Climate of the Great Barrier Reef, Queensland

Part 2. Climate change at Cairns

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Main points

- Like many of the Bureau's historical datasets conditions affecting temperature measurements at the Cairns post office are largely unknown. As site changes in 1900 and 1924 occurred in parallel with observations an objective statistical method and *post hoc* attribution of changepoints as outlined previously for Gladstone Radar is preferable to relying on incomplete and possibly misleading metadata.
- Metadata incorrectly specifies location of the original aerodrome site near the 1939 Aeradio office and ignored the move to the mounded-site near the centre of the airport in 1966. Also ignored is that by September 1983 the site was moved again out of the way of a new taxiway. During construction when neither site was operational, aerial photographs show a fourth site was established on reclaimed land near the location of the current automatic weather station. Data from that site either in-filled the record or were used to adjust for the 1983 relocation. The highly significant step-change in 1986 plausibly marked when in-filling or adjustments ceased.
- Rainfall reduces Tmax 0.033^{o}C/100 mm and together with site changes accounts for 53.7% of Tmax variation. Step-changes at the post office in 1900, 1924 and 1929 and at the airport in 1986 caused 1.01^{o}C of warming in the data and there is no residual trend or change attributable to the climate.

1. Data sources

Daily weather observations are available for the Cairns post office (Bureau ID 31010) from 1 December 1889 and for Cairns airport (31011) from 22 October 1942. Post office data continued until 1953; however, in order to replicate ACORN-SAT[1], daily datasets were abutted from October 1942 and summarised into annual averages, counts of observations/yr and other attributes (Appendix 1).

2. Site changes at the post office and airport

No Australian weather station sites have stayed the same and as is the case for many historic datasets, recent (28 July 2018) site summary metadata for the Cairns post office provides no useful insights about conditions that affected early observations. A file at the National Archives of Australia (NAA) (Barcode[2] 3092148) and photographs, show the post office was moved and replaced in 1907-08 then replaced by a two-storey building in 1928. According to Torok (1996)[3] first correspondence with the Bureau was in April 1908; by 1924 the site was "hemmed in by buildings"; it moved in December 1929 to a "slightly more open site" then in 1943 observations transferred to the airport meteorological (met) office. Torok did not indicate when a Stevenson screen was first installed at the post office.

Established on a narrow strip of mangrove-mudflats and saltpans north of the town in 1934, the aerodrome was upgraded in 1936[4] to improve serviceability and the runway was reoriented on a

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

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

[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. p. 243 of 547 pp.

[4] https://trove.nla.gov.au/newspaper/rendition/nla.news-article41750487

sandy rise so it was not inundated during king-tides. Aeradio was established by Amalgamated Wireless Australasia for the Civil Aviation Board in 1939 to track aircraft and advise of inclement weather. Observers trained by the Weather Bureau used theodolites to track hydrogen-filled balloons to monitor windspeed and direction, undertook 3-hourly observations and made short-term forecasts (Figure 1). A 2012 station list (which is no longer in the public domain) places the original met-enclosure on the western side of the main runway northwest of the current general aviation precinct at Latitude -16.8736°, Longitude 145.7458°, which are the same coordinates as the current site. However, a 1959 aerodrome plan (NAA Barcode 1602351 p. 156) and a 1952 aerial photograph (Figure 1) shows the enclosure about 90 m north of the Aeradio office adjacent to the apron (Latitude -16.8820°, Longitude 145.7489°).

Figure 1. Cairns control tower, operations centre (behind) and the Aeradio met-office in *c*. 1959 (left). The 40-foot (12m) anemometer and windvane (usually mounted on the roof) charted windspeed, duration and wind direction. The signal square in front of the control tower was used for emergency visual communication with aircraft. Radio operators originally occupied one side of the 1940s Aeradio office and met-staff the other and a vestibule was used for pre-flight briefings. In 1946 post-WWII functions were split between the Department of Civil Aviation, which later became Flight Services (responsible for air-traffic control) and the Weather Bureau, which became the Bureau of Meteorology. (Photographed from airside courtesy of the Civil Aviation History Society (CAHS)). An airside view of the operating precinct in 1952 (right) shows the main hanger (h), control tower (t), operations centre (o), met-office (mo) and met-enclosure (m) (portion of QAP0298012[1]; 30 June 1952).

Recent site summary metadata (28 July 2018) places the 1941 Aeradio site on the eastern side of the main runway beside Swampy Creek implausibly some 1200 m distant from the office (Latitude -16.8872°, Longitude 145.7572°). However, a 1946 aerodrome-map (NLA Barcode 1724185), the 1959 aerial photograph in Figure 1 and aerial photographs in 1968 and 1984 (QAP1774012 and QAP4288118) show it was never located there. The ACORN-SAT catalogue[2] (p. 17) does not reference the original site, but notes that “In December 1992 the site moved 1.5 km northwest (to the other side of the runway)”.

In about 1960 negotiations commenced with the Department of Civil Aviation to relocate the instrument enclosure away from the terminal area, which together with runways and taxiways was to be redeveloped. Options were canvassed (NAA Barcode 1602351 p. 47 and 49); however, the suggested new location (p. 156) was rejected in favour of another site on swampy ground close to the 36-foot high (10.9 m) anemometer-mast near the centre of the airport (-16.8836°, 145.7489°) (p. 24). Work commenced in September 1965 to raise the level of the new site above the natural ground surface and observations transferred there early in 1966. Coincidently, upper-air wind-finding radar was installed in a new building across the road from the previous Aeradio met-enclosure.

[1] https://qimagery.information.qld.gov.au/

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

Between June 1982 and September 1983 the main runway was extended northwards and a start was made on constructing new aprons, terminals and facilities on reclaimed land on the eastern side of the airport. Developments included construction of a taxiway, which required the 1966 mounded site to be moved to another mound about 170 m southeast (Figure 2). During construction neither site was operational and a fourth site was apparently established on reclaimed land close to where the current automatic weather station (AWS) is located.

QAP4045227 (25 June 1982) QAP4193015 (11 September 1983)

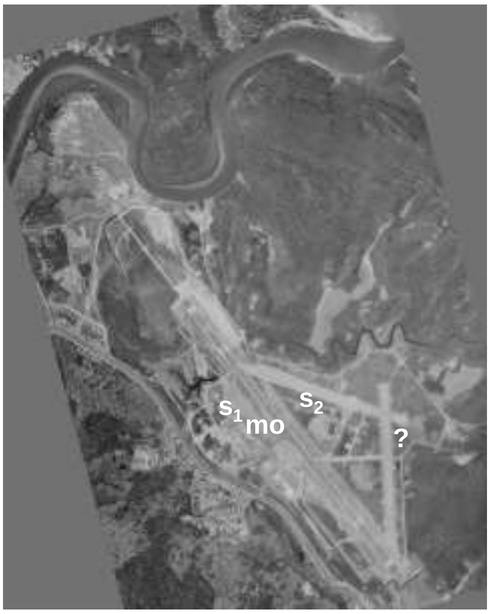
Figure 2. Changes at Cairns airport between June 1982 and September 1983 included lengthening of the main runway and changes to the WWII-era diagonal runways; commencement of construction of the new domestic and international terminals and associated works and construction of a N-S taxiway. According to metadata the wind-finding radar (wf) was installed in 1966. The original 1939 Aeradio site (S_1) moved to the centre of the airport (S_2) also in 1966. Construction of the taxiway required the site to move 170 m SE of its previous position before September 1983 (S_3) and a fourth site (S_4) was also established around that time close to the location of the current met-office and AWS site. (Sites S_2 and S_3 appeared not to be operational at the time of the photograph.) Metadata did not provide coordinates for the original (S_1) site neither is there a record of the site having moved in 1966 and 1983. Establishment of the S_4 site by September 1983 is not documented either. Considering that the S3 site was considerably disturbed, it appears that the S_4 site was used to in-fill data and smooth the transition between sites at least until 1985. Although Site S_3 is visible in the earliest Google Earth Pro satellite image (13 February 2002) it seems that observations ceased there in December 1992.

2.1 Metadata can’t be trusted.

Although critical to understanding factors affecting data, metadata mis-specifies location of the original site, timing of the moves in 1966 and before September 1983, establishment of the current site earlier than December 1992 and possible changes there, related to instrumentation (installation of a 60-litre screen is not specifically mentioned for instance).

In addition to site moves and changes, developments in the vicinity (Figure 3) also potentially affected data including lengthening of the runway to 1730 m in 1949, to 2020 m in the mid-1960s, 2600 m in 1982 and 3196 m in 1997. The potential for natural cooling was further reduced when some 65 ha of former open space was replaced by taxiways, hardstanding and new air-conditioned terminals 400 m east of the weather station between 1984 and 1997. Although such changes may not result in shifts in mean-Tmax, they may contribute additional variation (wind from certain directions may be warmer for example).

(a) 7 August 1952 (QAP0298012)



(b) 5 April 1968 (QAP1774012)

(c) 6 September 2005 (QAP6165059)

(d) Satellite image 10 October 2017

Figure 3. Time-lapse aerial photographs and a recent Google Earth Pro satellite image reveal extensions to the runways, development of new terminals and changes to the layout of Cairns airport between 1952 when it was a small military aerodrome and 2017 when it had one of the longest runways in Queensland. Also shown are the locations of the 1940s met-office and met-enclosure (mo and S_1), the 1966 and 1983 sites (S_2 and S_3) and location of the post-1994 AWS (S_4). There is no evidence that a met-enclosure was ever located beside Swampy Creek at Latitude -16.8872^o, Longitude 145.7572 ^{o} as stated in site-summary metadata (marked by the “?").

Part 1 of this series outlines the analysis approach, which is independent of metadata. Additional context is provided in this paper by also considering daily and annual rainfall.

3. Results

3.1 Rainfall

Although clustered into moist and dry epochs related to the El Niño southern oscillation, rainfall since 1890 is homogeneous and untrending (Figure 4).

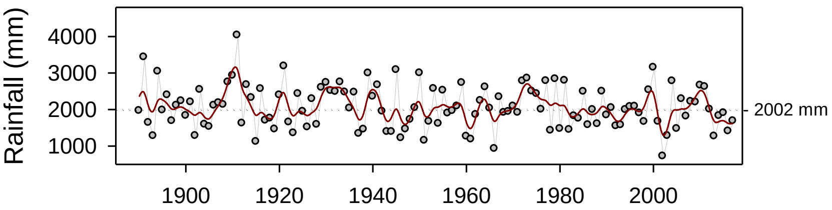


Figure 4. The spline curve ($Smooth_{PAST}$ = 7.0) tracks clustering of annual rainfall into moist and dry episodes. Overall trend is not significant (P_{unc} = 0.152) and there are no detectable shifts in the mean or meaningful cycles indicating the climate changed. (Median rainfall of 2002 mm is indicated by the dotted line.)

Frequency[1] of low rainfalls (rain/wet day <1 mm) was under-reported at the post office relative to the airport (~15% *vs*. 25% of raindays/year) and over-reported at the airport after 2002 (~30% of raindays/year). This caused the frequency of daily values less than the rainday median (4.3 mm/day) to be higher at the expense of rainfalls greater than 4.3 mm/day (Figure 5).

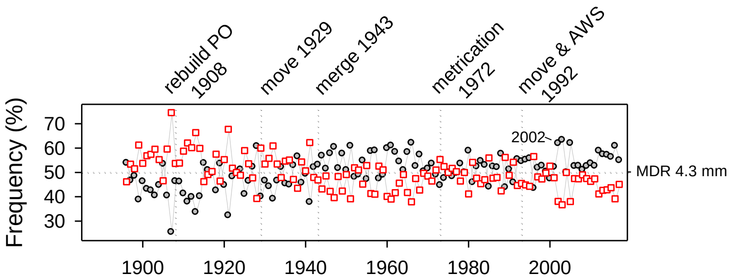


Figure 5. Deviations from the long-term median daily rainfall (MDR; 4.3 mm/day) are expected to be random and unrelated to site changes. However, daily rainfalls less than 4.3 mm were under-reported at the post office (small falls were either ignored or they accumulated in the gauge) and over-reported at the airport after 2002 (grey circles) and conversely for daily rainfalls >MDR (red squares). As frequency is affected by site changes in 1929, 1972 and after 2002, data are not homogeneous. (A 5-inch (127 mm) raingauge was used at the airport (*vs.* 8-inch (203 mm) at the post office) and it seems that measurements transitioned to a 203 mm tipping-bucket gauge after *c.* 2002 when manual observations probably ceased.) (By definition, frequency >MDR is mirrored by frequency <MDR.)

Additional detailed analysis (frequency of daily rainfall less than and greater than 10 mm/day; 25mm/day and greater than 100 mm/day) provides no evidence that the frequency of extreme rainfalls has increased or is likely to increase in the future.

3.2 Maximum temperature

As building developments that impact on Tmax data at the post office before 1933 are not detailed in metadata (Figure 6) their impact can only be determined statistically. Metadata also does not indicate when a Stevenson screen was first installed. Abutted post office data may also not be comparable with airport data (even if the mean is the same, variation and the incidence of extremes may be different for example). Developments at the airport after 1985 also resulted in a shift towards higher average Tmax.

[1] Daily rainfall frequency is expressed as percentage of raindays (rainfall >0.1mm) within classes or relative to the overall rainday median daily rainfall (MDR). (Because most days experience no rain the all-days median is zero. Distribution statistics are only sensibly calculated for days that experience rain and 50% of those days receive less than (more than) 4.3 mm.)

The sequenced analysis outlined in Part 1 is shown and annotated in Figure 7.

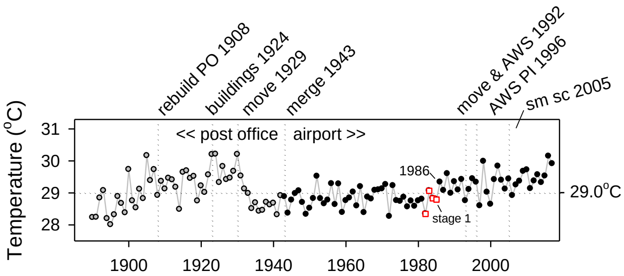


Figure 6. Abutted Cairns post office and airport Tmax aligned with documented site changes. Note that a Stevenson screen may not have been installed before 1900. The first stage of airport redevelopment from 1982 (red squares) included an extension of the main runway and construction of the terminal, control tower, taxiways and aprons and associated works east (seaward) of the runway.

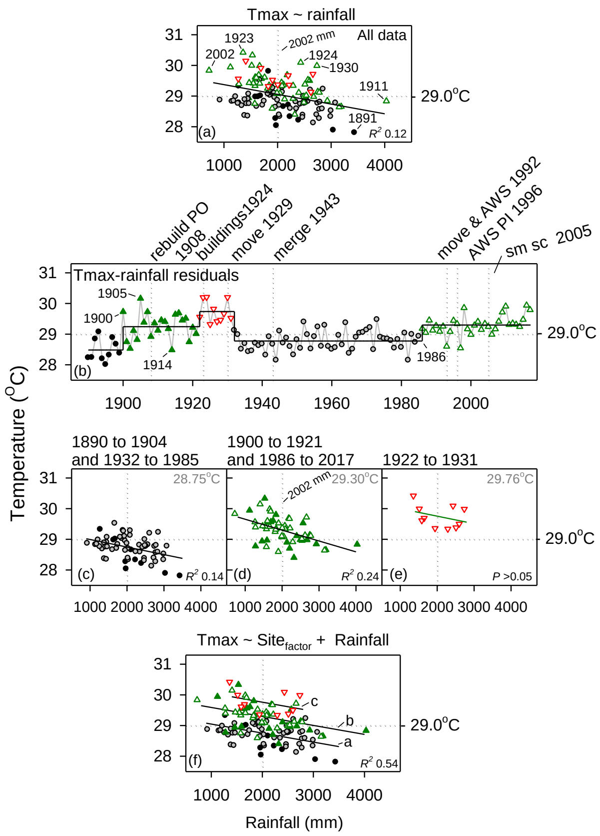


Figure 7. In (a) rainfall reduces Tmax 0.032°C/100 mm but the naïve relationship explains only 12.0% of Tmax variation. Variation that is *not* explained includes effects of site changes embedded in re-scaled Tmax-rainfall residuals (b). As the effect of rainfall on Tmax has been removed, step-changes in (b) (solid line) are due to some other factor. Segments whose median rainfall-adjusted means were the same (i.e. which are statistically coincident) are indexed the same (solid and open same-symbols) and reanalysed. Free-fit regressions ((c) to (e)) are parallel (responses to rainfall is the same) but relative to median rainfall and average Tmax (dotted lines) segment-means are offset (regressions are free-fit to show slopes are not coerced to be the same). Multiple linear regression (f) confirms that individual regression lines are parallel (interaction is not significant) and offset, rainfall reduces Tmax 0.029°C/100 mm overall and 53.7% of Tmax variation is explained.

Step-changes in Figure 7(b) cause 1.01°C of overall warming in the data. Multiple linear regression residuals are normally distributed and independent, variance is the same across categories and there is no residual overall trend indicating the climate has changed or warmed. *Post hoc* analysis of segmented trends also confirms that data consist of untrending segments separated by step-changes caused by site changes – buildings and redevelopment at the post office and a change at the airport in 1986, either due to developments east of the runway associated with Stage 1 construction of the new terminal complex, an undocumented move, or change resulting from smoothing the transition between the 1966 and 1989 sites. There is no evidence that the original Aeradio site was on the eastern side of the WWII-era N-S runway (which appears to have been decommissioned before 1968 (aerial photograph QAP1774012)) adjacent to Swampy Creek. As rainfall explains 19.4% of variation *not* explained by step-changes alone it is highly influential on Tmax.

5. Discussion and conclusions

5.1 Rainfall

While annual rainfall is episodic it is nevertheless homogeneous. However, the distribution of daily rainfall is affected by site and instrument changes (post office *vs*. airport and manual *vs*. tipping-bucket gauges). An increase in the average number of wet days from 133 to 154/yr in 1930 more likely reflected a change in exposure than a change in the climate. While frequency of raindays less than 25 mm/day has increased, frequency of rainfalls exceeding 25 mm/day is unchanged, thus there is no evidence that the frequency of daily extremes has increased.

5.2 Maximum temperature

Maximum temperature reflects interaction between atmospheric (synoptic) and local surface energy balance processes as modified by ambient conditions. The Tmax ~ rainfall relationship is highly significant ($P_{regZero}$ <0.001) but imprecise (R^2_{adj} = 0.120 (12.0%)). Known as *missing variable bias*, lack of precision arises because site-factors affecting observations at the post office and airport are not accounted for by the naïve case. The underlying problem is that exposure and orientation of the post office Stevenson screen and undocumented changes at the airport can't be resolved using metadata alone. Conditions in the post office yard are unknown while at the airport, location of the original Aerado site, subsequent relocations and possible adjustments to account for those using pre-1992 data from the current site are not detailed.

Metadata also does not describe other changes that possibly affected measurements. Reduced evaporation must increases heat advection to the local atmosphere and it is unlikely that replacing the post office with a larger 2-storey building in 1928 or replacing 65 ha of former mangrove flats with concrete, bitumen and air-conditioned multi-level terminals at the airport would not impact on temperature measured nearby. Furthermore, aerial photographs and Google earth Pro satellite images show the post-1992 airport site was infilled while bare ground indicates surrounding grass is sparse and unlikely to use water at the same rate as the vegetation it displaced.

- Despite repeated assurances by Bureau scientists that the history of ACORN-SAT sites has been exhaustively researched[1], metadata for Cairns is unreliable and misleading. The influential change in airport Tmax in 1986 is *most likely* due to adjustments made to account for the move from the 1966-mound to the new site in 1983, which is undocumented by metadata. Although site moves did not directly impact on Tmax it is nevertheless important that they (together with in-house adjustments to data) are diligently reported.

- Data consist of untrending segments disrupted by step-changes related to site changes. Changes at the post office in 1900 (possible installation of the Stevenson screen), 1924 (buildings) and 1929 (move) and the airport in 1986 directly result in 1.01°C of warming in Tmax data, which is unrelated to the climate.

- Rainfall reduces Tmax 0.033°C/100 mm and together with site changes accounts for 53.7% of Tmax variation. There is no residual signal indicating the climate has changed or warmed.

[1] E.g. http://www.bom.gov.au/climate/change/acorn-sat/documents/ACORN-SAT_Report_No_3a_WEB.pdf (p. 28)

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Appendix 1. Average annual Tmax and rainfall summarised from daily observations used in the analysis.

Year	Rainfall	AbsHiC	AbsLoC	YrAv°C	YrMedian	YrN	YrSkew	YrKurt	YrSD	YrVariance
1890	1965.8	34.6	19	28.26077	28.8	362	-0.40799	-0.17667	2.696629	7.271809
1891	3436.3	36	20	27.80139	27.6	360	0.135838	-0.68671	3.035147	9.212115
1892	1637.9	35.7	20.6	28.97328	29.4	363	-0.56543	0.124993	2.680815	7.18677
1893	1275.5	39.5	20.7	29.32	29.7	365	-0.11981	0.184058	3.052356	9.316879
1894	3041.9	37.9	21.2	27.88384	27.9	359	0.019498	-0.28281	2.876366	8.273481
1895	1979.1	35.1	19.9	28.03049	28.1	364	-0.25943	-0.56219	2.863829	8.201519
1896	2393.8	35.9	20.7	28.20955	28.4	335	-0.05832	-0.82596	3.00213	9.012783
1897	1684.5	36.6	22.7	29.00412	29.4	364	-0.06217	-0.56975	2.663209	7.092683
1898	2111.9	34.7	21.3	28.65344	28.8	363	-0.17666	-0.88374	2.857984	8.168075
1899	2232.6	36.7	17.3	28.32355	28.4	361	-0.10043	-0.07025	3.111944	9.684194
1900	1832.8	37.2	22.8	29.80531	30.1	320	-0.48337	0.801874	2.13314	4.550285
1901	2203.7	36.1	21.1	28.70347	28.9	346	-0.23177	-0.45596	2.884419	8.319872
1902	1278.6	37.4	21.8	28.77765	28.75	340	0.062712	-0.84282	3.234179	10.45991
1903	2542.3	38.4	22.8	28.95937	28.9	347	0.258764	-0.27051	2.821755	7.962304
1904	1590.5	35.6	22.2	28.96914	28.9	324	-0.06845	-0.74687	2.745236	7.53632
1905	1530.3	37.8	22.8	30.33371	30.6	267	-0.1504	-0.75467	3.021649	9.130363
1906	2111	34	22.8	29.36921	29.4	315	-0.22092	-0.54007	2.39359	5.729272
1907	2179	37.8	20.6	29.68886	29.4	350	0.107125	-0.66734	3.144753	9.889474
1908	2131.7	37.3	21.7	28.8989	28.9	365	0.110468	-0.62889	3.085067	9.517636
1909	2750	35.3	23.1	29.14254	28.9	355	0.020875	-0.6735	2.456783	6.035785
1910	2927.7	36.4	20.2	28.84588	28.3	364	-0.01046	-0.40088	2.915742	8.501553
1911	4031.1	38.4	21.1	28.8326	28.8	365	0.009225	-0.63847	3.138726	9.851599
1912	1620.4	37.2	22.2	29.54701	30	334	-0.1377	-0.72622	2.824109	7.975592
1913	2673.8	36.2	21.2	28.98061	28.8	361	0.088826	-0.95816	3.155817	9.959179
1914	2320.5	38.4	21.1	28.40164	28.3	365	0.168176	-0.19504	3.245131	10.53088
1915	1119.5	39.2	23.3	29.94214	30	337	0.090703	0.05573	2.750585	7.565719
1916	2566.5	37.7	21.9	29.53068	29.7	365	-0.09132	-0.95814	3.105055	9.641364
1917	1697.4	35.5	20.6	29.56923	29.8	364	-0.32756	-0.57478	3.124001	9.759381
1918	1757.2	37.2	21.4	29.60959	29.2	365	0.028737	-0.94006	3.363882	11.3157
1919	1460.4	37.2	20.6	28.93846	28.85	364	0.069131	-0.89212	3.098112	9.598296
1920	2395.8	35	20.9	29.11066	29	366	-0.06895	-0.39505	2.595258	6.735366
1921	3185.9	34.9	21.7	28.65808	28.4	365	-0.04818	-0.50033	2.413042	5.822771
1922	1649.8	38.4	17.5	29.69011	30	364	-0.23598	-0.12196	3.331023	11.09571
1923	1356.1	43.2	23.3	30.42247	30.3	365	0.353712	0.350758	3.15551	9.957241
1924	2431.1	40	23	30.0929	30	366	0.269648	-0.33985	3.209831	10.30302

1925	1944.6	37.4	22.2	29.36006	29.1	363	-0.02284	-0.64931	2.853316	8.141411
1926	1517.1	35.6	23.9	29.99616	30	365	-0.25778	-0.37786	2.335756	5.455754
1927	2290.5	37.8	18.1	29.34093	29.4	364	-0.1442	0.575454	2.786182	7.76281
1928	1584.2	36.1	22.6	29.61315	30	365	-0.29121	-0.75632	2.85142	8.130596
1929	2598	40.6	18.9	29.50169	29.4	355	0.082559	-0.26503	3.350394	11.22514
1930	2733.5	36.7	23.9	29.98926	30	363	-0.05803	-0.52245	2.481294	6.156818
1931	2510.3	39.4	22.7	29.3843	29.4	363	0.335693	0.187882	2.621132	6.870333
1932	2485.9	35	22.2	28.98849	30	365	-0.37611	-0.98198	2.977919	8.867999
1933	2750.1	38.3	20.6	28.76575	28.9	365	-0.093	-0.6565	3.093356	9.568851
1934	2473.5	38.9	20.8	28.37555	28.3	364	0.270537	0.328083	2.986735	8.920585
1935	2033.2	41.4	20	28.69589	28.3	365	0.583201	0.421662	3.480402	12.1132
1936	2470.5	36.7	14.7	28.29563	28.3	366	-0.58724	1.673647	2.75019	7.563542
1937	1335.2	36.9	21.4	28.68192	28.8	365	-0.1804	-0.16021	2.799392	7.836595
1938	1453.3	35.3	14.3	28.89835	29.15	364	-0.7104	1.338766	2.706038	7.322642
1939	2993.5	37.7	21.4	28.32849	28.2	365	-0.02121	-0.45117	2.671699	7.137977
1940	2354	36.8	23.2	28.58301	28.3	365	0.226069	-0.7031	2.723733	7.418722
1941	2670	36.6	22.3	28.12164	28	365	-0.01883	-0.75765	2.678649	7.175162
1942	1948.5	37.1	20	28.94959	28.9	363	0.119869	0.795044	2.350577	5.525214
1943	1390.6	37.9	22.2	28.88122	29.25	362	2.72E-05	0.773237	2.478714	6.144023
1944	1387.6	35.8	20.9	28.36236	28.55	356	0.05891	-0.64362	2.893293	8.371143
1945	3083.4	34.2	21.7	28.773	28.8	363	-0.10854	-0.5777	2.521036	6.355623
1946	1218.2	37.2	22.3	28.97562	29.1	365	0.00918	-0.54792	2.752089	7.573992
1947	1461.1	36	22.4	29.06088	29.1	363	0.004363	-0.784	2.680462	7.184874
1948	1722	35.7	19.9	28.70082	29.15	366	-0.29455	-0.74546	2.685644	7.212684
1949	2043.1	36.3	20.9	28.32727	28.4	363	-0.15685	-0.84297	2.944233	8.668508
1950	2998.6	35.5	19.5	28.51934	28.4	362	-0.09452	-0.41206	2.802682	7.855027
1951	1149.9	36.8	22.4	28.82192	28.9	365	-0.13285	-0.73746	2.580817	6.660617
1952	1670.3	36.1	21.8	29.51753	29.7	365	-0.35078	-0.59875	2.638029	6.959197
1953	2569.3	34	22.6	28.82055	29.3	365	-0.22184	-0.96698	2.676791	7.165208
1954	1611.2	33.9	22.2	28.65604	28.7	364	-0.12175	-1.01749	2.694652	7.261148
1955	2520.7	35.6	21.1	28.77225	28.9	364	-0.26758	-0.40043	2.636243	6.949779
1956	1895.6	36.8	20.4	29.28443	29.6	366	-0.08169	0.143201	2.767087	7.65677
1957	1960.8	35.1	21.7	28.63151	28.8	365	-0.10941	-0.7184	2.541354	6.458483
1958	2089.7	39	22.3	29.27699	29	365	0.401619	0.514071	2.580243	6.657656
1959	2731.9	37.2	20.6	28.38521	28	365	0.309379	-0.53459	3.206381	10.28088
1960	1262.6	37	21.3	28.75656	29.3	366	-0.30084	-0.46776	2.829686	8.007121
1961	1182.8	34.5	20.6	28.83644	29.1	365	-0.2926	-0.74433	2.790046	7.784355

1962	1858.6	35.1	22.4	29.02198	29.35	364	-0.31942	-0.7956	2.701782	7.299626
1963	2240	37.4	21.9	28.58984	28.65	364	-0.07975	-0.03792	2.638647	6.962458
1964	2614.8	37.4	22	29.19274	29.5	358	-0.19373	-0.23639	2.434234	5.925493
1965	2031	34.5	19.3	28.38137	28.5	365	-0.45064	0.03034	2.51375	6.318938
1966	928.1	37.2	23	28.86621	29.1	364	-0.03706	-0.26724	2.396091	5.741252
1967	2340.3	40.4	19.5	28.80879	29.1	364	0.240019	0.831302	2.833581	8.029179
1968	1912.4	34.4	21.7	29.07808	29.4	365	-0.39245	-0.60088	2.522952	6.365288
1969	1938	38.9	21	29.09479	29.3	365	-0.09632	0.405376	2.606385	6.793242
1970	2090.6	35.1	18.7	29.12274	29.2	365	-0.303	0.167059	2.432383	5.916487
1971	1912	39.4	20.7	29.25956	29.2	361	0.31045	0.320514	2.992876	8.957304
1972	2780.1	36.7	21.4	28.26257	28.15	366	0.249745	-0.34814	2.750939	7.567664
1973	2851.8	35.5	23	29.22356	29.3	365	-0.06038	-0.18911	2.161322	4.671311
1974	2498.5	36	20.8	28.75726	29	365	-0.2249	0.066825	2.405644	5.787124
1975	2428	36.6	21	28.73452	28.9	365	-0.34961	0.232602	2.290248	5.245234
1976	2000.1	35.8	22.1	28.86311	28.6	366	0.101484	-0.52554	2.732359	7.465786
1977	2783.9	37.1	21.4	28.56192	28.5	365	0.090497	-0.26805	2.540259	6.452914
1978	1425	36.1	22.2	28.74493	28.7	365	-0.0288	-0.06218	2.297121	5.276767
1979	2835.8	33.5	21.3	28.57836	28.8	365	-0.28379	-0.39971	2.38665	5.696096
1980	1471.8	35.1	22.7	28.75068	28.8	365	-0.05462	-0.6181	2.423722	5.874429
1981	2793.6	36.3	23.2	28.79918	28.7	365	0.260999	-0.33581	2.478141	6.141181
1982	1445.4	36.5	22	28.34451	28.3	364	0.118577	-0.71201	2.925832	8.560493
1983	1821.8	37.5	19.8	29.06411	29.4	365	-0.11669	-0.14642	2.745996	7.540494
1984	1752	39.2	21	28.8306	29	366	-0.08256	0.878366	2.446858	5.987116
1985	2490.2	35.8	21.6	28.79066	29	364	-0.25298	-0.64679	2.821468	7.960684
1986	1578.2	36.6	23	29.33709	29.35	364	-0.04769	-0.45181	2.44891	5.997161
1987	1993.4	36.9	21.6	29.07445	29	364	-0.11347	-0.50143	2.632752	6.931384
1988	1602.2	37	22.8	29.59781	29.75	366	0.049365	-0.24021	2.558691	6.546899
1989	2493.4	35.4	21.8	28.98626	29.2	364	-0.51145	-0.28634	2.671929	7.139205
1990	1842.2	36.6	20.5	29.3467	29.4	364	-0.19245	-0.40845	2.899476	8.406959
1991	2046	39.1	22.5	29.08956	29.1	364	0.201843	0.005981	2.449108	5.998128
1992	1546.8	39.1	22.7	29.41885	29.4	366	0.399928	0.485651	2.723515	7.417534
1993	1574.2	37.7	22.3	28.75315	28.6	365	0.250583	-0.01715	2.389025	5.707442
1994	1990.4	40	22.5	29.10575	29	365	0.383083	0.129853	2.932781	8.601203
1995	2074.8	40.5	19.1	29.43945	29.8	365	-0.04453	0.48467	3.074359	9.451681
1996	2083	36.4	21	29.33224	29.65	366	-0.1978	-0.25317	2.430897	5.909259
1997	1899.8	33.4	21.7	28.59562	28.7	365	-0.20647	-0.66652	2.364407	5.59042
1998	1664.8	37.2	22.6	29.98521	30.1	365	-0.25863	0.316229	2.188996	4.791704

1999	2534.6	35.7	20.8	29.01945	29	365	-0.13031	0.358503	2.278008	5.189318
2000	3148.8	34.9	21.5	28.64	28.9	365	-0.45264	-0.3258	2.506659	6.283341
2001	1667.8	36.4	24.2	29.41205	29.3	365	0.172774	-0.51498	2.22658	4.957656
2002	721	37.4	23.3	29.83315	30.1	365	-0.05813	-0.53085	2.500488	6.252442
2003	1279.2	35.6	23.4	29.39479	30	365	-0.3715	-0.73189	2.400641	5.763077
2004	2777.6	35.2	22.7	29.11448	28.9	366	-0.04281	-0.63008	2.377943	5.654612
2005	1470.8	36.1	22.1	29.43151	29.4	365	-0.11018	-0.7803	2.786776	7.76612
2006	2289	35.3	22.5	28.91671	28.9	365	-0.0701	-0.60605	2.459523	6.049253
2007	1813	37	21	29.24712	29.8	365	-0.52011	0.042072	2.779126	7.723543
2008	2215.2	36.4	22	29.36466	29.6	365	-0.19547	-0.31214	2.655625	7.052346
2009	2199.4	33.9	22.6	29.67315	29.9	365	-0.48423	0.03418	2.017626	4.070816
2010	2659.8	36.9	23.4	29.71753	29.8	365	0.121298	0.277769	2.094569	4.387219
2011	2623.2	35.8	22.5	29.13096	29.5	365	-0.1813	-0.70359	2.437212	5.94
2012	2003.4	34.9	21.9	29.36967	29.8	366	-0.38421	-0.50367	2.709149	7.339489
2013	1268.6	38.6	23.8	29.56548	29.5	365	0.299878	0.44112	2.365796	5.596992
2014	1826.6	34.8	20.3	29.31973	29.5	365	-0.38675	-0.09602	2.570414	6.607027
2015	1906.4	36.5	22.5	29.52712	29.4	365	0.013212	-0.30972	2.544646	6.475224
2016	1406.4	37.9	23.7	30.14836	30.4	366	-0.12508	-0.45576	2.547485	6.489682
2017	1688.6	36.2	23.3	29.90986	29.7	365	-0.13507	-0.4081	2.461642	6.059683

Appendix 2. Tmax scenarios. Sh refers to $shift_{factors}$ that define respective data segments. (Segments whose median-rainfall adjusted means are the same are coincident and are combined in second-round analysis.)

Model	Segments	Seg. Mean (°C)[1]	Coefficient$^{(P)}$ (°C/100 mm)	R^2_{adj}
(i) Tmax ~ rain	na	Na	$0.032^{P<0.001}$	0.120
(ii) Tmax ~ ShMaxRes + rain	1890-1899	28.50 (a)	$0.028^{P<0.001}$	0.554
	1900-1921	29.26 (b)		
	1922-1931	29.76 (c)		
	1932-1984	28.80 (a)		
	1985-2017	29.32 (b)		
(iii) Tmax ~ ShMaxRes1 + rain	1890-1899 & 1932-1985	28.74 (a)	$0.029^{P<0.001}$ (AIC[2] 99.21)	0.537
	1900-1921 & 1986-2017	29.29 (b)		
	1922-1931	29.76 (c)		
	$Delta_{overall}$	1.01°C		
(iv) Tmax ~ ShMaxRes2 + rain	1890-1904	28.67 (a)	$0.032^{P<0.001}$	0.534
	1905-1931	29.50 (b)		
	1932-1985	28.80 (a)		
	1986-2007	29.20 (b,c)		
	2008-2017	29.57 (c)		
	$Delta_{overall}$	0.90°C		
	Interaction	***P* = 0.033**		
(v) Tmax ~ ShMaxRes3 + rain	1890-1904 & 1932-1985	28.77 (a)	$0.033^{P<0.001}$ (AIC 99.90)	0.534
	1905-1931& 2008-2017	29.52 (b)		
	1986-2007	29.20 (c)		
	$Delta_{overall}$	0.43°C		

[1] Values followed by the same letter are not different.

[2] AIC Akaike information criterion which measures the relative quality of alternative models describing the same dataset.

Analysis is resolved when:

(i) Median-rainfall adjusted differences between segment means are different (Cases (iii) and (v))

(ii) Interaction is not significant (Case (iv) fails the criterion).

(i.e. individual regressions are parallel and offset.)

Subsidiary requirements are that AIC is minimised and that residuals are normally distributed, independent (not autocorrelated) and variance is the same across Sh_{factor} categories (variance is homoskedastic).

Case (iii) is the most parsimonious statistical description of the data.