusty track (a) *vs*. the 1941 Aeradio site (b) where surrounds were probably watered to suppress dust. Until it moved down the road to (c) the Stevenson screen at **Thargomindah** post office was affected by watering and veggie tanks (d); the AWS at the airport is beside a dusty track (e). (History of the post office is poorly known including that it burnt-down on 1 January 1953.)	(a) (b) (c) (d) (e)	-27.5553 135.4456 -27.5567 135.440 -27.9978 143.8197 -27.9967 143.8213 -27.9867 143.8150
The wind profiler array beside the Stevenson screen at **Tennant Creek** (2013) increases temperature (herbicide is used there too) (a). The wind-profiler is too close to the screen also at **Mildura** (b) and **Carnarvon (WA)** (c), and other sites too.	(a) (b) (c)	-19.6423 134.1833 -34.2358 142.0867 -24.8878 113.6700
Urban encroachment at **Cobar MO** before the site moved in 2000 (a); and at **Halls Creek** (b). The Warakurna road was sealed 20 m from the screen at **Giles** in 2011 (c) (it seems herbicide is used there too).	(a) (b) (c)	-31.4840 145.8284 -18.2292 127.6636 -25.0341 128.3010
The **Woomera AWS** is mulched with bluestone gravel (a), while the screen at Moomba is in the dust between the airport runway and supply dump (b).	(a) (b)	-32.1558 136.8054 -28.0997 140.1956
Unlike the previous site at the police station (a), the AWS at **Birdsville** is surrounded by sand hills and gibber plains (b).	(a) (b)	-25.9003 139.3486 -25.8975 139.3472
The original (undocumented) 1941 Aeradio site at **Charleville** (a); (b) the 1956 Flight Services Unit site; the 1990 airside site (c); and the 2003 meteorological office site (d). An undocumented move or change also occurred also around 1978.	(a) (b) (c) (d)	-26.4086 146.2566 -26.4142 146.2592 -26.4147 146.2608 -26.4139 146.2558
There is nothing at Delta, 123.6 km west of Bourke (a), which reported the record-hottest September day in NSW. Data start on 24 August 2017; the 'record' 41.3°C is set 35-days later on 27 September when the AWS was reporting only whole degrees! The AWS near the Borrona Downs airstrip ran from 20 July 2017 before conking-out on 28 August (b).	(a) (b)	-30.1007 145.3339 -29.7529 143.0964
Jervois AWS and Curtin Springs (NT) are used to homogenise **Alice Springs**. Jervois is beside a dusty track (a); the Curtin Springs manual site is in a dusty trucking-yard (b).	(a) (b)	-22.9494 136.1442 -25.3139 131.7571
No useful metadata is available for the **St George (Qld.)** post office (a) or the **Port Hedland** post office (WA), which was demolished in 1967 (b).	(a) (b)	-28.0361 148.5814 -20.3139 118.5742