Climate of the Great Barrier Reef, Queensland

Part 3. Climate change at Townsville

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Main points

- While climate scientists at the Bureau of Meteorology claimed "*There are no documented moves until one of 200 m northeast on 8 December 1994*" aerial photographs and Royal Australian Air Force plans and documents held by the National Library and National Archives of Australia show the Stevenson screen at Townsville airport moved at least three, possibly four times while it was on the eastern side of the main runway before 1969; and probably twice between when it moved to a mound on the western side in January 1970 and to the site of the current automatic weather station in December 1994.
- Not all site moves and changes affected maximum temperature (Tmax) but those that did (the move from the vicinity of the 1939 Aeradio office to the aerosonde hut probably in 1953/4; from east of the office to the mound in January 1970 and the documented move to the 60-litre screen and AWS in December 1994) account for all the warming. Tmin stepped-up in 1968, probably in response to nearby disturbances and shading during the late afternoon after the previous met-office was extended.
- Accounting simultaneously for site-related changes and covariates (rainfall for Tmax and Tmax for Tmin) leaves no residual trend, change or cycles attributable to the climate. Thus there is no climate change and no measurable warming.
- It is unequivocal that the Bureau's climate scientists ignored changes that happened, and adjusted for some that made no difference in order to create trends in homogenised data that have nothing to do with the real climate.

1. Background

Home to James Cook University's ARC Centre of Excellence for Coral Reef Studies[1], the Great Barrier Reef Marine Park Authority[2] the Australian Institute of Marine Science[3] and with collaborative links to the University of Queensland, The Australian National University, University of Western Australia and CSIRO; and the Great Barrier Reef Foundation and the Global Change Institute (both located in Brisbane), Townsville is the epicentre of multi-billion dollar research projects that focus on the Great Barrier Reef.

As all the institutes and their professors, the Government of Queensland and especially the Great Barrier Reef Foundation believe climate change is the single most important threat to the reef[4] it is timely to examine how the local climate has changed since records commenced at Townsville aerodrome in 1940.

The following study aims is to quantify changes in Townsville's climate and how those might impact on the Great Barrier Reef.

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[1] https://www.coralcoe.org.au/about/the-centre-of-excellence

[2] http://www.gbrmpa.gov.au/

[3] web@aims.gov.au

[4] E.g. http://www.gbrmpa.gov.au/our-work/threats-to-the-reef/climate-change and https://www.barrierreef.org/?gclid=EAIaIQobChMIp4XMrpSw3wIVGyQrCh3uWQfnEAAYASAAEgLXVPD_BwE

1.1 Data sources

Daily maximum and minimum temperature (Tmax and Tmin) for Townsville Aero (Bureau ID 32040) downloaded from the Bureau of Meteorology's Climate Data online facility were summarised into annual datasets using the statistical package *R*[1] and analysed using the same methodology case-studied in Part 1 of this series using data for Gladstone Radar. As data for 1940 are incomplete, analysis commenced in 1941. Data used in the study is given in Appendix 1.

1.2 History of the Townsville airport weather station

The original landing ground was established in the 1930s on a reserve about 9 km from Townsville south of a bend in the Ross River. Amalgamated Wireless Australasia established an Aeradio facility there for the Civil Aviation Board in 1939 to monitor aircraft and inform pilots of inclement weather between Brisbane and Port Moresby. The 20 by 14 feet (6 by 4.3 m) one-room office (National Archives of Australia (NAA) Barcode 1711911[2]) was manned by radio operators and observers trained by the Weather Bureau in Melbourne, whose duties included using theodolites to track weather balloons released at fixed-times to monitor windspeed and direction, observing surface weather usually at three-hourly intervals and preparing local forecasts and pre-flight briefings. Used as a fighter-base during WWII, maps in an NAA file (Barcode 171191) identify the cycle/walking path north of River Park Drive in the present-day suburb of Annandale (Latitude -19.30^{o} Longitude 146.79^{o}) as the original Ross River airstrip.

As the strip was boggy and restricted and not suitable for heavy aircraft, in 1939 the Council built another landing ground near the Garbutt meatworks railway siding north of the town. The new strip was immediately taken over by the Royal Australian Air Force (RAAF) as a forward operations base and developed into a heavy-duty multi-runway aerodrome, with the Council and Main Roads Commission undertaking construction. The Aeradio building, staff and equipment relocated to the civilian precinct (near the Ansett and ANA terminals) at Garbutt in about March 1940.

RAAF and Unites States Army Air Force (USAAF) meteorologists operated concurrently with Aeradio observers at least during the early days (Figure 1). RAAF meteorologists were housed separately (in Building 80), which was close to the HQ and signals buildings at the base while the USAAF's 15th Weather Squadron apparently occupied another building north of the civilian terminals. Archived maps and plans show the RAAF and Aeradio (and possibly the USAAF) operated separate meteorological (met) enclosures, hydrogen generators and theodolite tracking equipment (e.g. NAA Barcode 1724184; 32458325). In 1941 plans were drawn for a new RAAF operations room (NAA Barcode 10282256; Building 81) to house various functions including signals, meteorology, navigation and crew briefing, which appears to be the RAAF HQ (Figure 1). On its completion, the RAAF met-enclosure apparently moved to a stage on the roof of Building 81.

Also in 1940, Aeradio staff were conscripted as a unit of the RAAF and by 1942 met-operations had apparently consolidated within the small Aeradio office, which required an extension to be added as an annex (NAA Barcode 966914, p. 44). An aerodrome map and aerial photograph show the instrument enclosure in a grassy area northeast of the office.

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[1] R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

[2] Search by Barcode at: http://soda.naa.gov.au/barcode/

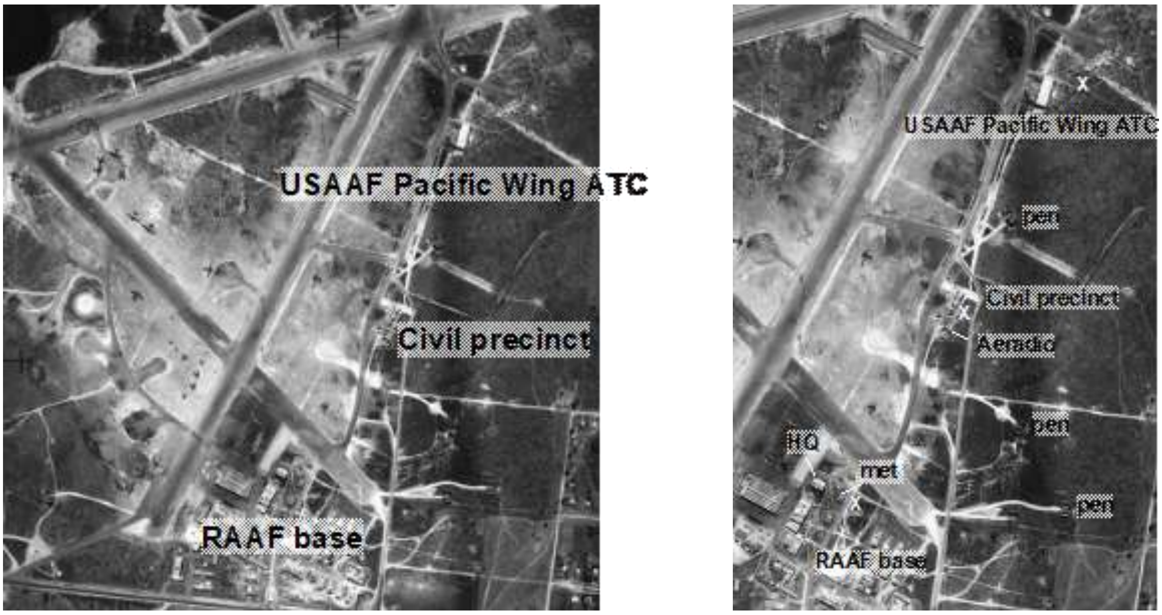

Figure 1. Garbutt aerodrome in 1943 (National Library of Australia uncatalogued print V293) showing buildings, aircraft dispersal areas, turning circles and splinter-proof pens. Prior to July 1943 the USAAF, Aeradio and RAAF operated separate meteorological enclosures (marked X). According to a file at the National Archives of Australia (NAA Barcode 966914) in 1944 the RAAF enclosure moved to the roof of "the signals and operations building No. 81". By 1942 the relocated 4-person Aeradio office from Ross River reportedly housed 17 met-staff: nine RAAF and eight USAAF personnel and the building was extended by a 12 m by 9 m annex, which is visible in subsequent aerial photographs.

By 24 April 1944[1] another operations centre (presumably civilian) and store (building W101 and W102) were built north of the civilian precinct and a new met-enclosure and hydrogen shelter were situated nearby (Figure 2). After wartime arrangements ceased in July 1946 Aeradio moved to the Department of Civil Aviation (and later became Flight Services) and met-officers moved to the Weather Bureau within the Department of the Interior (which later became the Bureau of Meteorology). In 1948 a new met-office was planned (NAA Barcode 5051556) with its axis parallel to the main runway but when built it was reoriented 90^{o}. At about the same time the former operations centre was refurbished as the terminal and Aeradio operators and met-observers were co-located in the new office.

According to NAA files, radio-aids offices were planned for Garbutt, Amberley, Cloncurry and Charleville airports in 1950 (e.g. NAA Barcodes 1021539 to 1021541). A February 1952 aerial photograph[2] and January 1954 aerodrome map (NAA Barcode 32458325) shows there were no developments west of the main runway until a new RAAF/DCA control tower and the Bureau's met-aids building were constructed the following year in 1955.

The Bureau's Garbutt instruments file (which is open and online at the National Archives of Australia (Barcode 12879364)) reports that on 6 March 1956 Cyclone Agnes blew down the Stevenson screen, which was near the aerosonde hydrogen shelter and all instruments were destroyed (p. 196). The replacement screen was apparently re-installed in a possibly pre-existing met-enclosure about 70 m east of the office (at Latitude -19.2558^{o}, Longitude 146.7722^{o} (estimated using Google Earth Pro)) where it remained in service until 1970.

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[1] Aerial photograph print 1132 (24 April 1944) https://nla.gov.au/nla.cat-vn4602228

[2] Aerial photograph print 5005 (1 February 1952) https://nla.gov.au/nla.cat-vn4602275

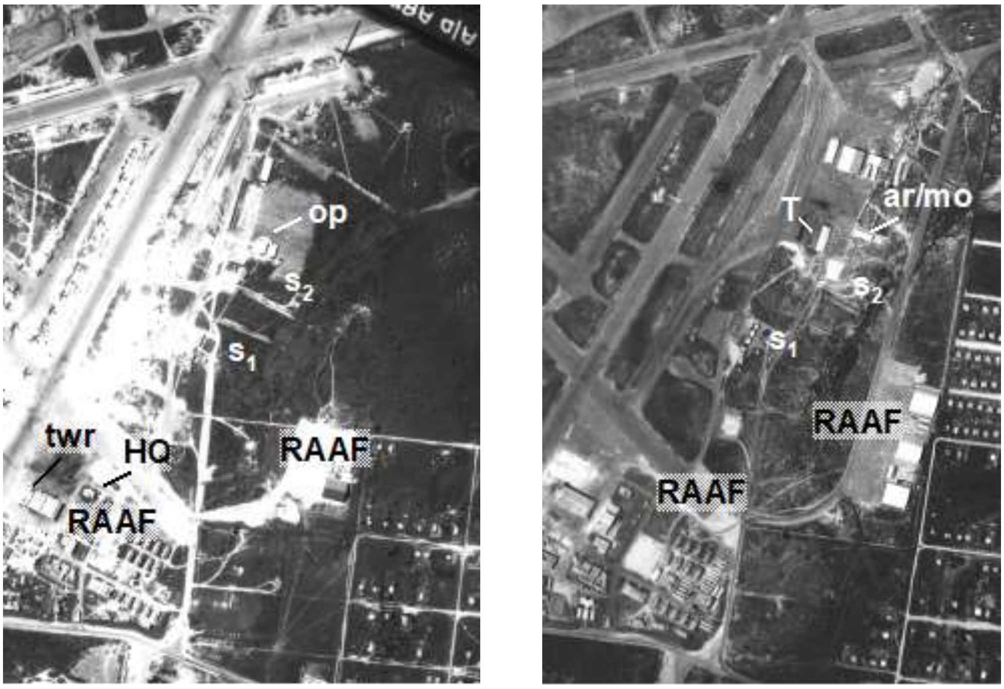
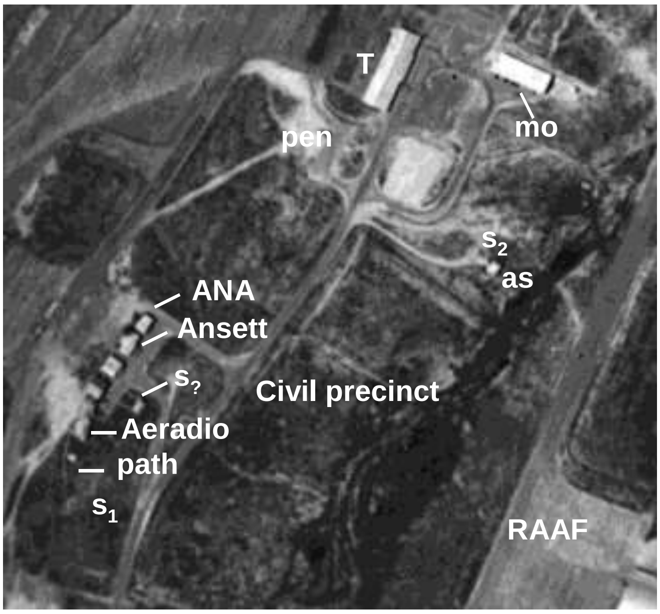


Figure 2. While the RAAF control tower (twr) was located at the end of the original hanger southwest of the HQ, a new operations (op) centre opened before 24 April 1944 (left). Also, while the Aeradio met-enclosure (S_1) appeared to be operating, another site (and hydrogen shelter) opened on a raised pad south of the op-centre (S_2). By 1 February 1952 (right) the op-centre has been reconfigured as the terminal (T), an Aeradio-met-office (ar/mo) was built perpendicular to the main runway and new RAAF hangers were in use. (In 1952 there were no buildings or developments west of the main runway.)

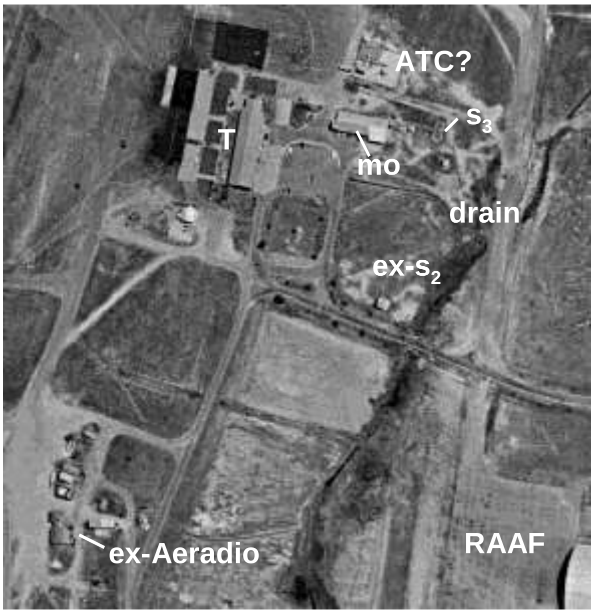
Further, in 1963 negotiations commenced with the RAAF to establish a new site, which would house all instruments and equipment in a single met-enclosure (instruments file p. 145). The location agreed to in 1965 was on the western side of the runway between the 1955 radio-aids building and new control tower complex (at Latitude -19.2510^o, Longitude 146.7660^o) (p. 111) (Figure 3). Specifications required the 100-foot (30 m) square area include a fenced 54-foot (16.5 m) square section built-up 3 ft (900 mm) above natural ground level topped with 12-inches (300 mm) of local topsoil and graded-off. Real-time temperature and humidity data sensed by a Fielden automatic weather station (AWS) located in the enclosure were to be relayed to the control tower and met-aids office. Building the enclosure and connecting telemetry cabling was completed by August 1968 (p. 74) and although observations commenced in 1969 it did not become the official site until 1 January 1970 (p. 69).

Shortly after the Garbutt Instruments file was closed-off (21 May 1974) another site commenced operating in the vicinity of the radio-aids office before 23 June 1976 (at Latitude -19.2500^o, Longitude 146.7663^o) (Figure 4). A new met-watch office was built 80 m west of the radio-aids building (which was subsequently demolished) and all staff co-located to the new office in February 1995. (The re-purposed met-office on the eastern side of the runway is still being used.) According to ACORN-SAT metadata[1], observations transferred to an AWS and 60-litre screen at a new, mounded site 100 m northeast of the office on 8 December 1994.

[1] http://www.bom.gov.au/climate/change/acorn-sat/documents/ACORN-SAT-Station-Catalogue-2012-WEB.pdf



February 1952 (https://nla.gov.au/nla.cat-vn4602275)



December 1960 (QAP1085017, Townsville-Cowley run 1 print 17.

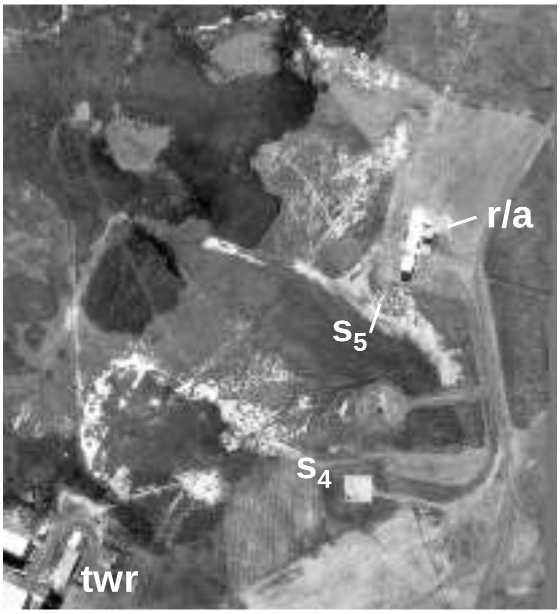
October 1972.

Close-up of the western side of the runway October 1972.

Figure 3. An overview of the various locations of the Townsville airport weather station before 1960 and the unconfirmed location of the aerosonde (as) site (S_2) (top panels). (A map (NAA Barcode 1724184) shows the original Aeradio site may have been located as indicated by $S_?$). Lower left: from 1 January 1970 observations transferred to a new site (S_4) west of the main runway, which was raised about 2 m above the natural ground level (Portion of Townsville aerodrome CAS623, run 10, print 20, 19 October 1972 (https://nla.gov.au/nla.cat-vn4602323). Note the various trench-lines laid for telemetry between remote sensors and the tower.

1.3 Metadata is unreliable

According to 27 July 2018 site-summary metadata, the 1940 Aeradio site was at Latitude -19.2492, Longitude 146.7647, which is the final location of the S_5 site shown in Figure 4. The ACORN-SAT catalogue states: "*Observations have been made at Townsville Airport since 1942. There are no documented moves until one of 200 m northeast on 8 December 1994, at which time an automatic weather station was installed. Observations at the new site were made under the original number, while the old site continued until December 2000 under the station number 032178*."



June 1976 (QAP32238483)

June 1992 (QAP5084165)

August 1995 (QAP5268210)

15 July 2002 (Google Earth Pro)

Figure 4. Changes at the Townsville radio-aids (r/a) office between 1976 and July 2002 (which is earliest Google Earth Pro satellite image) include that another site (S_5) operated south of the office before 1976 (upper-left); the radio-aids office was replaced by a combined met-watch office (mo) and observers previously housed east of the runway moved there in February 1995. The radio-aids building was demolished before August 1995 (lower-left) but the S_5 Stevenson Screen apparently continued to be used. No site was located at coordinates for the site referred to as 'Townsville Aero comparison' (032178) in 1995 (X); however the previous S_5 Stevenson screen moved there by July 2002.

The Bureau's Garbutt instruments file (p. 74, 191) indicates that the screen relocated from the radiosonde hut to near the office after Cyclone *Agnes* in March 1956 and that the radiosonde screen was sent to Boulia in October 1957 (p. 184). Aerial photographs and maps show it was the third (or fourth) relocation of the screen since it was originally installed near the Aeradio office in July 1940 (p. 229) (Figure 3). The file also details negotiations with the RAAF to establish the new mounded-site west of the runway and mentions that the protocol set out in Circular No. 66, para. 5(B) required observations to commence there from 1 January 1970. However there is no mention of the new site in metadata or of the three or four sites in the vicinity of the radio-aids/met-watch offices on the eastern side (Figure 4). Neither does metadata mention that a screen was installed south of the radio-aids building before July 1976 or that it moved again after 1995.

1.3.1 Uncertainties

High-level aerial photographs may be difficult to interpret and some features may not be well-contrasted depending on time-of-day and the angle from which they were taken. A map independently corroborates the original 1940 Aeradio site (designated $S_?$ in the February 1952 photograph in Figure 3). The path leading to an enclosure discernable in the original of the photograph points to the S_1 site. The S_2 site is difficult to identify possibly because there was no 'site' just a Stevenson screen used to baseline radiosonde flights, while the enclosure east of the office is clearly visible in 1952 but not 1947. A radiosonde building referred to the instrument file (p. 201) predates construction of the radio-aids facility on the western side of the runway but it is not referred to in any other file or plan available in the public domain. As there are no maps or aerial photographs available from QAP, Geosciences Australia or at the National Library between 1 February 1952 and 8 January 1959, site changes during that time could not be collaborated. Nevertheless, it is unequivocal that observations transferred to the mounded site on the western side of the runway on 1 January 1970. Later (probably around 1976) another Stevenson screen was installed at the radio-aids building and that screen moved after 1995.

2. Statistical analysis

As outlined in Part 1 of the series, linear regression partitions between variation caused by a physically related covariable (deterministic variation explained by the regression equation) and variation that is unexplained by the naïve case. Additional signals such as cycles, step-changes ((Sh)ifts) and oscillations due for instance to the El Niño southern oscillation, which are not accounted for result in non-random behaviour in residuals (Figure 5). Testing residuals for randomness, normality and independence verifies that hypothesised relationships reflect the data generating process only and not some other latent factor.

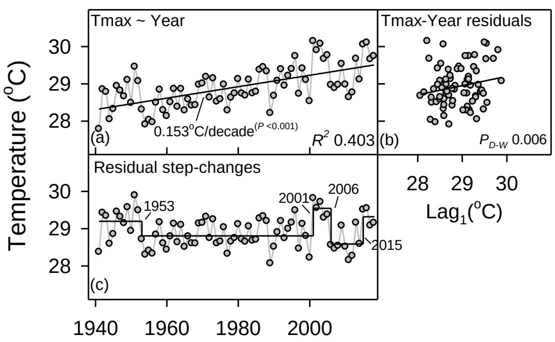


Figure 5. Naïve regression (a) suggests Tmax has increased 0.153oC/decade since 1940. However, although residuals (rescaled by adding grand mean Tmax) are normally distributed (P_{normal} =0.68; Anderson-Darling test) the lag1 plot (b) and Durbin-Watson test (*P*) shows that are autocorrelated. Furthermore, step-changes show residuals are not time-random (c). Thus although 40.3% of variation is explained by the naïve case, the model is faulty and does not depict the data generating process.

3 Results

3.1 Preamble

Statistical tools were 'blind' to historical aspects of the site detailed in Section 1.2 and site-summary (27 July 2018) and ACORN-SAT metadata, so the methodology, which was outlined in Part 1 is objective, independent of metadata and replicable. The approach also sidesteps the problem that not all site changes are documented and not all documented changes impact on data.

Step-change analysis combined with multiple linear regression with the physically causal covariate as the control, and analysis of residuals is used to identify and compare site-change scenarios that plausibly explain changes in Tmax and Tmin data. The required outcome is that: (i), segmented regressions are offset relative to the covariate (covariate-adjusted segment means are different); (ii), slopes are homogeneous (interaction is not significant); (iii), statistical assumptions are verified and where two models appear to be equally plausible, provided number of rows are the same, the Akaike information criterion (AIC)[1] is used to identify the most parsimonious. (As Stevenson screens may move to sites whose ambience is similar to a previous one, coincident segments are re-coded the same and reanalysed as a single group.)

3.2 Maximum temperature

Although all Tmax scenarios listed in Appendix 2 (Cases (iii) to (ix)) were all analysed and compared, only Case (ix) met the criteria that segmented regressions are parallel and offset relative to the covariate (rainfall) and that with all cases included, AIC of competing models (Case (vi) *vs*. Case (viii)) is minimised (Figure 6). It was found that mean-Tmax for the segment from 1941 to 1953 was the same as from 1970 to 1994 (Case (vii)) (i.e. separate relationships were coincident), thus those segments were re-coded the same and reanalysed as Case (viii); it was also possible that the step-change in 2015 (Case (v)) may be an artefact related to the shortness of the post-2015 record (i.e. more data is needed to confirm veracity of the step-change).

Case (viii) is finally analysed with suspected outliers omitted (Case (ix)). Although it seems like splitting hairs, the most parsimonious model provides the best estimate of the median-rainfall adjusted cumulative sum of site-related changes (0.83^{o}C for Case (vi) *vs*. 0.58^{o}C (Case (viii)) or with outliers omitted, 0.55^{o}C). Changepoints that don't fit the data such as Case (iv) and (v) result in wildly different step-sum estimates (0.99^{o}C and 1.18^{o}C) and are likely to be biased.

At each iteration residuals were examined for possible violations of linear regression assumptions, graphically, and using an overall global test (R package *gvlma*[2]). Outliers were also examined and data segments tested for within-segment trends (Table 1). (Data from 1954 to 1956 are problematic and further research suggests the site moved from the Aeradio site in 1953 or 1954 and the relocation in 1956 was not influential.)

Annotated within the caption, Figure 6 provides a graphical summary of Tmax analysis with shifts in Tmax ~ rainfall residuals aligned with changes that are either undocumented in Bureau metadata (the probable move in 1953/4 from the Aeradio site and the move to the mounded site in 1970) and the documented move to the current ASW site (where a 60-litre screen is used) on 8 December 1994. Pending receipt of additional data the shift in 2015 may or may not be significant ($P = 0.064$). (2015 was also the driest year since 1941 and therefore likely also to be the warmest climatically). The final model (Case (ix) in Appendix 2) is depicted in Figure 6(f). An influence plot indicates data for 1941, 1944 and 1958 are out of range and probably influential on trend but were not excluded or investigated further.

As residuals from the analysis are normally distributed, independent and variance is the same across categories (homoscedastic) no unexplained systematic rainfall-domain signal remains. Also, as no residual step-changes, trends or cycles are evident in the time-domain rainfall and step-changes in 1954, 1970 and 1994 account for all the warming in the data.

[1] Burnham, K.P, Anderson, D.R and Huyvaert, K.P. 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observations, and comparisons. Behav Ecol Sociobiol 65, 23-35. doi 10.1007/s00265-010-1029-6)

[2] https://cran.r-project.org/web/packages/gvlma/gvlma.pdf

Table 1. Trend analysis of individual data segments

Tmax segment	Raw data trend	*P*
Overall	0.153°C/decade	$P < 0.001$; R^2_{adj} 0.396
1941 to 1953	0.427°C/decade	ns
1954 to 1969	0.395°C/decade	$P = 0.022$; R^2_{adj} 0.274
1955 to 1969[1]	0.330 °C/decade	$P = 0.074^{ns}$; R^2_{adj} 0.166
1970 to 1994	0.124°C/decade	ns
1994 to 2018	0.096 °C/decade	ns

[1] Significance is due to data from 1954 to 1956, which are clustered below average.

[2] Reanalysed from 1955 the relationship is not significant (ns).

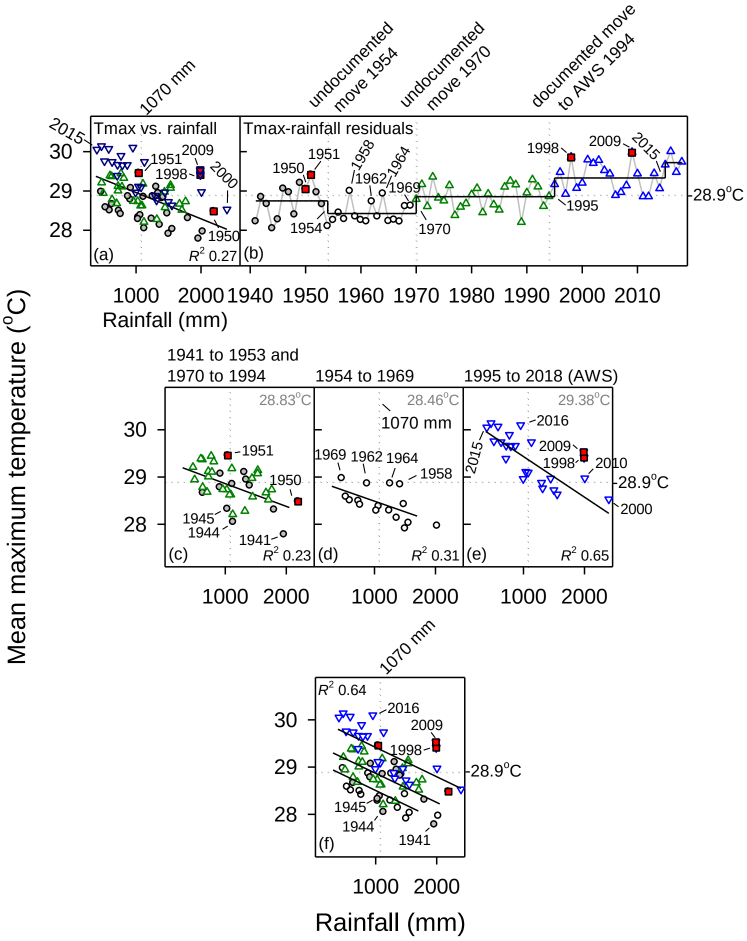


Figure 6. Due to outliers and embedded step-changes rainfall explained only 19.3% of Tmax variation overall (a). (Excluding data for 1950, 1951, 1998 and 2009 increased R_{adj} to 0.274.) Residual step-changes in (b) align with undocumented relocations in 1953/4 (from the Aeradio office to the aerosonde) and 1970 (when observations transferred to the western side of the runway). The move to the new AWS-site and 60-litre Stevenson screen in December 1994 increased mean Tmax from 24.46°C to 29.38°C (median rainfall adjusted). While there is no difference in mean-Tmax between 1941 to 1953 and 1970 to 1994, the site behind the office (1954 to 1969) was cooler possibly due to irregular watering or closeness to the drain. Ignoring outliers (red squares) and although data for 1958, 1962 and 1964 appear to be anomalous, individual regressions (c) to (e) are significant, lines are parallel and offset and together with rainfall explain 64.3% of Tmax variation.

2.3 Minimum temperature

Dependence of Tmin on antecedent temperature was firstly evaluated by repeated sampling of daily-Tmin, Tmax the previous day and rainfall, either as the amount of reported on the day or binary as rainfall incidence (ifRain, 1,0). Data were sampled randomly at the rate of 10% of rows/year from 1941 to 2018 using the R package *dplyr*[1].

For all of 10 rounds of sampling and analysis of the form (Tmin ~Tmax (+ Rain (or ifRain)) dependence on Tmax was highly significant (P <0.001) and including rainfall (or ifRain) increased variation explained from 58 to 60% (for Tmax alone) to 63 to 65% (including Rain or ifRain). Positive rainfall coefficients show Tmin was higher on cloudy, rainy days, which is consistent with cloudiness reducing emissions of longwave radiation from the landscape to space, which reduces nighttime cooling.

Sequential covariate analysis of Tmin scenarios (Appendix 2) found the step-change in 1968 (Case (iv)) [or ignoring outlier data for 1941 and 1951 (Case (vii))], more likely explains the data than forcing a supposed change in 1970 corresponding with the move (Case (viii)) (Figure 7). Relocating to the met-office following Cyclone *Agnes* in March 1956 also did not impact on Tmin.

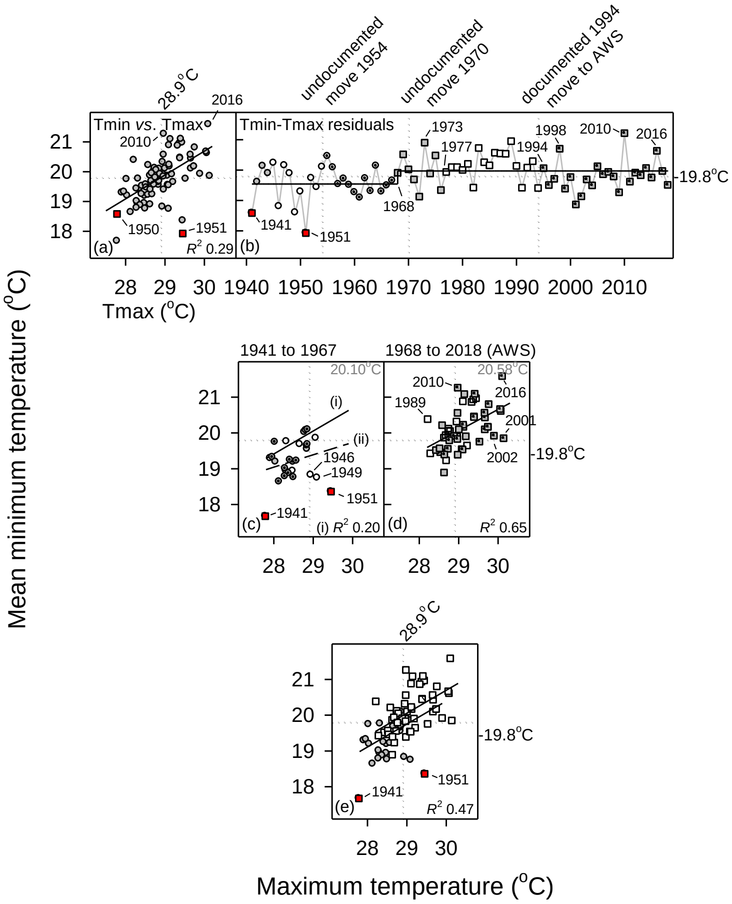


Figure 7. Despite three known and several undocumented site changes, a single step-change is detected in Tmin-Tmax residuals in 1968 (b). Free-fit regression lines in (c) show outliers in 1941 and 1951 skew the regression relative to that when they are ignored (i) resulting in regression (ii) being not significant (P = 0.21). Multiple linear regression of the step-change with Tmax shows lines are statistically parallel but as R^2_{adj} = 47% much variation is unexplained. Influence plots show data for 1949, 1972, 1989, 2001, 2010 and 2016 are influential (by Cooks distance) and out of range but were not ignored.

Segmented analysis shows that as trend before and after 1968 was not significant, the step-change model was more appropriate than a naïve trend model (Table 2). Case (vii) residuals are normally distributed, independent and homoscedastic and there is no residual trend or unaccounted-for signal in the time-domain. Warming in Tmin data is therefore due to the step-change not the climate.

[1] https://cran.r-project.org/web/packages/dplyr/dplyr.pdf

Table 2. As Tmin data consist of untrending segments joined by a step-change in 1969, the overall trend of 0.16°C/decade is spurious.

Tmin segment	Raw data trend	*P*
Overall	0.162°C/decade	P <0.001; R^2_{adj} 0.287
1941 to 1967	-0.158°C/decade	ns
1968 to 2018	0.088°C/decade	ns

4. Discussion

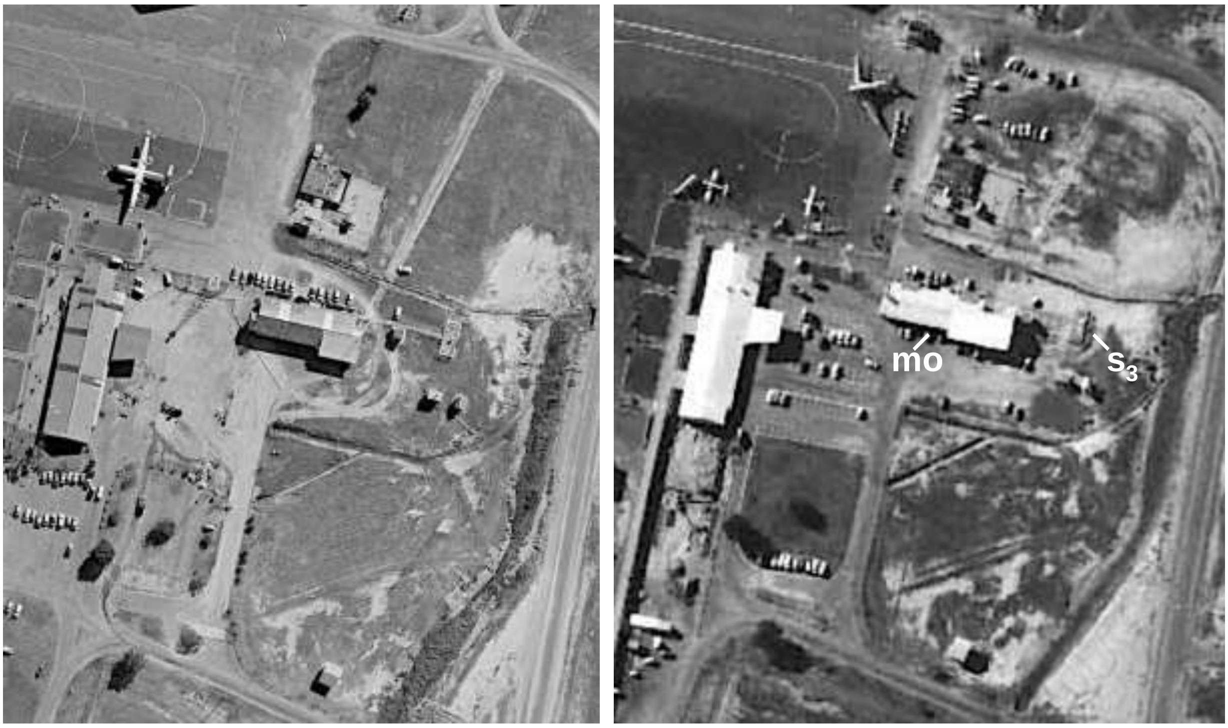
Although detected changepoints in temperature data were optimised and verified using independent statistical methods, three issues remain unresolved: (i), the timing of the move from near the original Aeradio office to the radiosonde site and the exact location of that screen in relation to the met-office; (ii), the cause of Tmin step-change in 1968; and, (iii), whether the up-step in 2015 is likely to be confirmed by future data.

There was evidence of a met-enclosure east of the new met-office in 1952; however, there is also a path and another enclosure south of the Aerado office (Figure 3). The instrument file mentions a radiosonde hut (Hut 16A on RAAF drawing 51/52/42A) existing in 1953 (p. 201) but the drawing is unavailable. As there were no buildings immediately north of the met-office in 1952 or west of the runway before 1955, the only obvious candidate is the isolated building on a raised pad between the met-office and the previous Aeradio site referenced 'as' in the Figure. The distinct step-down in Tmax in 1954 is consistent with the site moving to a cooler location. Whatever happened afterwards in the vicinity of the met-office (including relocating the screen after Cyclone *Agnes* in 1956 and extending the office before 1969) was not influential on Tmax.

Tmin increased abruptly and permanently in 1968 and aerial photographs show extensions to the eastern end of the office cast shade towards the enclosure in the late afternoon (Figure 8), also land was disturbed possibly in preparation for a car-park. Together those changes are the probable cause of the up-step. Changes before 1968, the move in 1970 and subsequently were not influential on Tmin, thus data consist of two untrending segments joined by a single discontinuity.

On-going changes in the vicinity of the weather station shown by time-lapse Google Earth Pro satellite images (15 July 2009 to 13 October 2017) include that herbicide is used irregularly to control vegetation (the site and its surrounds are generally bare of groundcover); and that earthworks commenced for construction of a building and car-park west of the site in May 2017. The building was completed by 26 July and occupied before 13 October. Hardstanding associated with another smaller development completed before 18 July 2017 is just 17 metres west of the Stevenson screen.

The site changed dramatically in a short space of time (Figure 9). Reducing transpiration by vegetation in the vicinity of the Stevenson screen also reduces the potential for cooling *via* the water cycle. Increased advection of sensible heat to the local atmosphere, in-turn increases Tmax (or causes spikes or over-ranging by the electronic AWS probe). Also, heat stored in buildings and hardstanding areas such as car parks during the day is advected to the local atmosphere at night, which increases Tmin. Changes are irreversible; the site is warmer and likely to remain warmer irrespective of the climate.



1 July 1965 at about 9.35 am (QAP15231119) 12 June 1969 at about 3.15 pm (QAP2011174)

Figure 8. Aerial photographs show the met-office was extended between July 1965 and June 1969. A memo in the Garbutt instrument file (p. 70; 29 October 1969) notes that extensions to the building "restricts the sun reaching the (sunshine recorder and actinograph) from 5 pm".

3 October 2009 13 October 2017

Figure 9. Google Earth Pro satellite images show developments in the vicinity of the Townsville airport met-enclosure are permanent and likely to impact on temperature measurements. Google Earth Pro measurement tools show hardstand areas to the west of the site are within 17 m of the Stevenson screen.

5. Conclusions

Despite its important as an ACORN-SAT site used to track Australia's warming, Townsville's temperature datasets are dominated by poorly catalogued site and instrument changes and with those correctively identified and verified there are no residual signals indicating the climate has changed or warmed. There is therefore no likelihood of adverse climate-related consequences on Barrier Reef ecosystems.

Author's note: Although this draft paper has been carefully researched and uses statistical tools, data and other evidence that is available in the public domain, the Author accepts no responsibility for errors of fact arising from the scarcity of information or photographs etc. whose interpretation is difficult.

Dr Bill Johnston (Draft version: 3 February 2020.)

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Appendix 1. Dataset used in the study

Count	Median		Average		Average			
78	1069.65		28.91534821		19.82316846			

Year	Rain	RainLag1	MaxAv	MaxN	MaxVar	MinAv	MinN	MinVar
1941	1964.1	1798	27.78109589	365	6.111207587	17.67506849	365	33.93764594
1942	1117.4	1964.1	28.84438356	365	6.553244468	19.55	360	17.75331476
1943	913.1	1117.4	28.77671233	365	8.201901249	20.02109589	365	18.34337242
1944	1128.5	913.1	28.04344262	366	8.117915787	19.19315068	365	20.85629911
1945	1034.4	1128.5	28.32093664	363	6.817626745	19.75906593	364	16.90716276
1946	1344.7	1034.4	28.93726027	365	8.438772693	18.82417582	364	26.23528169
1947	1402.8	1344.7	28.81404959	363	8.394636318	20.07	360	15.97057382
1948	633.1	1402.8	28.65824176	364	8.395772107	19.67978142	366	20.02791886
1949	1312.2	633.1	29.09972527	364	8.351542624	18.7478022	364	29.49947174
1950	2195.9	1312.2	28.47972603	365	8.36255487	18.9369863	365	19.73876562
1951	1042.3	2195.9	29.45287671	365	7.484586482	18.35917808	365	21.98676306
1952	923.5	1042.3	29.06593407	364	8.082582872	19.85384615	364	22.87202373
1953	1800.7	923.5	28.30438356	365	7.499211501	18.94725275	364	25.37390428
1954	1503.4	1800.7	27.90494505	364	6.810278509	19.29340659	364	17.46425393
1955	1561.1	1503.4	28.02630137	365	8.095350294	19.74410959	365	16.47521933
1956	2029.1	1561.1	27.96428571	364	9.937178276	19.32231405	363	21.20008082
1957	737.8	2029.1	28.48767123	365	6.696633298	19.18712329	365	16.8493667
1958	1422.7	737.8	28.83763736	364	7.338001014	19.64849315	365	17.11530679
1959	1242.5	1422.7	28.2862259	363	7.692295938	19.00493151	365	23.19327232
1960	1366.9	1242.5	28.13142077	366	7.07361277	18.63661202	366	24.14320383
1961	596.8	1366.9	28.50137363	364	6.495122075	18.75643836	365	22.62861915
1962	879.6	596.8	28.85796703	364	6.872525883	19.67835616	365	19.98142586
1963	1068.9	879.6	28.37651934	362	7.07875461	18.86997245	363	24.49216215
1964	1259.7	1068.9	28.85874317	366	7.310484991	20.08956044	364	17.97190173
1965	1032.7	1259.7	28.28109589	365	6.187031763	18.78159341	364	18.7968228
1966	532	1032.7	28.57753425	365	5.974164233	19.21780822	365	16.48817101
1967	766.8	532	28.40876712	365	8.572505344	19.24230769	364	19.13539521
1968	1482.8	766.8	28.42103825	366	8.186816453	19.51830601	366	19.63629411
1969	464.2	1482.8	28.97123288	365	8.075131718	20.56054795	365	16.73382387
1970	722.5	464.2	29.00520548	365	8.479066235	20.09862637	364	20.38129287
1971	1106.4	722.5	29.18109589	365	12.04538341	19.90357143	364	23.06012495
1972	1090.4	1106.4	28.62739726	365	7.752049526	18.89453552	366	23.60479198
1973	1531.3	1090.4	29.1430137	365	4.620205178	21.08383562	365	13.46778745
1974	1705.7	1531.3	28.5169863	365	7.472567816	19.5690411	365	24.16186858
1975	1447.5	1705.7	28.58054795	365	5.578164534	20.21452055	365	15.89327759
1976	1437.1	1447.5	28.97568306	366	8.613955012	19.39146006	363	30.60045173
1977	1319.8	1437.1	28.28027397	365	8.441752672	19.4290411	365	24.53360485
1978	1070.4	1319.8	28.62383562	365	8.995281951	19.86648352	364	20.80476887
1979	1025	1070.4	28.73452055	365	8.316167695	19.95111111	360	21.46434417
1980	721.8	1025	29.12213115	366	7.122056816	20.16857923	366	20.52172236
1981	1761.6	721.8	28.73342466	365	8.727121481	20.06153846	364	20.16165713
1982	701	1761.6	28.68109589	365	10.17263616	19.2361516	343	28.17968339
1983	781.8	701	29.10684932	365	10.37333208	20.88054795	365	18.97234036
1984	961.1	781.8	28.73961749	366	7.578343963	20.11967213	366	20.54569414
1985	629.6	961.1	28.78328767	365	11.16337378	20.05123288	365	27.22778007
1986	624	629.6	29.36986301	365	7.70216619	20.93543956	364	17.88036592
1987	767.6	624	29.44246575	365	7.454922475	20.96767123	365	20.50845747
1988	810.6	767.6	29.32650273	366	7.328857325	20.86502732	366	19.23488315
1989	1121.8	810.6	28.20931507	365	10.19771519	20.38575342	365	19.29644483
1990	1668	1121.8	28.67013699	365	13.57655081	19.93972603	365	23.24784058
1991	1530.2	1668	29.07479452	365	6.255351949	19.54520548	365	23.83759371
1992	597.8	1530.2	29.38743169	366	8.334252564	20.46202186	366	22.28954001
1993	496	597.8	28.94465753	365	5.831159566	20.31780822	365	16.12003914
1994	469.6	496	29.20958904	365	9.016253952	19.64767123	365	24.8200289
1995	709.8	469.6	29.38958904	365	9.669561644	20.44356164	365	22.13131146
1996	630.2	709.8	29.74027397	365	7.006258166	20.17021858	366	25.13064488
1997	1496.8	630.2	28.72465753	365	6.849445281	19.55808219	365	21.50908972

1998	1992.2	1496.8	29.40767123	365	6.531094837	21.09452055	365	15.19601385
1999	1076.4	1992.2	29.0969863	365	6.572545838	19.53753425	365	22.06042797
2000	2399.8	1076.4	28.53114754	366	7.304890186	19.46120219	366	22.89476458
2001	467.2	2399.8	30.14164384	365	6.419964323	19.85027473	364	25.68812665
2002	768.6	467.2	29.89561644	365	9.217068644	19.91972603	365	24.46785157
2003	580.4	768.6	30.06986301	365	6.593539816	20.61479452	365	18.29774755
2004	864.8	580.4	29.66420765	366	7.176934576	20.09836066	366	27.10684662
2005	513.6	864.8	29.76054795	365	10.17294475	20.80520548	365	20.18148382
2006	993.8	513.6	28.96164384	365	7.420392895	19.89890411	365	21.34807572
2007	1295.4	993.8	28.88	365	10.54187912	19.91369863	365	24.60953711
2008	1445.2	1295.4	28.96830601	366	8.147376301	19.83169399	366	23.18803383
2009	1989.4	1445.2	29.52849315	365	5.197592503	19.75753425	365	21.04228511
2010	2006.4	1989.4	28.97534247	365	4.815379347	21.26356164	365	13.50858618
2011	1551.4	2006.4	28.63424658	365	7.185060214	19.3939726	365	28.73562291
2012	1314.6	1551.4	28.76174863	366	9.910204057	19.79508197	366	21.8594278
2013	715.2	1314.6	29.6660274	365	7.104776757	20.43205479	365	18.08899714
2014	1037.2	715.2	29.11205479	365	8.358205931	20.22630137	365	21.05782282
2015	397.6	1037.2	30.05123288	365	7.866461388	20.66684932	365	21.59304636
2016	951.4	397.6	30.10081967	366	8.113451381	21.58465753	365	14.50520352
2017	789.6	951.4	29.65384615	364	6.941390125	20.56263736	364	18.95799413
2018	1129	789.6	29.7399449	363	7.990527069	20.17115385	364	22.95511602

Appendix 2. Scenario tests

	Scenario$^{(P)}$[1]	Segments	MeanT°C; (P_{same})[2]	P_{reg}; R^2_{adj} (AIC)[3]	Outliers omitted
Tmax					
i.	Tmax ~ Rain$^{(P<0.001)}$	na		<0.001; 0.193	
	Coeff: -0.053°C/100 mm rainfall)				
i_a	Tmax ~ Rain$^{(P<0.001)}$	na		<0.001; 0.274	1950, 1951,1998, 2009
	Coeff: -0.067°C/100 mm rainfall)				
ii.	Tmax ~ Rain$^{(P<0.001)}$ +RainLag1$^{(ns)}$	na		<0.001; 0.195	
iii.	Tmax ~ ShMax$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1968	28.58 (a)	<0.001; 0.551	
	Coeff: -0.043°C/100 mm rainfall	1969-1991	28.87 (b)	(70.75)	
		1992-2018	29.37 (c)		
		StepSum[4]	0.78°C		
iv.	Tmax ~ ShMaxRes$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1953	28.77 (a,b)	<0.001; 0.628	
		1954-1969	28.46 (a)	(na)	
	Coeff: -0.049°C/100 mm rainfall	1970-1994	28.89 (b)		
		1995-2014	29.36 (c)		
		2015-2018	29.76 (c)		
		StepSum	0.99°C		
v.	Tmax ~ ShMaxRes1$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1969	28.59 (a)	<0.001; 0.601	
		1970-1994	28.88 (b)	(na)	
	Coeff: -0.046°C/100 mm rainfall	1995-2014	29.35 (c)		
		2015-2018	29.77 (c)		
		StepSum	1.18°C		
vi.	Tmax ~ ShMaxRes2$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1969	28.60 (a)	<0.001; 0.581	
		1970-1994	28.89 (b)	(65.30)	
	Coeff: -0.049°C/100 mm rainfall	1995-2018	29.42 (c)		
		StepSum	0.83°C		
vii.	Tmax ~ ShMaxRes2a$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1953	28.78 (a, b)	<0.001; 0.608	
		1954-1969	28.46 (a)		
	Coeff: -0.051°C/100 mm rainfall	1970-1994	28,89 (b)		
	(Changepoints align with site moves.)	1995-2018	29.43 (c)		
		StepSum	0.66°C		
viii.	Tmax ~ ShMaxRes2b$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1953&		<0.001; 0.609	
		1970-1994	28.85 (a)	(59.93)	
	Coeff: -0.053°C/100 mm rainfall	1954-1969	28.46 (b)		
		1995-2018	29.43 (c)		
		StepSum	0.58°C		
ix.	**Tmax ~ ShMaxRes2b**$^{(P<0.001)}$ + Rain$^{(P<0.001)}$	1941-1953&		<0.001; 0.643	1950, 1951,1998, 2009
		1970-1994	28.83 (a)	(na)	
	Coeff: -0.062°C/100 mm rainfall	1954-1969	28.46 (b)		
		1995-2018	29.38 (c)		
		StepSum	0.55°C		
Tmin					
i.	Tmin ~ Rain$^{(P<0.015)}$	na		0.015; 0.063	Nil
	Coeff: -0.042°C/100 mm rainfall				
ii.	Tmin ~ Tmax$^{(P<0.001)}$	na		<0.001; 0.364	
	Coeff: 0.801$^{o}C_{min}/^{o}C_{max}$				
iii.	Tmin ~ $ShMin_{max}Res^{(P<0.001)}$ + Tmax$^{(P<0.001)}$	1941-1972	19.52 (a)	<0.001; 0.495	
		1973-1998	20.14 (b)	(na)	
	Coeff :0.618$^{o}C_{min}/^{o}C_{max}$	1999-2009	19.67 (a, b)		
		2010-2018	20.15 (b)		
		StepSum	0.62°C		
iv.	Tmin ~ $ShMin_{max}Res1^{(P<0.001)}$ + Tmax$^{(P<0.001)}$	1941-1967	19.96 (a)	<0.001; 0.474	
		1968-2018	20.56 (b)	(124.51)	
	Coeff :0.524$^{o}C_{min}/^{o}C_{max}$	StepSum	0.60°C		
v.	Tmin ~ $ShMin_{max}Res1.1^{(P<0.001)}$ + Tmax$^{(P<0.001)}$	1941-1968	19.44 (a)	<0.001; 0.472	
		1969-2018	20.04 (b)	(124.69)	
	Coeff :0.511$^{o}C_{min}/^{o}C_{max}$	StepSum	0.60°C		

vi.	Tmin ~ $ShMin_{max}Res2^{(P<0.001)}$ +	1941-1969	20.04 (a)	<0.001; 0.449	
	$Tmax^{(P<0.001)}$	1970-2018	20.57 (b)	(128.01)	
	Coeff :0.546$^{o}C_{min}/^{o}C_{max}$	StepSum	0.53^{o}C		
vii.	**Tmin ~ $ShMin_{max}Res1$**$^{(P<0.001)}$ +	1941-1967	20.10 (a)	<0.001; 0.470	1941, 1951
	$Tmax^{(P<0.001)}$	1968-2018	20.58 (b)	**(109.37)**	
	Coeff :0.552$^{o}C_{min}/^{o}C_{max}$	StepSum	0.48^{o}C		
viii.	Tmin ~ $ShMin_{max}Res2^{(P<0.001)}$ +	1941-1969	20.18 (a)	<0.001; 0.449	
	$Tmax^{(P<0.001)}$	1970-2018	20.59 (b)	(112.27)	
	Coeff :0.575$^{o}C_{min}/^{o}C_{max}$	StepSum	0.42^{o}C		

[1] *P* determined by Type-II analysis of variance; in all cases Sh_{factor} by covariate interaction is not significant (ns).
[2] Covariate adjusted segment means that are the same are followed by the same letter in parenthesis.
[3] Akaike Information Criterion (estimator of the relative quality of models applied to the same dataset) is given only for those where all factors are significant, segment means are different and number of rows is the same.
[4] StepSum is the overall median covariate adjusted change in T attributable to step-changes alone.