Sydney Observatory's temperature trends, extremes and trends in extremes.

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Summary.

Sydney Observatory is Australia's longest continuously reporting weather station. The climate hasn't changed; temperature has not increased neither are extremes more frequent or increasingly severe.

Moving the weather station in 1917 and automation in August 1990 are the only changes documented and neither is influential on data. Changes that are not documented include construction of the 1922 Weather Bureau office and the Sydney Harbour Bridge (1921-1932); demolishing and rebuilding the Fort Street School (before 1941); moving the site to the southeast corner of the cottage yard (1948/49); opening of the Cahill Expressway (1958); enclosing the yard with a 2.4 m high brick wall south of the screens (1972/73); replacing the large screen with a small one (probably in 1997) and traffic changes. Temperature trends and recently reported records reflect site changes not the climate. **An open public inquiry into the Bureau's handling of site records and data and its on-going campaign of climate-alarm advocacy is long overdue.**

Introduction.

Sydney Observatory (Figure 1) (Observatory Hill: ID 66062; Latitude Longitude[1] -33.8607 151.2050) is the longest continuously reporting weather station in Australia. With data from 1 January 1859 it is also one of the longest intact records in the southern hemisphere and the main reference weather station for Australia's largest city. This essay examines claims[2] that temperature has increased in recent decades and that upper-range extremes are more frequent and more severe.

Figure 1. The louvered thermometer house in front of the Observatory in 1864. (Courtesy, State Library of NSW.)

Background.

Daily, monthly and annual maximum and minimum temperature (Tmax and Tmin) embed two conflated signals: (i) variation due to the weather, which is of day-to-day interest to Sydneysiders; and, (ii) the site's background heat-signature: the ambient-baseline represented by the mean (Figure 2). Day-to-day temperatures and records expressed relative to the average assumes the baseline is constant, unaffected by site changes and that deviations from the mean reflect the climate.

While not all site and instrument changes affect measurements, those that do show up as step-changes (shifts) in dataset means, which are detected statistically and attributed to causal factors afterwards (*post hoc*). While detecting step-changes is straightforward, identifying their cause is impeded by inaccurate metadata[3] and lost or inaccessible documentation about specific events and conditions affecting observations. Ignoring influential step-changes (changepoints) and adjusting for ones that don't impact on data results in trends that don't reflect the climate.

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[1] For time-lapse satellite images paste values directly into the Google Earth Pro search bar and double-click on the date-box in the bottom left corner. (Only download from Google (https://www.google.com/earth/download/gep/agree.html))

[2] Sydney in January 2017: the warmest month on record. Bureau of Meteorology Monthly Climate Summary for Sydney (Wednesday, 1 February 2017) (Accessed 5 February 2017).

[3] Metadata is summary information about the data; the Bureau's site summary for example is metadata.

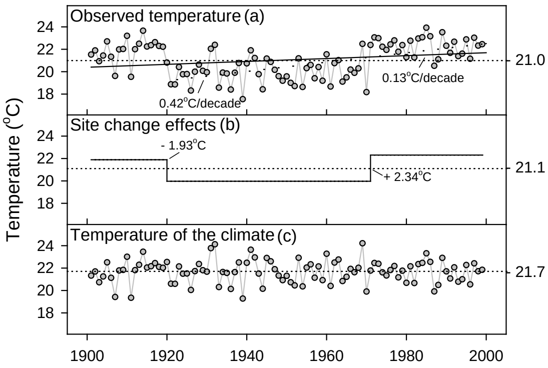

Figure 2. Observed temperature (a) is the sum of its parts [(b) + (c)] and in this hypothetical example the 'true' climate signal (c) is obtained by deducting step-changes in the mean (b) from observed temperature (a). (As data in (a) embed the site-change signal the overall trend (0.13^{o}C/decade) is spurious. (Illustrated also is that 'trend' can be manipulated by picking start and end dates.) (The dotted horizontal line is the mean for each case.)

Understanding site-change impacts is important. For example in 1866 thermometers moved from an open-fronted Glashier stand (a type of instrument shelter) to the thermometer-house. While the move did not affect Tmax, reduced nighttime radiative cooling caused average Tmin to abruptly step-up. Later when the shelter became shaded (Figure 3) average Tmax stepped-down 0.32^{o}C but Tmin was unchanged.

As site and instrument changes affect trend independently of the climate it is vital they are identified and explained. However, primary evidence such as original data registers and notes are mostly unavailable or have been destroyed. For the Observatory the only reference is an incomplete summary restated from Simon Torok's (1996) PhD thesis[1]:

- Late 1860's: Instruments moved to a large shed after being held on Glaisher stand.
- 1910: Instruments moved from shed to Stevenson Screen.
- 1917: Instruments moved from Observatory to position at cottage where they are to the present.

(a) (b)

Figure 3. Instruments moved from the louvered thermometer-house (a) to a Stevenson screen (b) in about 1906 (photographed in 1874 and 1903 respectively). Shading (or watering) is probably the reason average Tmax stepped-down 0.32^{o}C in 1879. Moving to the screen surrounded by grass caused Tmax to increase 0.64^{o}C in 1906. (Photographs courtesy of (a) the State Library of NSW and (b) the National Archives of Australia.)

The ACORN-SAT catalogue[2] doesn't add much more: "Originally the site was in the main Observatory grounds. It moved about 100 m south to its current location in 1917. The earlier site was a more exposed

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[1] Torok SJ (1996). Appendix A1, in: *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.

[2] Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) Station Catalogue and other documentation (available at http://www.bom.gov.au/climate/change/acorn-sat/index.shtml#tabs=ACORN%E2%80%90SAT&-network=)

location on a hilltop and had lower maximum and higher minimum temperatures than the current location. An automatic weather station was installed at the current site on 8 August 1990 …. The area is heavily built-up and has been since at least the late 19th century. An analysis of minimum temperature trends in the ACORN-SAT data showed no evidence of an abnormal warming trend relative to non-urban sites in the region, indicating that any urban influence on the data was already fully developed by the time ACORN-SAT begins in 1910".

The Observatory is within a grassy former military reserve and not built-up; photographs show the original site open to the south and east (e.g. Figure 1); sheltered to the west by gardens, a paling fence and planted trees (Figure 3) while the Observatory was always directly north of the thermometer-house and screen.

The question is: Do changes in Sydney Observatory temperature data reflect changes at the site or changes in the climate?

The current Stevenson screen is about 60 m from the middle of the Bradfield Highway, which is one of Australia's busiest roads. Encircled by the Cahill Expressway up-ramp (which after a decade of construction opened in 1958) it shares an area of about 1 ha with the Fort Street School (rebuilt in 1941) and its concrete playground (and heritage-listed Jackson Bay fig tree); the re-built school gymnasium (which opened in 1952); the now-derelict 1922 NSW Weather Bureau office; the historic 1862 messengers cottage (now the school office) and the section of Upper Fort Street remaining after the Harbour Bridge was built from 1920 and opened in 1932.

When the number of traffic lanes on the Harbour Bridge increased from four to six in 1950 numbers of tollgates increased from six to 12, which required the roadway 45 m north of the cottage to be widened. Restrictions on lane changing were lifted and tidal traffic-flow introduced in 1966 (four of six lanes southbound in the morning; reversed in the afternoon); southbound-only tolling started in 1970; the Western Distributor opened in 1972 and electronic tolling became compulsory in 2009. Minimising delays increased northbound traffic-flow, which added additional heat to the local atmosphere in the afternoon around the time Tmax usually occurs (2 to 4 pm). While background heat increased either step-wise due to abrupt changes (*vis-à-vis* Figure 2) or trend-like during build-up phases to when no more traffic could pass, the climate stayed the same.

Analysis aligns step-changes in mean temperature with site changes verified independently by documents and photographs held by archives, and aerial photographs and satellite images (see also http://joannenova.com.au/2017/01/ sydney-observatory-where-warming-is-created-by-site-moves-buildings-freeways/). Multiple lines of evidence show four important changes are undocumented while another is possibly documented incorrectly[1] (Figure 4)):

- Historic aerial photographs taken in 1943 and 1949[2] unequivocally show Stevenson screens moved from beside the school to the southeast corner of the cottage yard probably in 1948 or early 1949.
- Extraneous heat resulting from preparatory roadwork and opening of the Cahill Expressway up-ramp (and widening the Bradfield Highway for additional merging lanes) caused Tmax and Tmin to step-up in 1955 and 1958.
- Tmax and Tmin both stepped-up in 1972 after a 2.4 m high brick wall replaced an open fence south of the screens. The wall stored and trapped heat during the day (and radiated or advected it to the local atmosphere at night) and interrupted cool-air drainage. Steps may also be confounded with traffic changes and opening of the Western Distributor, which occurred at about the same time.
- Installing the automatic weather station (AWS) in the former large 230 L screen on 8 August 1990 made no difference, possibly because thermometers were available to check data until May 1995. However, installing a small 60 L screen caused a synchronous step-change in 1998 (Figure 5).

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[1] Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) Observation Practices (page 13).

[2] Compare https://maps.six.nsw.gov.au/ 1943 basemap with December 1949 City of Sydney Archives photograph (http://www.photosau.com.au/CoSMaps/maps/pdf /AO1/AO014.pdf)

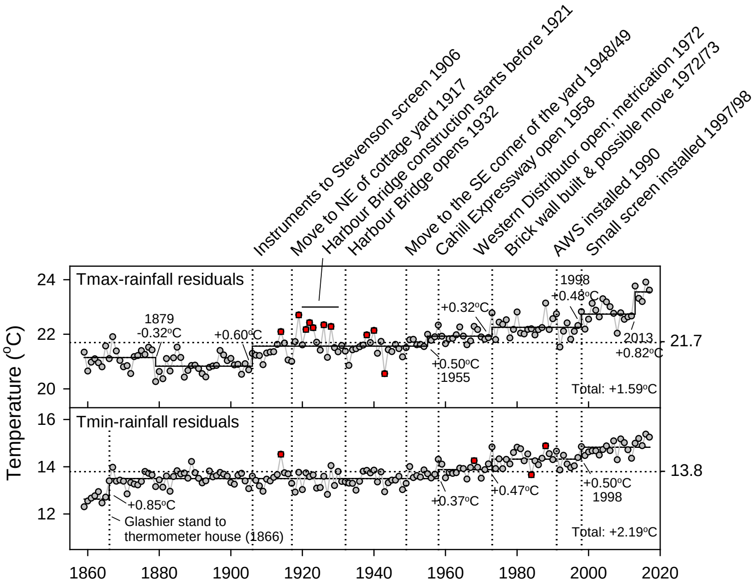

Figure 4. Residual step-changes in Sydney Observatory temperature data aligned with site changes verified independently (the effect of rainfall is removed statistically). Red squares indicate statistical outliers. As step-changes are aligned with site changes *post hoc*, analysis is independent and unbiased by prior knowledge. The Tmax decline in 1879 is due to shading of the thermometer house.

A close-up photograph of the small screen's serial number (97/C0526) shows it was made in 1997; data step-changes indicate it was probably installed either that year or in early 1998 so documentation that it was installed in 2000 is likely to be inaccurate. The screen (Figure 5) is neglected: some paint is peeling; cobwebs are obvious between the louvers, and a light covering of black soot: diesel-exhaust, road and traffic grime, dulls its surfaces, biases its performance and indicates equipment is poorly maintained.

Figure 5. The small Stevenson screen in the cottage yard (27 December 2017) is dulled by road-grime. (The yard opens towards the Bradfield highway (left)). A 1966 photograph shows two screens on the camera-side of the 'T' at the end of the path separated from the school gymnasium (behind) by an open wire fence. Aerial photographs and data step-changes indicate the wall was probably built (or re-built) in 1972/73; sections affected by mortar-corrosion have been re-pointed. By trapping and radiating heat towards the screens and impeding airflow including cool-air drainage the wall changed the local heat balance.

Site changes and rainfall affect temperature extremes.

Counts of extreme temperatures/year [daily Tmax less than the 5th and greater than the 95th dataset percentiles (Lo(w) and Hi(gh) extremes respectively)] track cool and warm 'tails' of the distribution of daily values. Of particular interest is the Hi/Lo count-ratio, which after normalisation[1] is analysed for step-changes.

[1] Log_{10} transformation makes raw-ratio data symmetrical: small values become larger and large values smaller, which allows data to be analysed as though they were scaled linearly.

Tmax depends on rainfall, which at Sydney is clustered into high- and low-rainfall epochs, thus site-change effects on temperature extremes are inseparable from persistent rainfall changes. Also, as different factors are involved, counts of upper and lower extremes vary independently and their ratio is not expected to be constant (Figure 6).

Deviations from the mid-line (the overall count-average) are most noticeable after the site moved to the cottage and the Weather Bureau office and Harbour Bridge were built (and opened); the Cahill Expressway opened; the wall was built, and the small screen was installed**.**

Site changes have a permanent impact on upper-range extremes and as step-changes in their ratio are significant and result from rainfall and site-changes acting together, it cannot be claimed that upper-range temperatures have increased due to changes in the climate.

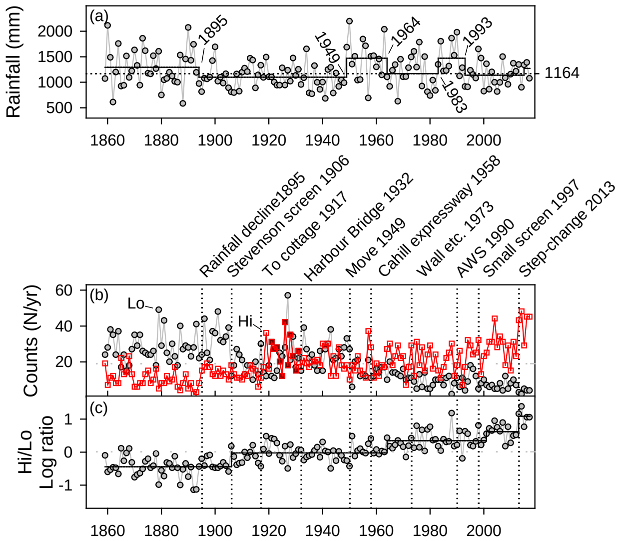

Figure 6. Rainfall (a) consists of moist and dry epochs interspersed by abrupt changes and is neither random nor trending. As rainfall since 1993 is not different from the median (dotted line), the current epoch is not unusually dry. Counts of low and high extremes (b) and their ratio (c) are affected concurrently by rainfall and site and instrument changes. Numbers of upper extremes (red squares) step-up when rainfall abruptly declined in 1895; low extremes stepped-down when instruments moved to the Stevenson screen in 1906. After the move to the cottage in 1917 counts were more-or-less random until the Cahill Expressway opened and the wall was built. Upper-range extremes stepped-up permanently after the small screen was installed and again in 2013.

Large *vs*. the small Stevenson screen.

The small-screen up-step in 1998 (Figure 4) is investigated using equi-length segments each side of the changepoint chosen so the screen-change is the only influential factor. Segments from 8 August 1990 (when the AWS was installed) to 7 August 1997 and 8 August 1998 (after the screen was replaced) to 7 August 2005 (about 2500 data-days per tranche) are compared in Figure 7.

Differencing large and small-screen percentiles[1] (small minus large, which is the reference) visualises the *nature* of the up-step. Possibilities are: (i), differences are random around zero (± instrument uncertainty of 0.2°C) (variation may change but the mean is the same); (ii), differences are consistently high (or low) across the percentile range (variation is similar but segment means are different) or (iii), they are biased systematically or within particular percentile bandwidths (differences are related to temperature).

Small-screen Tmax is biased-high (by 0.7°C (± 0.2°C)) at temperatures less than the 75th (large-screen) percentile (25°C) (Figure 7). Bias unexpectedly declines at higher temperatures linearly as Tmax increases. Small-screen Tmin increases systematically, quasi-linearly with the temperature being measured between the 25th and 75th percentiles, and also declines in the upper quartile range (Tmin greater than 18°C).

[1] Daily values within %-frequency intervals: thus five percent of daily values are less than the 5th percentile temperature; 10%, are less than the 10th and so on. The 25th percentile is also called the lower quartile; the 50th is the median and the 75th is the upper quartile; by definition 50% of data lie within the interquartile range.

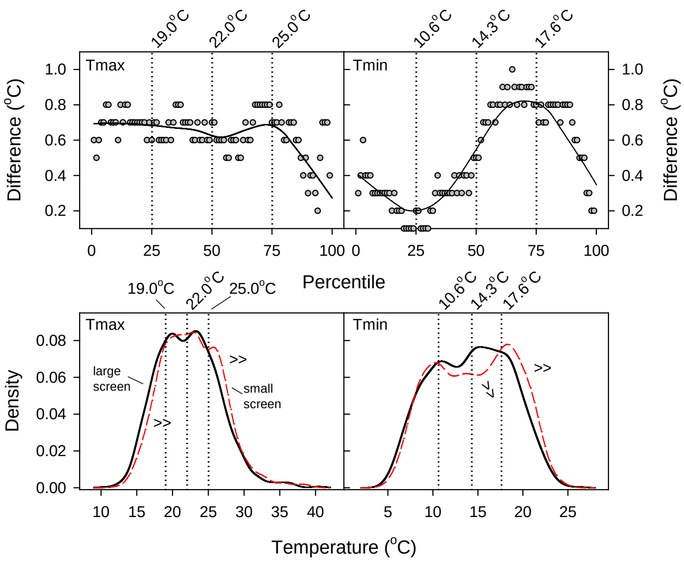

Figure 7. Small minus large-screen percentiles calculated over equal time intervals centred on the 1998 step-change (top panels) visualise the *nature* of the small-screen effect (parts of data distributions that contribute to the up-step). Probability density functions (lower panels) visualise the *effect* of the change on data-distributions. (Large-screen quartile and median temperatures are shown.) As more than 75% of daily Tmax values are up to 0.7°C warmer (top panel), the small-screen distribution (dashed red line, lower panel) shifts warmer (sideways). The asymmetric shift in Tmin results from small-screen data being skewed higher (pushed-out) in the temperature range between about 17°C and 20°C at the expense inter-quartile (average) range values.

As the instrument is the same, the systematic (non-random) nature of percentile differences is consistent with step-changes being due to calibration or screen-bias problems. Although changes in albedo (reflectance due to paint-gloss differences), positioning of the sensor in the screen, or changed exposure are possible factors; it is more likely that the considerably greater volume of the former screen (230 L *vs*. 60 L) buffered the sensor from transient eddies of warm air (from traffic, pavements and the wall) that cause data-spikes on warm days. For small-screen data to remain in-range spikes are progressively filtered or trimmed resulting in a downturn relative to upper-range large-screen percentiles.

Probability density functions are similar in concept to smoothed frequency-histograms[1], which visualise the *shape* of data distributions. Possibilities are that: (i) if temperatures for one dataset are higher on average and distributions (spread and height) are the same, curves displace sideways (shape is similar but medians are different); (ii) medians can be the same (or not) while the 'spread' (variation) is different including if the tail of one distribution extends relative to the other; and, (iii) irregular distortions (changes in symmetry) may indicate a variety of factors are involved or that data behave inconsistently. (Statistical tests[2] show large- and small-screen Tmax and Tmin are not normally distributed and that data-distributions and medians are not the same.)

The side-ways shift (Figure 7) shows small-screen temperatures are warmer but not because the tails of distributions are remarkably different. In both cases, the likelihood of moderately warm temperatures is higher; for Tmax at the expense of moderately cool values, for Tmin at the expense of values within the inter-quartile or average temperature range.

Tmax and Tmin step-changes in 1998 are not due to a simple shift in the mean. Mid-range temperatures were affected more than cool or warm extremes. While Tmax stepped-up generally, percentile differences suggest values greater than the 75th percentile were capped artificially or filtered *in situ* for extraneous spikes. Tmin percentile differences are not random either. Systematic warming within the inter-quartile range indicates the small-screen positive-distribution-shift is instrument related. Exposure may have

[1] Numbers of observations within narrow temperature-range classes.

[2] Shapiro-Wilk and Anderson-Darling tests for normality, Kolmogorov-Smirnov and Anderson-Darling tests for equality of distributions, and Mann-Whitney and Mood's tests for equal medians (central tendency).

changed, the small screen may be more sensitive to radiation and heat-transfer from the wall or the single probe could be closer to the northern face of the screen than in the large screen where thermometers are exposed on the same plane. Evidence does not support that the up-steps are climate-related.

The anomalous 2013 step-change.

The Tmax up-step (0.82°C) in 2013 is implausible and its cause is obscure:

- the instrument stayed the same and the screen is unchanged;
- the change is unrelated to rainfall (there was no shift in the climate);
- it can't be corroborated independently by manual observations; and,
- a significant step-change is only detected in Tmax.

Time-lapse Google Earth Pro satellite images straddling the changepoint (11 March 2007 and 30 June 2009 *vs*. 31 January 2014) don't evidence substantial changes in the vicinity (the screen was not moved and trees were not felled for instance). Nevertheless, differences between medians and distributions [data from 1 January 2008 to 31 December 2012 *vs*. 1 January 2013 to 31 December 2017 (about 1820 data-days/tranche)] are statistically significant.

Post-2013 Tmax percentiles increased from 0.4°C to 1.0°C (±0.2°C) within the first-quartile range (the coolest 25% of daily values) remained high then unexpectedly spiked out-of-control at the 95th percentile (daily values over 30.0°C) (Figure 8). The record-highest temperature (45.8°C on 18 January 2013) is 4.3°C higher than the pre-2013 high (41.5°C; 5 February 2011); 16.8°C higher than the previous day's Tmax (29.0°C) and 21.0°C higher than Tmax on the following day (24.8°C). About 73 individual values (the upper 4% of daily data) are anomalously out-of-range relative to pre-2013 percentiles. A change in the way data-spikes are filtered or capped is the likely cause.

Tmin percentile differences are not random either. First-quartile-range temperatures increased systematically to be 0.5°C higher while values above 21°C are trimmed or capped to contain warm-range spikes. As there was no up-step in mean-Tmin changes effectively cancelled each other out.

Discussion and conclusions.

- Sydney's climate hasn't changed. Temperature measured at the Observatory is impacted-on by site and instrument changes, which from 1950 are ignored to imply the climate has warmed when it hasn't. Analysis of temperature-rainfall residuals; searches of archives; time-stamped aerial photographs and recent satellite imagery together with *post hoc* alignment of step-changes and verified site changes; and analysis of data distributions shows the chorus of claims made in the press, grey-literature[1] and on *The Conversation*[2] that Sydney's climate has warmed are baseless.

- For temperature on 18 January 2013 to step-up 16.8°C from the previous day's maximum (26.8°C relative to the previous overnight minimum) then dissipate by 24.3°C before dawn the next day (and 21.0°C relative to the next-days maximum) would require a massive transfer of energy (which had to come from somewhere and move-on somewhere else). Considering that:
    - Tmax stepped-up permanently from 2013 for no apparent reason;
    - daily percentiles are biased systematically;
    - values greater than pre-2013 30°C are not in-control; and,
    - there was no corresponding spike in daily solar exposure in January 2013,

  recent record temperatures and heatwaves are either caused by faulty equipment or are exaggerated to stir fear about the climate.

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[1] E.g. (i) https://www.climatecouncil.org.au/angry-summer-report; (ii) https://www.sbs.com.au/news/200-weather-records-broken-during-australia-s-angry-summer-climate-council; (iii) http://www.smh.com.au/federal-politics/political-news/205-records-in-90-days-angry-summer-is-the-new-normal-says-climate-council-20170307-gut45k.html.

[2] E.g. http://theconversation.com/sydney-so-hot-right-now-whats-behind-the-citys-record-run-of-warm-weather-55756

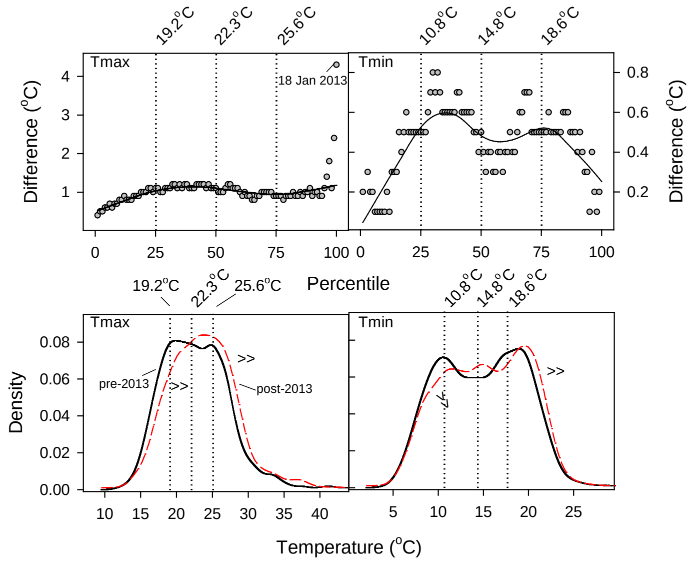

Figure 8. Percentile differences (post- minus pre-2016 percentiles) and Tmax and Tmin cumulative density functions centred on the anomalous step-change in 2016 show Tmax values warmer than the pre-2013, 95^{th} percentile (30^{o}C) bear no relationship to the overall distribution. Percentile-range bias is the reason for the positive (warm) shift in Tmax density. Systematic bias in Tmin suggests that the calibration of the temperature probe across the average temperature range is inconsistent and that values greater than 19^{o}C are trimmed or filtered so they remain plausibly in-range.

- After 1938 when work on the Cahill Expressway up-ramp started, staff passed within 15 m of the Stevenson screens to access their former office and observers were constantly in attendance.

  It's impossible that rebuilding of the school, the move in 1947/48, opening of the expressway, construction of the wall and traffic-changes were not noticed or that works were not documented in local files or the data register. As they are not in the National Archives or other repositories, it's plausible that site and instrument files (and possibly the data registers) have been deliberately destroyed, which is an issue that the Bureau must address.

- No sites have stayed the same. The Observatory is one of hundreds of Australian sites where ignored changes (most recently due to AWS and small screens) cause spurious trends, extremes and trends in extremes. Despite its importance, the Observatory is poorly researched and failures outlined here are symptomatic of the Bureau's ardent support of global warming at the expense of scientific rigor.

Consequences are also far-reaching. Faulty observatory data are used as a template to adjust ACORN-SAT sites at Cobar (48027), Walgett (52088), Gunnedah (55024), Williamtown RAAF (61078), Bathurst (63005), Richmond RAAF (67105), Nowra RAN (68072) and Moruya Heads Pilot Station (69018). Those datasets adjust others: Moruya Heads Pilot Station adjusts Sydney Observatory, Bathurst, Canberra (70014) and Dubbo (65070). Williamtown RAAF does Coffs Harbour (59040), Port Macquarie (60139), Scone (61363), Bathurst, Sydney Observatory and Moruya Heads Pilot Station. Canberra adjusts Dubbo, Nowra RAN, Moruya Heads Pilot Station and Bathurst. Gunnedah does Moree (53115), Inverell (56242), Dubbo and Bourke (48245). Dubbo adjusts Tibooburra (52088), Tibooburra, Alice Springs and so on.

Statistical circularity is obvious; resulting ACORN-SAT datasets are not independent and the entire ACORN-SAT network used to estimate Australia's warming is compromised by arbitrarily chosen (or ignored) changepoints, which result in spurious-trends.

- **It is concluded that temperature trends, frequency of extremes and trends in extremes at Sydney Observatory are due to site changes and don't reflect the climate.**

- **Trust in the Bureau is lacking. An open public inquiry into its operations, record-keeping, data-handling processes and procedures (and advocacy) is necessary and overdue.**

Acknowledgements.

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