THE NEW ZEALAND CLIMATE SCIENCE COALITION

Supplementary Information: Statistical Audit of the NIWA 7-Station Review

July 2011

This report documents the detailed individual station adjustments for site changes for the six stations not covered in the main NZCSC report "Statistical Audit of the NIWA 7-Station Review".

Background

This document is designed to be read in conjunction with the New Zealand Climate Science Coalition's main report on the NIWA 7-station temperature series for New Zealand. It presents the detailed adjustments made to each of the six stations not covered in detail in that report. The stations are:

- Lincoln
- Hokitika
- Nelson
- Masterton
- Auckland
- Wellington

Lincoln

We examine the Lincoln temperature series, to determine if there are any differences between the results obtained using the R&S and NIWA methods. The following sections detail this process.

We have used the same station data NIWA used, and the same station shifts have been examined. Similarly, the same neighbouring stations have been used for comparisons.

Site Change in 2000

NIWA Result

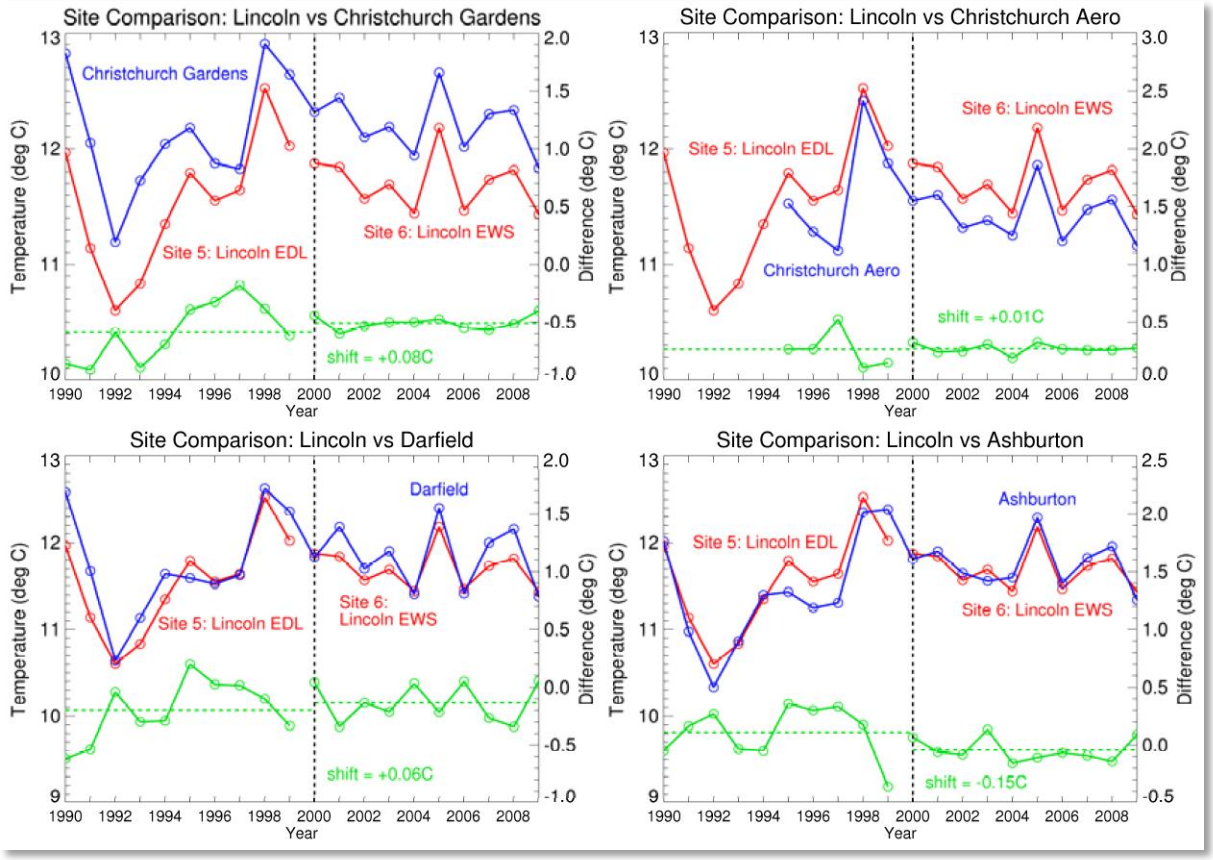


Figure 1: NIWA comparisons with Lincoln 2000

The background to the examination of this site change is given in the NIWA document detailing the Lincoln composite series (pgs 5-8)[1]. The Lincoln Broadside EDL/EWS (agent 4882/17603) changeover series is compared to Christchurch Gardens (agent 4858), Christchurch Aero (agent 4843), Darfield (agent 4836), and Ashburton Council (agent 4778).

NIWA finds an overlap of 0.26°C but regards the timescale to be too short, and uses their neighbouring stations comparison method to calculate a shift of **0.0°C** for the 2000 adjustment (+0.08 +0.01 +0.06 -0.15)/4 °C.

[1] "Creating a Composite Temperature Series for Lincoln" http://www.niwa.co.nz/__data/assets/pdf_file/0004/108886/Lincoln_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

The overlap period is 10 months. The Lincoln Broadside EWS minus EDL difference plot is shown below.

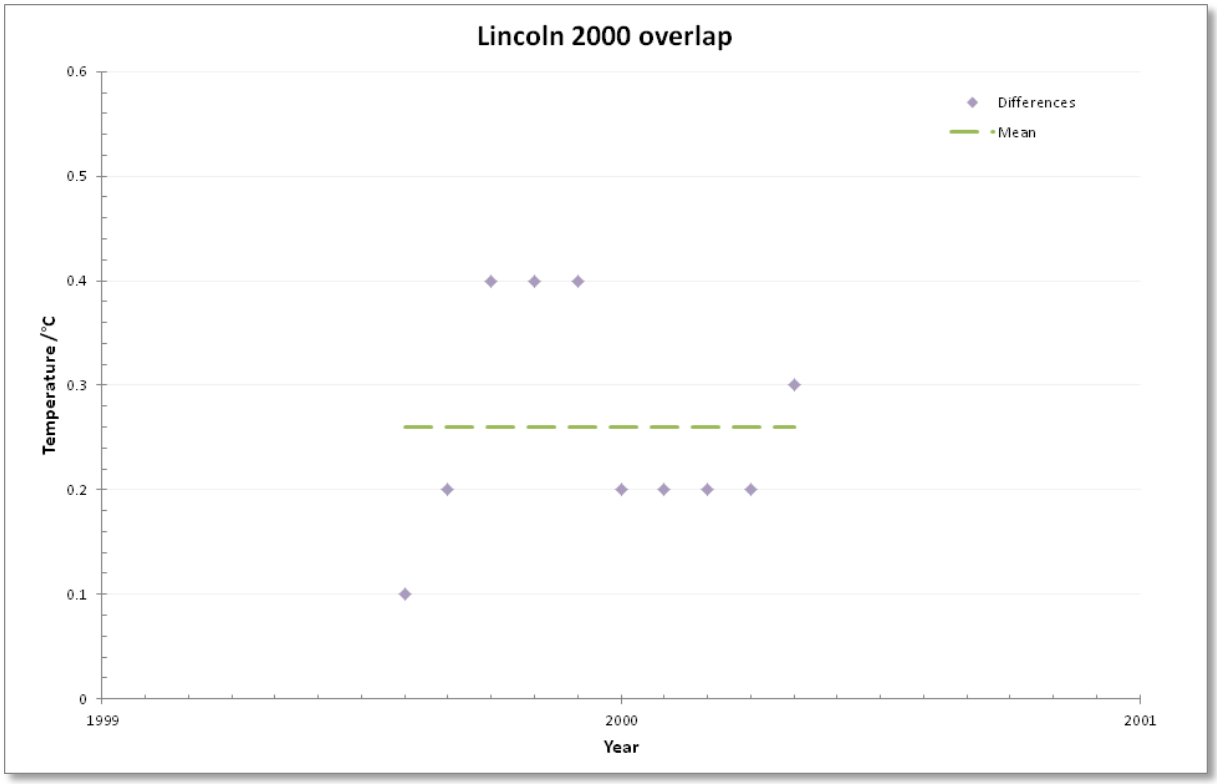


Figure 2: Lincoln 2000 EDL/EWS overlap

The overlap period runs from July 1999 to April 2000. During this time the later EWS site was consistently warmer than the earlier EDL site, on average by +0.26 ± 0.09°C at the 95% confidence level. In all months the difference was positive, and in no month was the difference less than 0.1°C. It is unclear why NIWA felt that this result was not good enough, it is certainly statistically significant.

A quick visual check of the y-series for k=1 shows a negative temperature difference at Lincoln relative to the other stations, with low variation. This implies the pre-2000 values should be raised, should the result prove statistically significant.

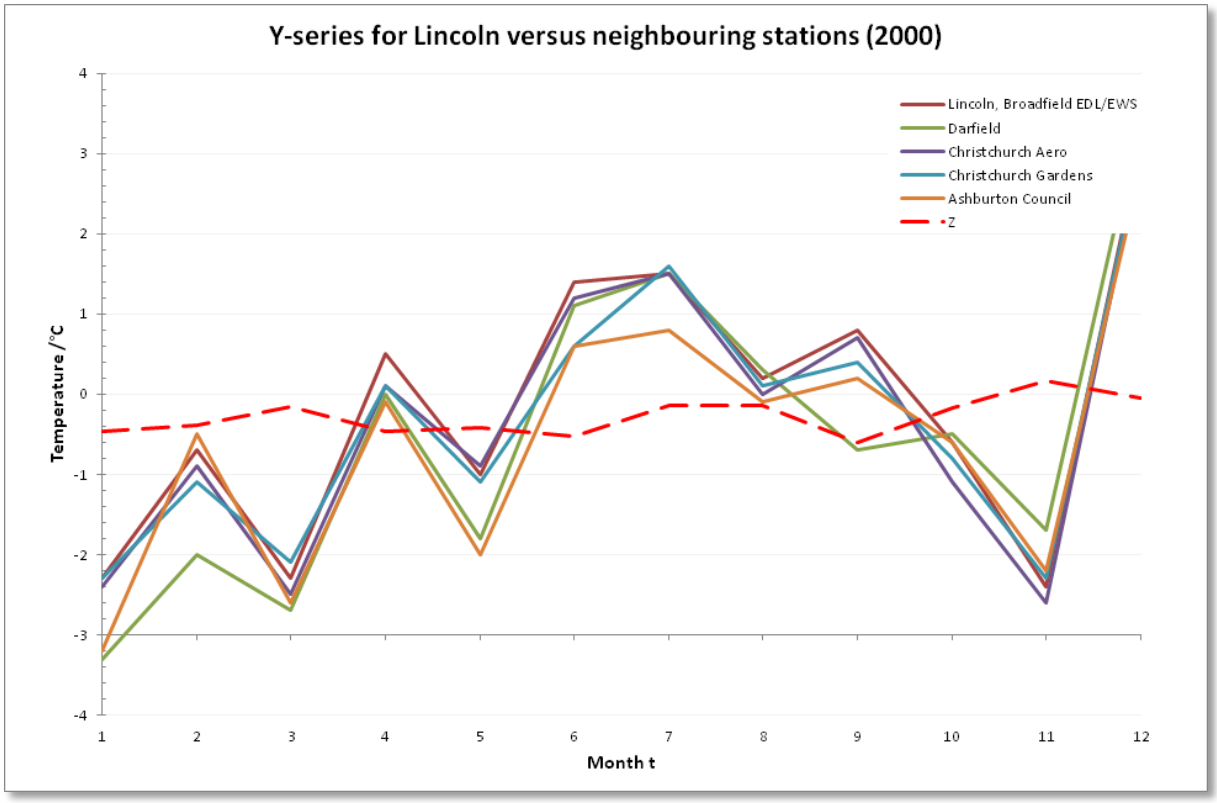


Figure 3: Lincoln y-series versus neighbouring stations, 2000

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Darfield	0.94	0.22
Christchurch Aero	0.99	0.27
Christchurch Gardens	0.99	0.26
Ashburton Council	0.97	0.25

For the case of the 2000 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.28 ± 0.15 °C	No	Yes
2	+0.08 ± 0.09 °C	Yes	No
3	-0.04 ± 0.10 °C	Yes	No

The *k=1* result shows a very definite result (consistent with the 0.26°C obtained from the difference check above) and would usually be given the highest weighting, since a site change effect should be immediately visible in the *k=1* case at the 95% confidence level. However, since *k=2* was not significant, and neither was *k=3*, we have decided to err on the side of caution and make no adjustment. This is the correct approach to take, according to R&S.

So no adjustment is made for 2000.

Site Change in 1987

NIWA Result

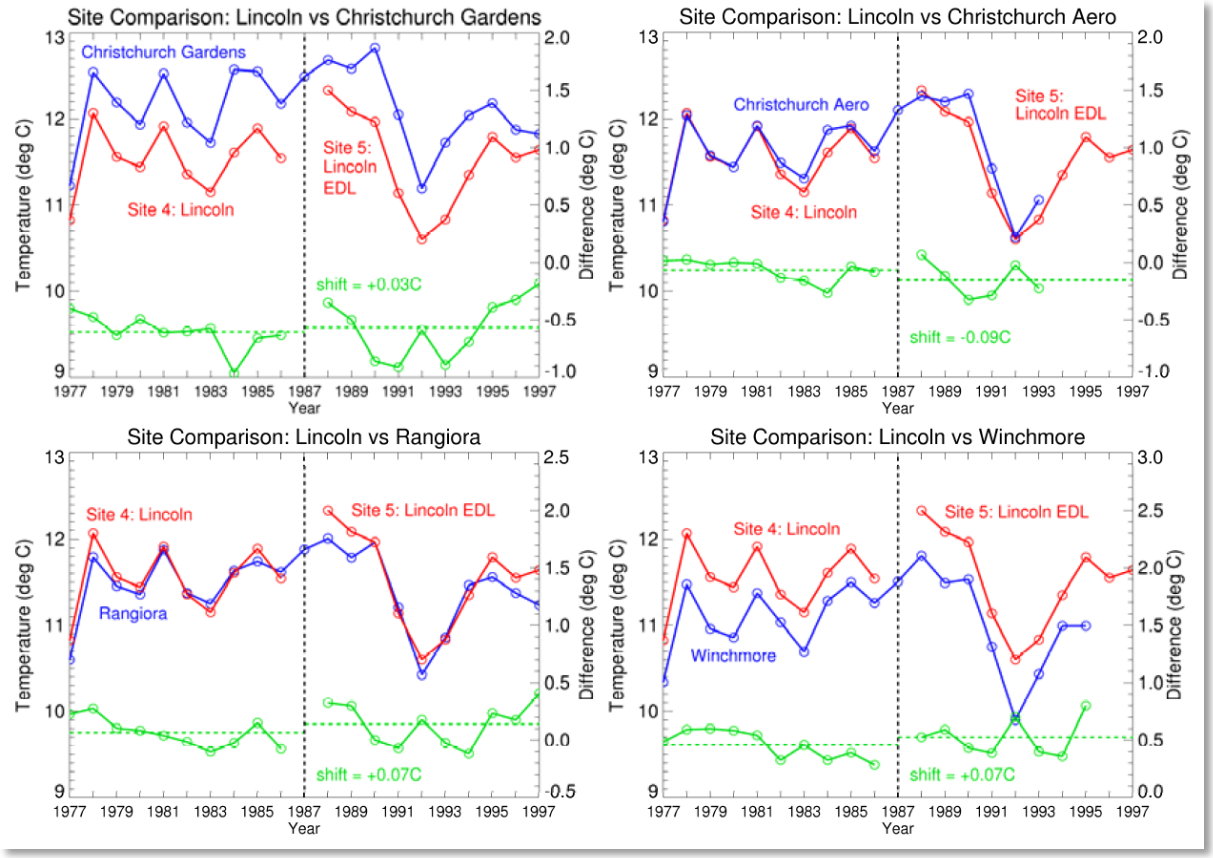


Figure 4: NIWA comparisons with Lincoln 1987

The background to the examination of this site change is given in the NIWA document detailing the Lincoln composite series (pgs 9-10)[2]. The Lincoln / Lincoln Broadside EDL (agent 4881/4882) changeover series is compared to Christchurch Gardens (agent 4858), Christchurch Aero (agent 4843), Rangiora (agent 4827), and Winchmore EWS (agent 4764).

NIWA finds an overlap of -0.03°C but regards the timescale to be too short, and uses their neighbouring stations comparison method to calculate a shift of **+0.02°C** for the 1987 adjustment (+0.03 -0.09 +0.07 +0.07)/4 °C.

Note the use of annual instead of monthly values; the asymmetric periods before and after the site change; the long comparison period of 1977-1997; the lack of any applied weightings (all values are simply averaged).

[2] "Creating a Composite Temperature Series for Lincoln"
http://www.niwa.co.nz/__data/assets/pdf_file/0004/108886/Lincoln_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

The overlap period is 7 months. The Lincoln Broadside EDL minus Lincoln difference plot is shown below.

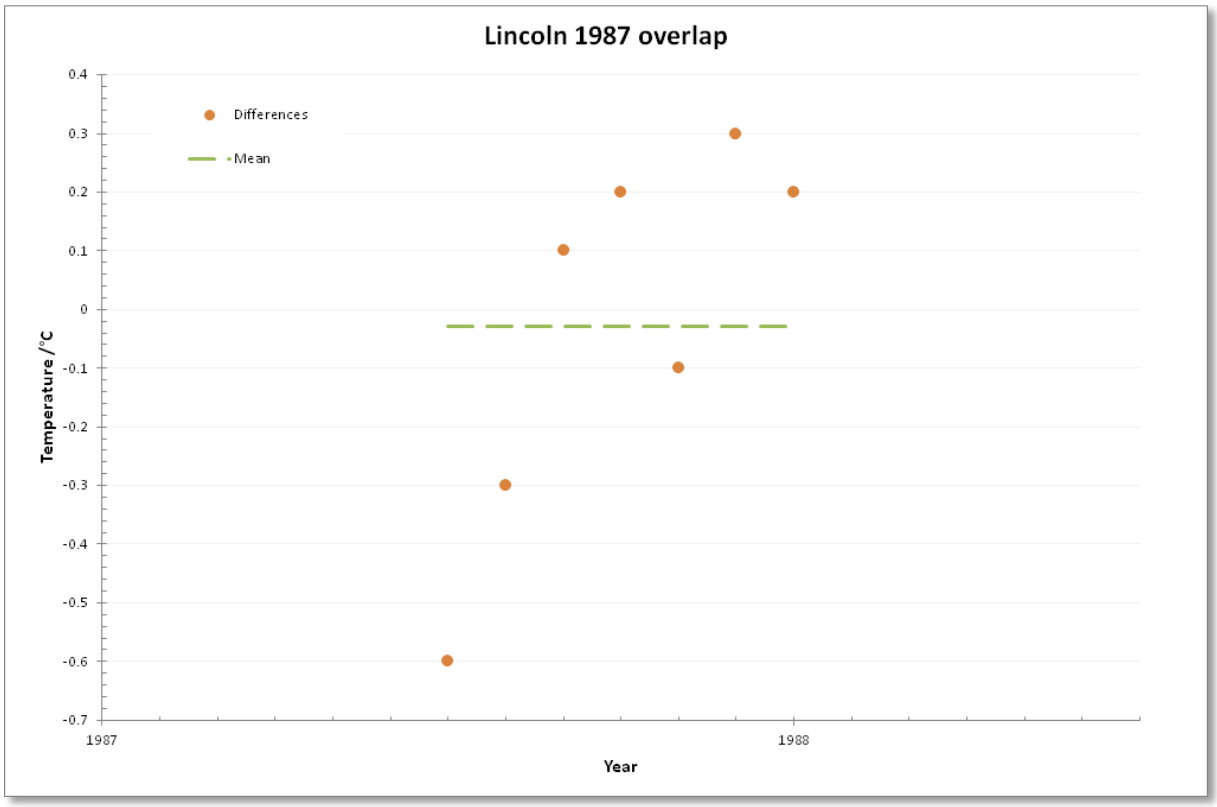


Figure 5: Lincoln 1987 EDL/EWS overlap

The overlap period runs from June 1987 to December 1987. During this time the later EDL site was on average cooler than the earlier Lincoln site, by 0.03±0.36°C at the 95% confidence level. In other words, there is no confidence at the 95% level that a valid shift occurred.

This supports NIWA's position that 7 months is too short to determine the shift, given the variability of this data set. However, note that NIWA did not support their qualitative assessment with any statistical analysis.

A quick visual check of the y-series for k=1 shows a slightly negative temperature difference at Lincoln relative to the other stations, with moderate variation. This implies the pre-1987 values should be raised, should the result be statistically significant.

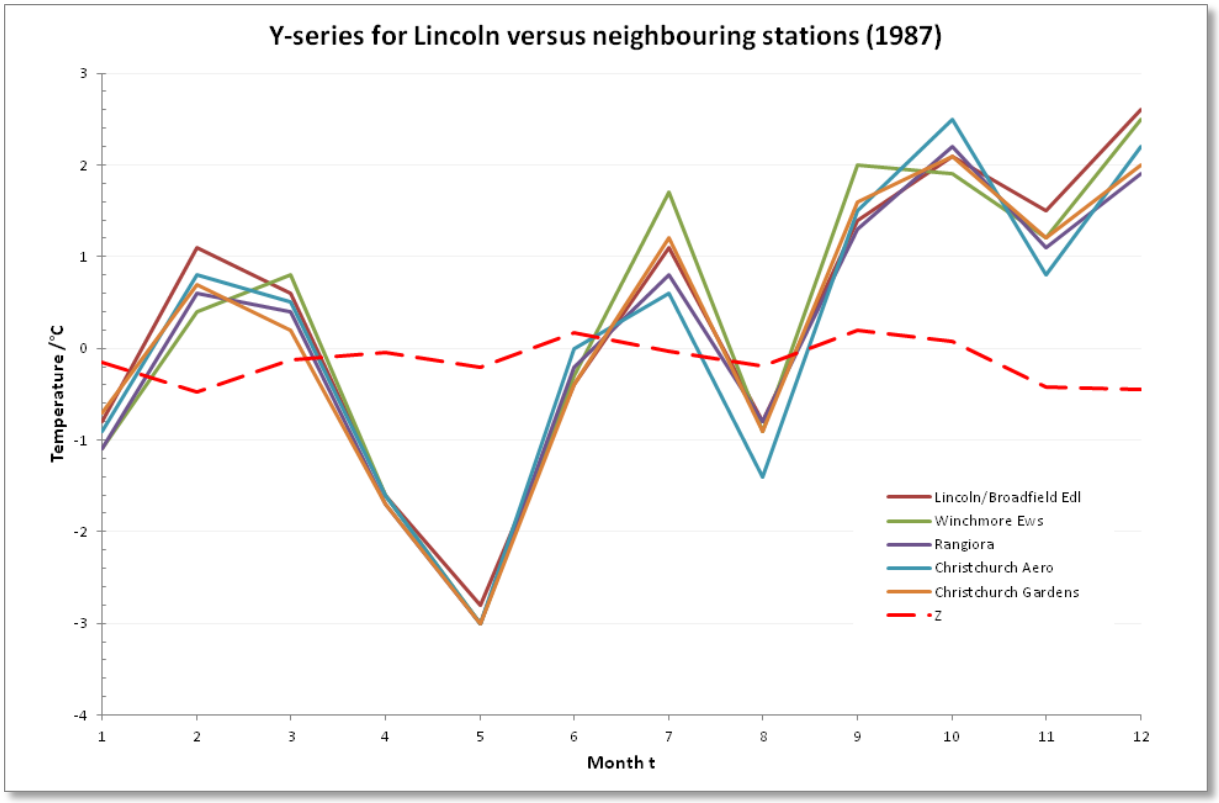


Figure 6: Lincoln y-series versus neighbouring stations, 2000

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Winchmore EWS	0.98	0.24
Rangiora	0.99	0.27
Christchurch Aero	0.98	0.24
Christchurch Gardens	0.99	0.26

For the case of the 1987 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.14 ± 0.15 °C	Yes	No
2	+0.16 ± 0.10 °C	No	Yes
3	+0.06 ± 0.12 °C	Yes	No

Only *k=2* shows any significant result at the 95% confidence level, and even then not by much. Since *k=1* was not significant, and neither was *k=3*, we have decided to err on the side of caution and make no adjustment. This is the correct approach to take, according to R&S.

So no adjustment is made for 1987.

Site Change in 1976

NIWA Result

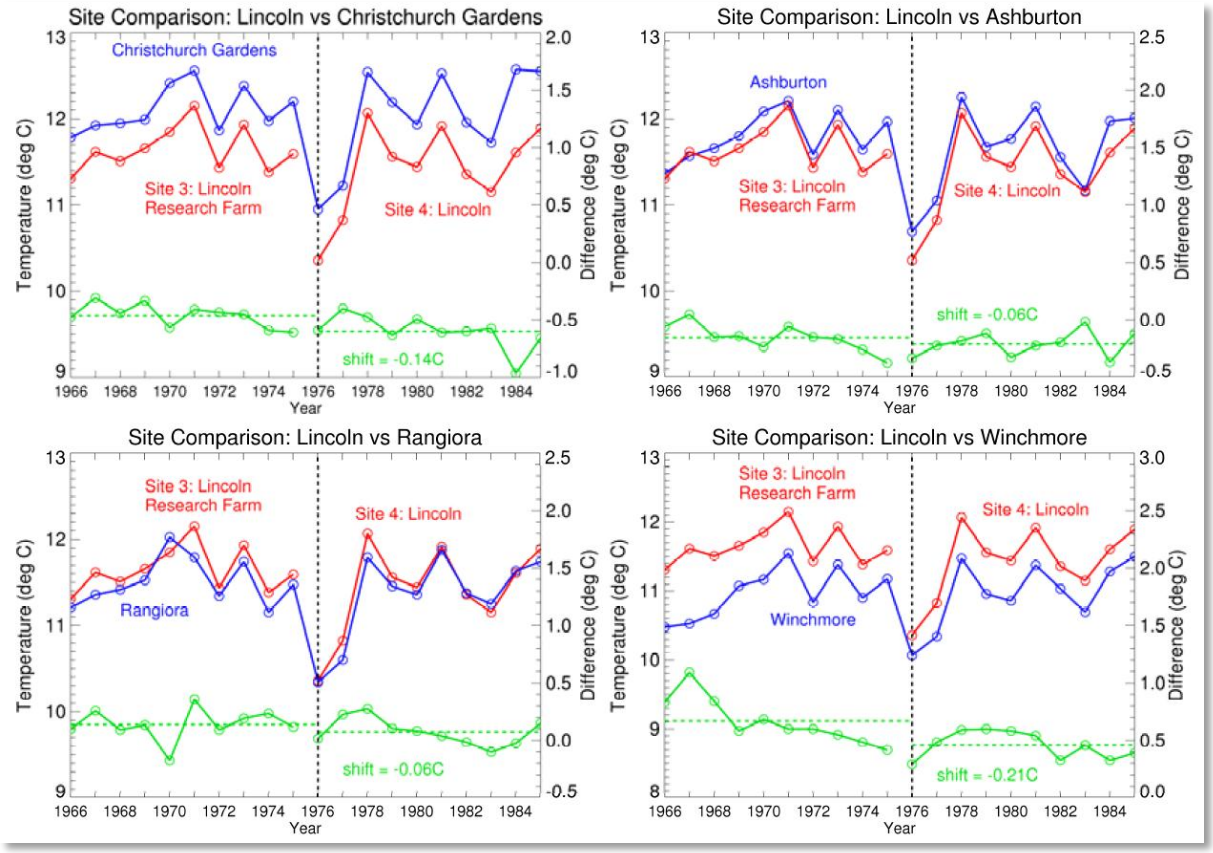


Figure 7: NIWA site comparison - Lincoln 1976

The background to the examination of this site change is given in the NIWA document detailing the Lincoln composite series (pp 5-8)[3]. The Lincoln Research Farm/Lincoln changeover series (agent 4881) is compared to Christchurch Gardens (agent 4858), Rangiora (agent 4827), Winchmore (agent 4764), and Ashburton Council (agent 4778).

NIWA calculates a shift of **-0.12°C** for the 1976 adjustment (-0.14 -0.06 -0.06 -0.21)/4 °C.

[3] "Creating a Composite Temperature Series for Lincoln" http://www.niwa.co.nz/__data/assets/pdf_file/0004/108886/Lincoln_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S

A quick visual check of the y-series for k=1 shows no significant temperature difference at Lincoln relative to the other stations (6 data points above zero, 6 below – see dashed red line in plot below).

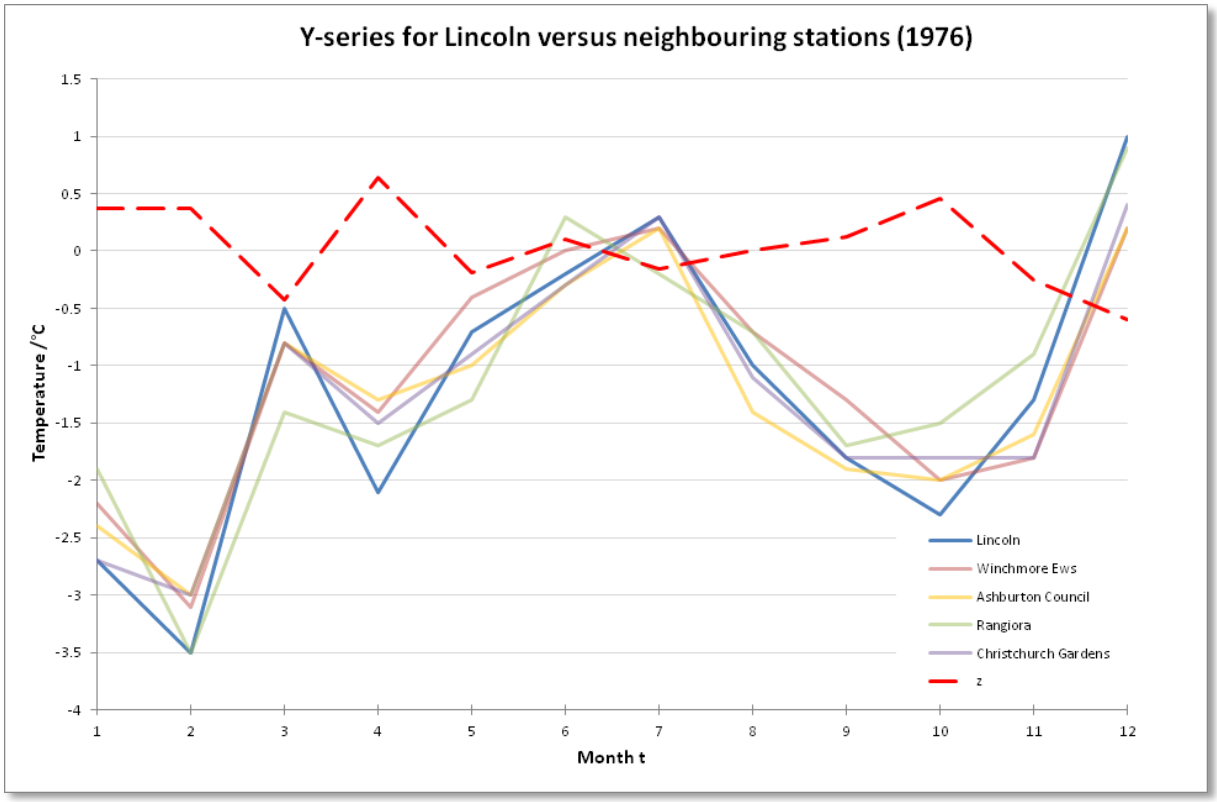


Figure 8: Lincoln y-series versus neighbouring stations, 1976

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Winchmore EWS	0.95	0.25
Ashburton Council	0.96	0.27
Rangiora	0.91	0.21
Christchurch Gardens	0.97	0.27

For the case of the 1976 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.04 ± 0.24 ºC	Yes	No
2	+0.01 ± 0.16 ºC	Yes	No

So the adjustment is not made.

Site Change in 1964

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Lincoln composite series (pp 12,13). The Lincoln/Lincoln Research Farm changeover series (agent 4881) is compared to Christchurch Gardens (agent 4858), Christchurch Aero (agent 4843), Darfield (agent 4836), and Ashburton Council (agent 4778).

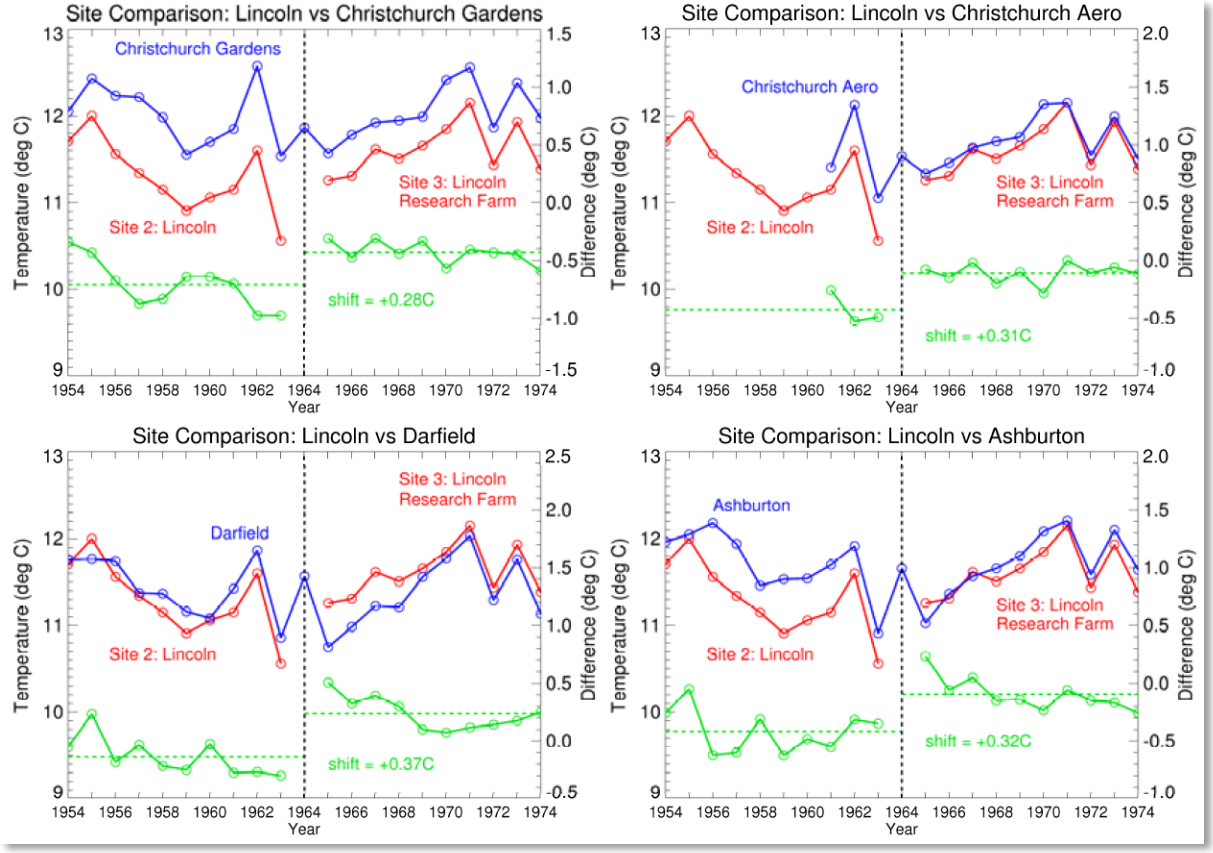


Figure 9: NIWA site comparison - Lincoln 1964

NIWA calculates a value of **+0.32°C** for the 1964 adjustment (+0.28 +0.31 +0.37 +0.32)/4 °C.

Results from R&S

A quick visual check of the y-series for k=1 shows a negative temperature difference at Lincoln relative to the other stations (1 data point above zero, 11 below, see dashed red line in plot below). This implies the pre-May 1964 Lincoln values should be raised, if the result proves to be statistically significant.

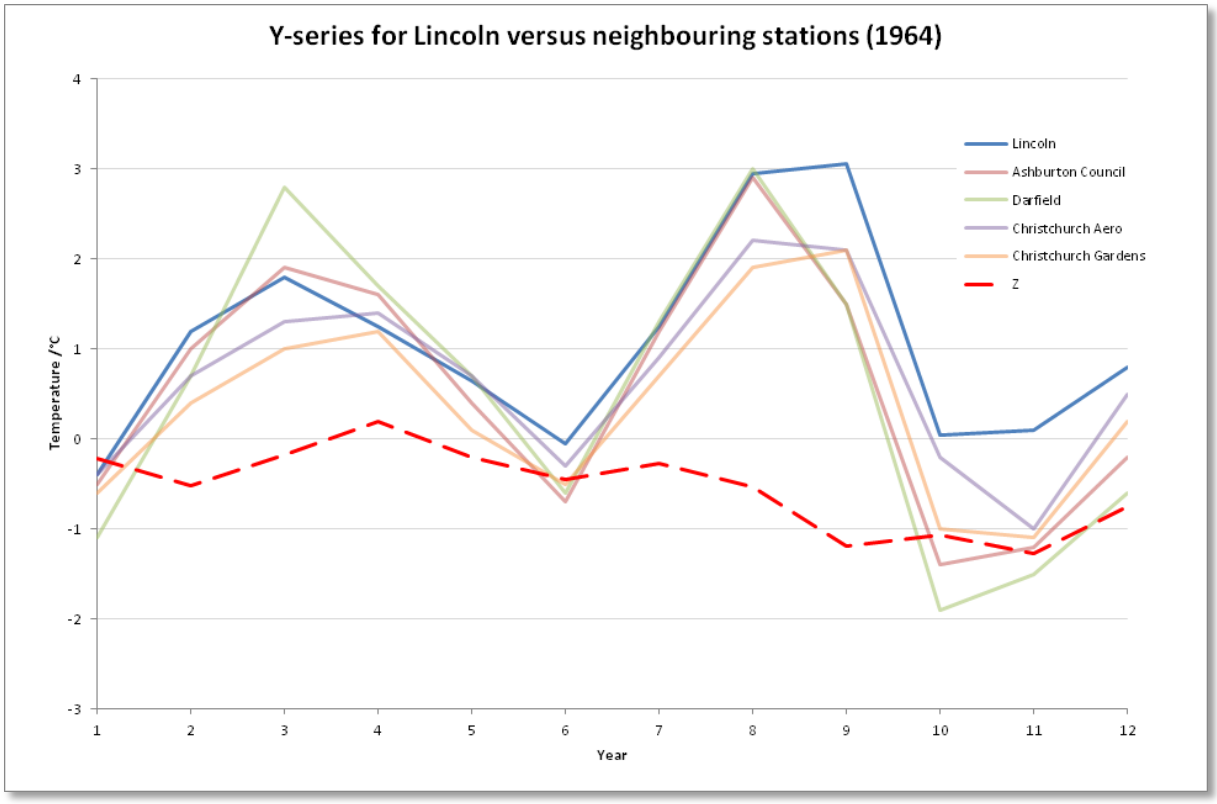


Figure 10: Lincoln Site 2/3 y-series versus neighbours, 1964

The weighting factors were calculated using k=1, and are[4]:

Station	ρ	w
Ashburton Council	0.88	0.22
Darfield	0.84	0.19
Christchurch Aero	0.94	0.29
Christchurch Gardens	0.95	0.30

For the case of the 1964 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.54 ± 0.29 °C	No	Yes
2	+0.56 ± 0.15 °C	No	Yes

So the adjustment is: **raise** the pre-May 1964 values by (0.54 + 0.56)/2 = **0.55°C**[5].

[4] Some monthly temperatures have been increased by 0.55°C as per page 12 footnote 19, NIWA document.

[5] ie: replace $x_t^{(0)}$ by $x_t^{(0)} - \bar{z}$ for t<τ, see R&S page 905

Site Change in 1944

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Lincoln composite series (pp 14,15). The Site1/2 changeover series (agent 4881) is compared to Christchurch Gardens (agent 4858), Onawe Duvauchelle Bay (agent 4928), Waimate (agent 5102), and Ashburton Council (agent 4778).

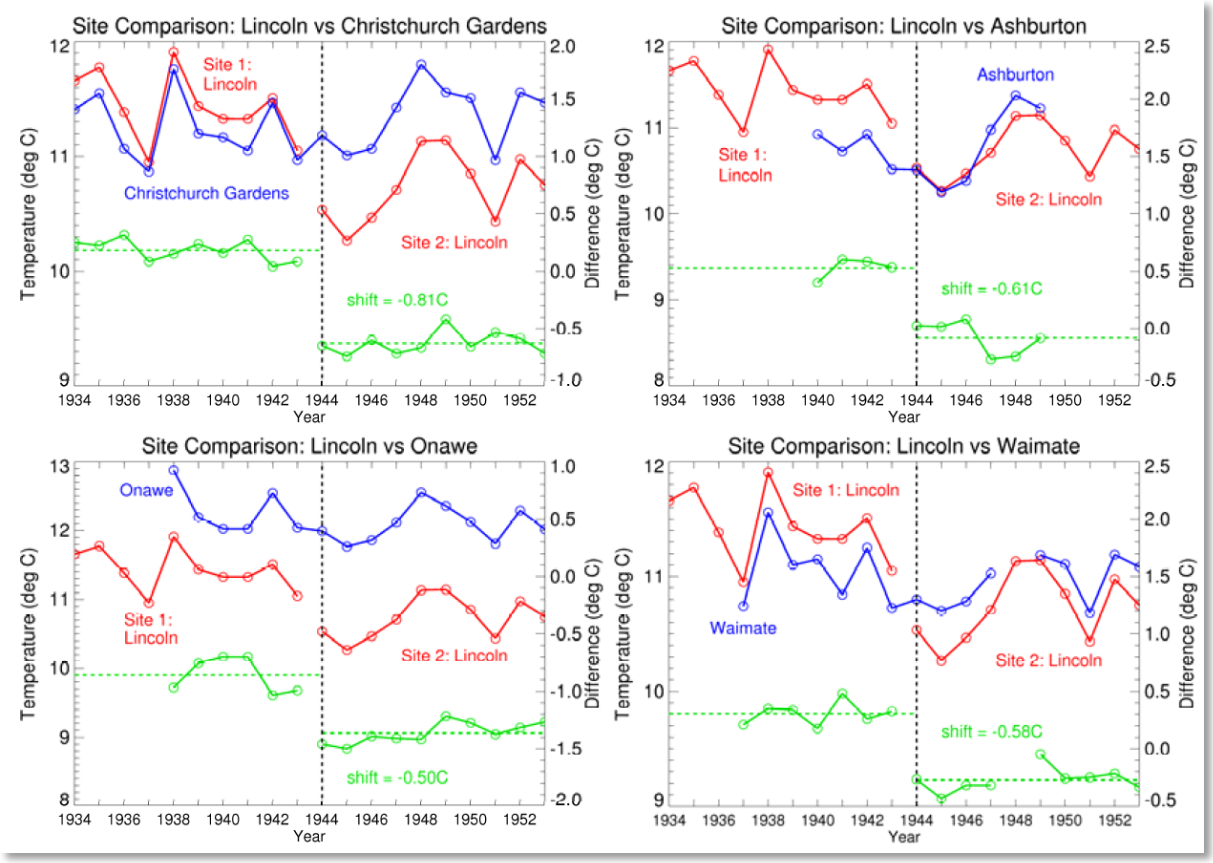


Figure 11: NIWA site comparison - Lincoln 1944

NIWA arrives at a value of **-0.63°C** for the 1944 adjustment (−0.81−0.61 −0.50 −0.58)/4 °C.

Results from R&S

A quick visual check of the y-series for k=1 shows a positive temperature difference at Lincoln relative to the other stations (all 12 data points above zero – see dashed red line in the plot below). This implies the pre-January 1944 Lincoln values should be lowered, if the result proves to be statistically significant.

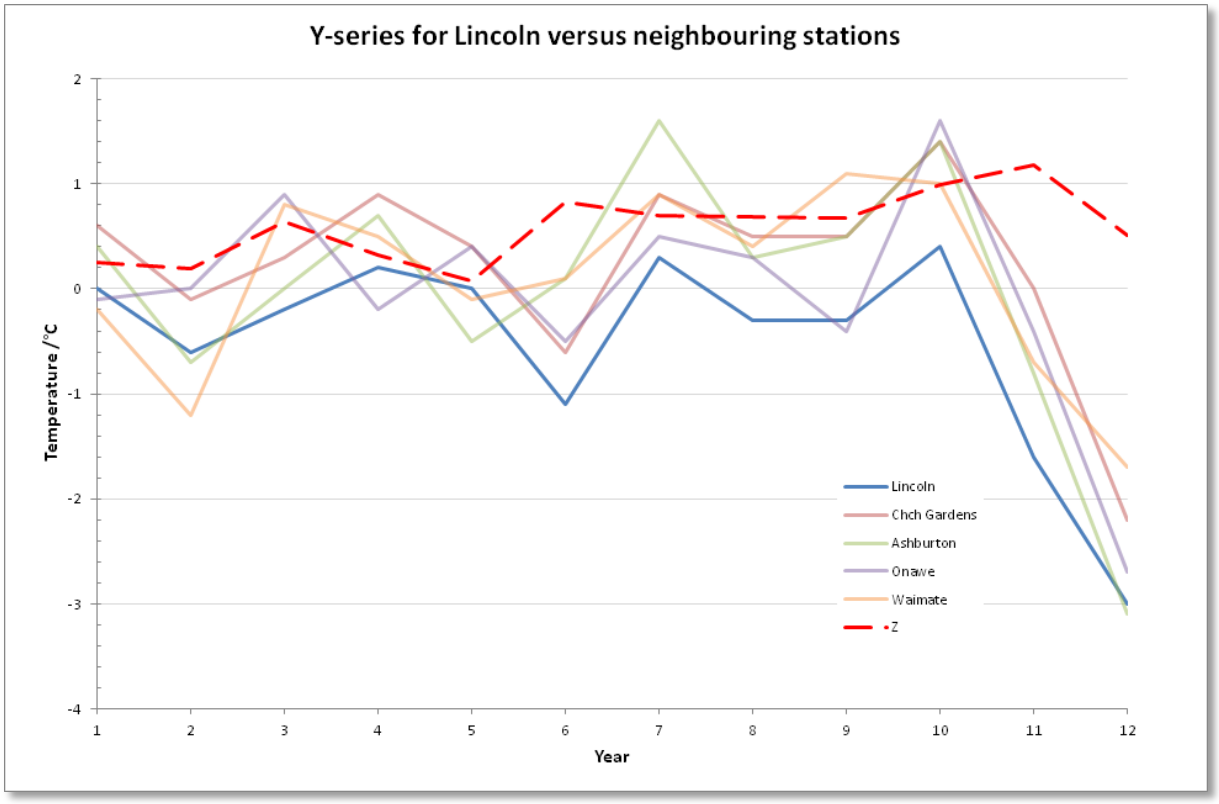


Figure 12: Lincoln Site 1/2 y-series versus neighbours, 1944

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Christchurch Gardens	0.94	0.34
Ashburton Council	0.90	0.27
Onawe	0.87	0.24
Waimate	0.77	0.15

For the case of the 1944 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.59 ± 0.21 °C	No	Yes
2	-0.61 ± 0.14 °C	No	Yes

So the adjustment is: **lower** the pre-January 1944 values by **-0.60°C**[6].

[6] ie: replace $x_t^{(0)}$ by $x_t^{(0)} - \bar{z}$ for t<τ, see R&S page 905

Adjustments for the first Lincoln station

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Lincoln composite series (pp 15-18). The Site1 series (agent 4881) is compared to Christchurch Gardens (agent 4858).

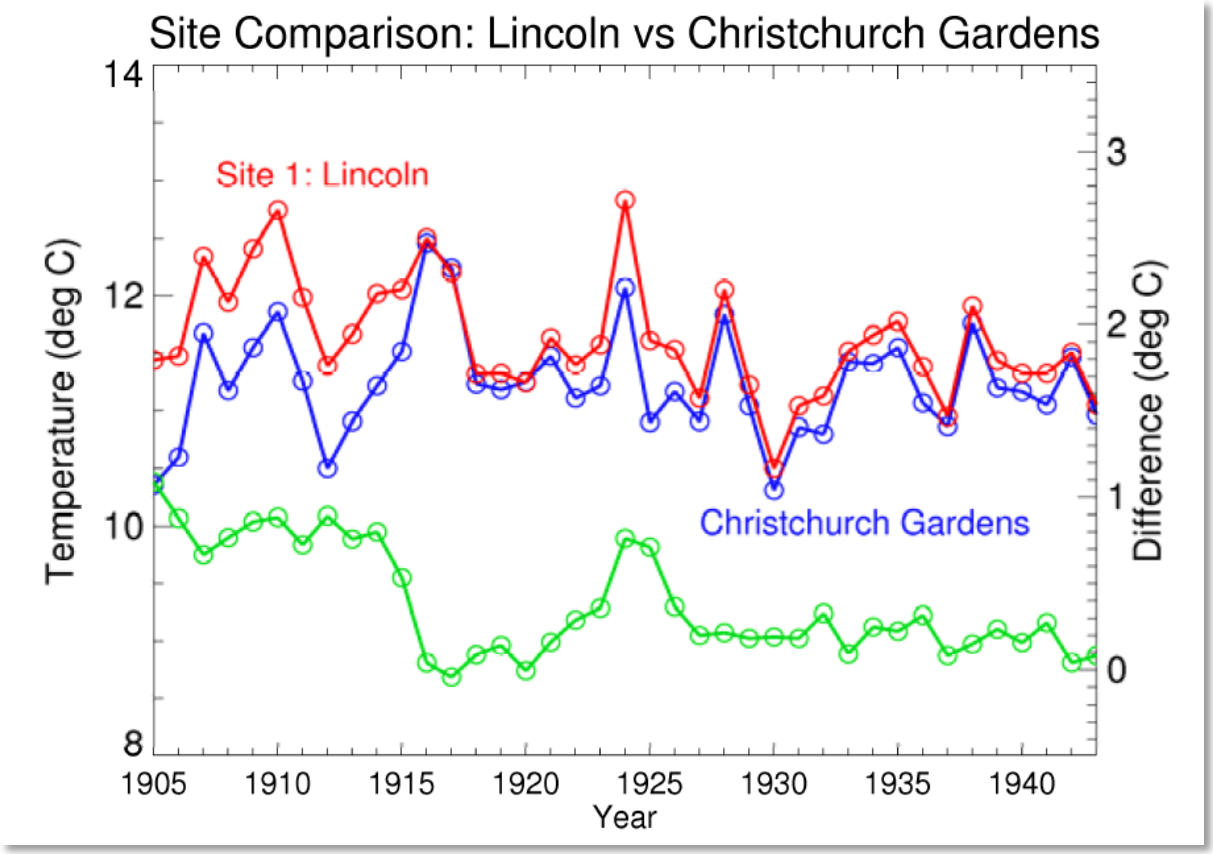


Figure 13: NIWA site comparison - Lincoln First Station

NIWA uses a penalised maximal t test (Wang et al., 2007) to determine non-climatic shifts in the Site 1 temperature series. It is noted that there is actually no documented reason to suggest that any adjustments are necessary at this site.

NIWA states:

> The enclosure of Lincoln Site 1 was well exposed when the station was first established in 1881, but the land around Lincoln College was subsequently developed and shelter belts were planted right up to the edge of the enclosure (Fouhy et al., 1992).

The use of this site therefore clearly violates R&S (1993), which states:

> Some changes are gradual and some sudden. We use the term site change to mean any sudden change of non-meteorological origin. Gradual changes can seldom be assigned with any certainty to non-meteorological causes. Where long-term homogeneous series are required, for example, for studies of climate change, it is best to choose stations that are unlikely to have been affected by gradual changes in shading or urbanization.[7]

It is therefore better to reject a site that has known shading or urbanization, rather than to try to adjust it. NIWA even notes (footnote 23) that the pre-1927 data should not be used:

> Due to the amount of missing data and the fluctuations in the observed temperatures, the early record of Lincoln Site 1 should be treated with caution. Salinger (1981) noted that the Lincoln record prior to 1927 'should be used with caution for climatic change work'.

Returning to R&S on the subject of known site changes, it states:

> This paper is concerned with the estimation of site-change effects when the times of changes are known *a priori*, such as when the station was moved or the instrument replaced.[8]

In other words, one must first know that a change has actually occurred at a certain time before looking for shifts. On top of this, the stated problem with this site is sheltering, which is a gradual problem. So it is unclear why NIWA were looking for step-changes. Regardless of the clear instructions in the peer-reviewed literature they reference themselves, NIWA nevertheless presses ahead with their analysis.

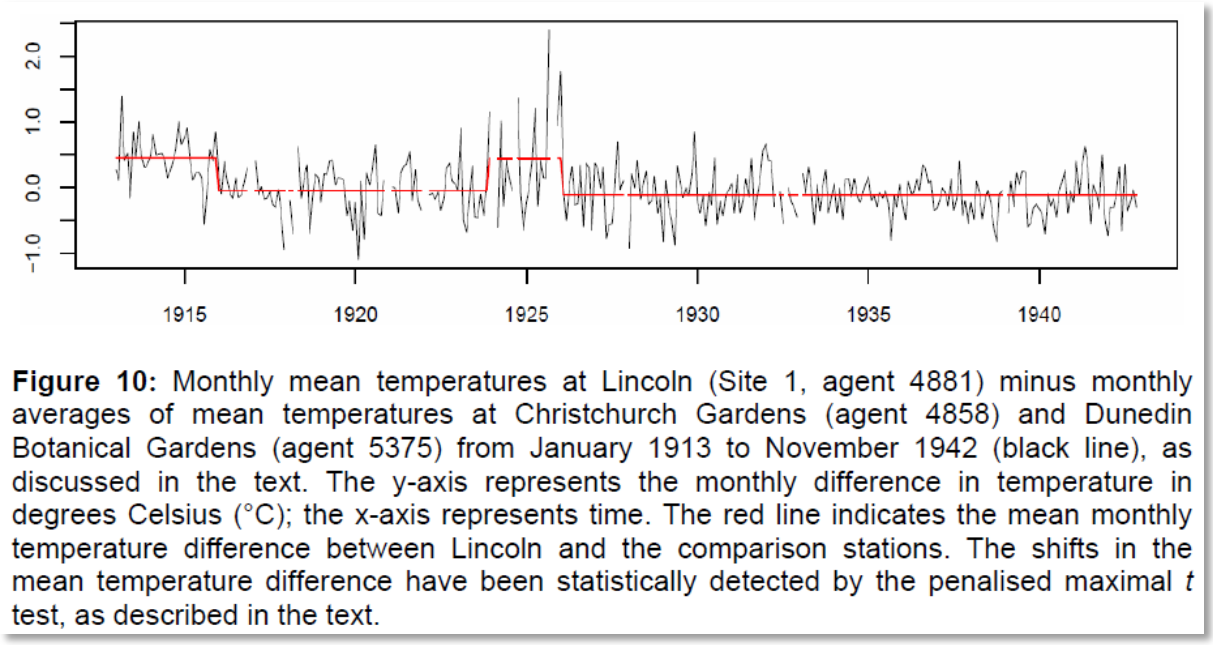


Figure 10: Monthly mean temperatures at Lincoln (Site 1, agent 4881) minus monthly averages of mean temperatures at Christchurch Gardens (agent 4858) and Dunedin Botanical Gardens (agent 5375) from January 1913 to November 1942 (black line), as discussed in the text. The y-axis represents the monthly difference in temperature in degrees Celsius (°C); the x-axis represents time. The red line indicates the mean monthly temperature difference between Lincoln and the comparison stations. The shifts in the mean temperature difference have been statistically detected by the penalised maximal *t* test, as described in the text.

Figure 14: NIWA site shift analysis - Lincoln Site 1

[7] R&S page 899
[8] R&S page 900

NIWA arrives at a shift of **-0.61°C** for the 1926 adjustment, **+0.57** °C for 1923, and **-0.52** °C for 1915.

Each of these adjustments will now be analysed using the R&S method. It must be noted, however, that according to R&S the correct approach is to discard the pre-1927 data altogether, as it is subject to gradual sheltering changes by NIWA's own admission. If the pre-1927 data *is* included, no adjustments should be attempted, for two reasons:

1. Gradual changes can seldom be assigned with any certainty to non-meteorological causes.
2. The lack of *a priori* knowledge of any sudden siting changes for Site 1 implies that looking for shifts in a compromised data series is unwise at best, invalid at worst.

Results from R&S

January 1926 Adjustment

The data is very poor in this period. The correlations were so poor for *k=1* that *k=2* had to be used. The weighting factors calculated using *k=2* are:

Station	ρ	w
Christchurch Gardens	0.79	0.67
Dunedin Botanical Gardens	0.66	0.33

For the case of the January 1926 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.35 ± 0.74 °C	Yes	No
2	-0.51 ± 0.37 °C	No	Yes

The *k=1* and *k=2* results are contradictory (not a good sign). *k=3* could have been calculated to break the deadlock, but this 36-month analysis would overlap with the 1923 adjustment. Ideally, no adjustment should be made here, as the data is poor, there are no known site changes to justify an adjustment, and it is entirely unclear whether the adjustment is because of poor data or a non-climatic site event. According to R&S, only clear and obviously significant results should be used to justify an adjustment.

However, since *k=2* just barely returned a significant result, and if NIWA insisted on forcing an adjustment against all advice from their peer-reviewed references, then the adjustment would be: **lower** the pre-January 1926 values by -**0.51°C**.

November 1923 Adjustment

The data is again very poor in this period. The correlations were so poor for *k=1* that *k=2* had to be used. The weighting factors calculated using *k=2* are:

Station	ρ	w
Christchurch Gardens	0.87	0.64
Dunedin Botanical Gardens	0.76	0.36

For the case of the November 1923 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.66 ± 0.44 °C	No	Yes
2	+0.51 ± 0.33 °C	No	Yes

So the adjustment is: **raise** the pre-November 1923 values by **(0.66 + 0.51)/2 = +0.59°C**.

December 1915 Adjustment

The correlations were slightly better in this period, but the use of *k=2* was still required. The weighting factors calculated using *k=2* are:

Station	ρ	w
Christchurch Gardens	0.95	0.56
Dunedin Botanical Gardens	0.90	0.45

For the case of the December 1915 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.21 ± 0.23 °C	Yes	No
2	-0.38 ± 0.13 °C	No	Yes
3	-0.51 ± 0.16 °C	No	Yes

The *k=1* and *k=2* results were inconclusive, so *k=3* was used to break the deadlock.

So the adjustment is: **lower** the pre-December 1915 values by **(-0.38 - 0.51)/2 = -0.45°C**.

Site 1 Summary

NIWA calculates a shift of -0.61°C for the 1926 adjustment, +0.57 °C for 1923, and -0.52 °C for 1915.

R&S arrives at a shift of -0.51°C for the 1926 adjustment, +0.59 °C for 1923, and -0.45 °C for 1915.

Putting the Lincoln Time Series Together

The table below shows a summary of the NIWA versus R&S adjustments.

Table 1: Comparison between NIWA and R&S results

Site Label	Site Name	From	To	NIWA Adj	R&S Adj	NIWA sum	R&S sum
Site 1	Lincoln (4881)	Jan 1905	Nov 1915	-0.52	-0.45	-0.97	-0.42
		Dec 1915	Oct 1923	+0.57	+0.59	-0.45	+0.03
		Nov 1923	Dec 1925	-0.61	-0.51	-1.02	-0.56
		Jan 1926	Dec 1943	-0.63	-0.60	-0.41	-0.05
Site 2	Lincoln (4881)	Jan 1944	Apr 1964	+0.32	+0.55	+0.22	+0.55
Site 3	Lincoln (4881)	May 1964	Dec 1975	-0.12	0.00	-0.10	0.00
Site 4	Lincoln (4881)	Jan 1976	May 1987	+0.02	0.00	+0.02	0.00
Site 5	Lincoln Broadfield EDL (4882)	Jun 1987	Dec 1999	0.00	0.00	0.00	0.00
Site 6	Lincoln Broadfield EWS (17603)	Jan 2000	present	0.00	0.00	0.00	0.00

The time series from 1909 to 2009 is shown Figure 15 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

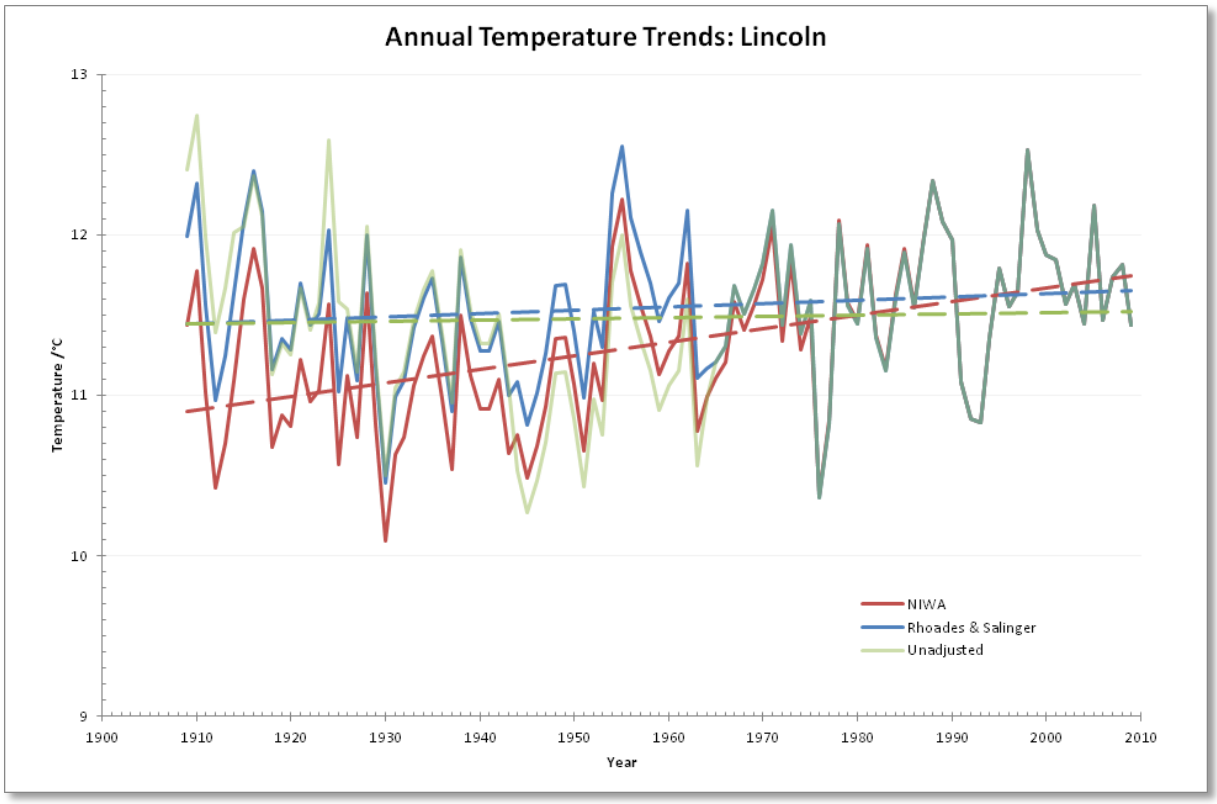


Figure 15: Annual Temperature Trends for Lincoln

The trends over the 1909-2009 period are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.08
NIWA method	0.83
Rhoades & Salinger method	0.21

The difference in trend is 0.83 – 0.21 = 0.62°C/century. In other words, the NIWA method overstates the Lincoln trend by 0.62/0.21 = 295%.

Hokitika

Hokitika is a station included in the NIWA 7-station series to represent the West Coast. It is a station that has a history of poor data, and should not be included. In a peer-reviewed reference to this station[9], Hokitika is specifically mentioned (along with Dunedin) as a station "unworthy of investigation due to periods of unsatisfactory records between 1930 and 1970". This conclusion is confirmed by several errors NIWA themselves found when preparing their own series.

Since it has been included by NIWA, it will be examined here as well. We examine the Hokitika temperature series, to determine if there are any differences between the results obtained using the R&S and NIWA methods. The following sections detail this process.

We have used the same station data NIWA used, and the same station shifts have been examined. Similarly, the same neighbouring stations have been used for comparisons.

[9] J.W.D. Hessell, "Apparent trends of mean temperature in New Zealand since 1930", *New Zealand Journal of Science*, 1980, Vol. 23, 1-9

Site Change in 1967

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Hokitika composite series (pp 4-9)[10]. The Hokitika Southside/Hokitika Aero composite is compared with various other stations, using their annual averaging method.

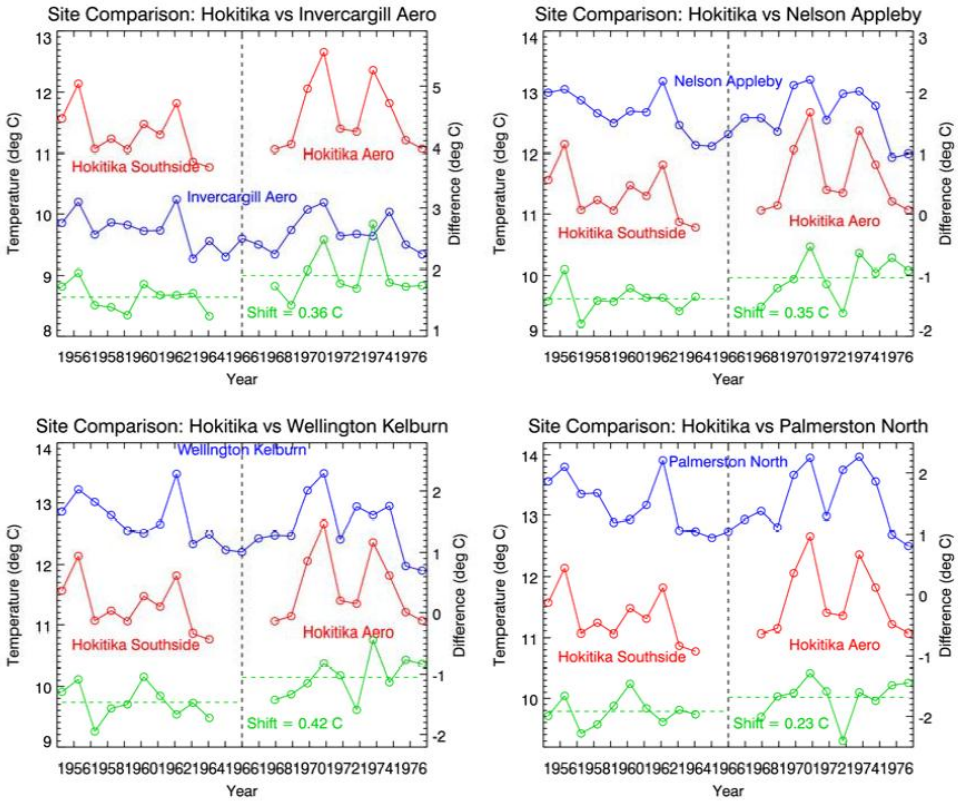


Figure 16: NIWA site comparison – Masterton 1991

NIWA calculates a shift of **+0.05°C** for the 1967 adjustment. Previously, this shift was ignored by NIWA in their Feb 2010 series.

The reason given for addressing this site change at all is an instrument shift of only 180m. It is highly unlikely that such a small movement would result in large temperature shifts, so ideally no adjustment should be made. However, in this case because the applied adjustment is so small, we shall simply accept NIWA's analysis for the 1967 shift.

Site Change in 1964

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Hokitika composite series (pp 4-9)[11]. The adjustment is based on a 14-month overlap analysis

[10] "Creating a Composite Temperature Series for Hokitika" http://www.niwa.co.nz/__data/assets/pdf_file/0008/108917/Hokitika_CompositeTemperatureSeries_15Dec2010_FINAL.pdf

between Hokitika Southside and Hokitika Aero. NIWA obtain an adjustment result of **+0.29°C** for pre-1964 values. No confidence limits are published, although the standard deviation of 0.23°C is mentioned.

Overlap Calculation Using Monthly Temperatures

When a significance test is performed, the following result is obtained: 0.29 ± 0.13°C. This confirms the adjustment.

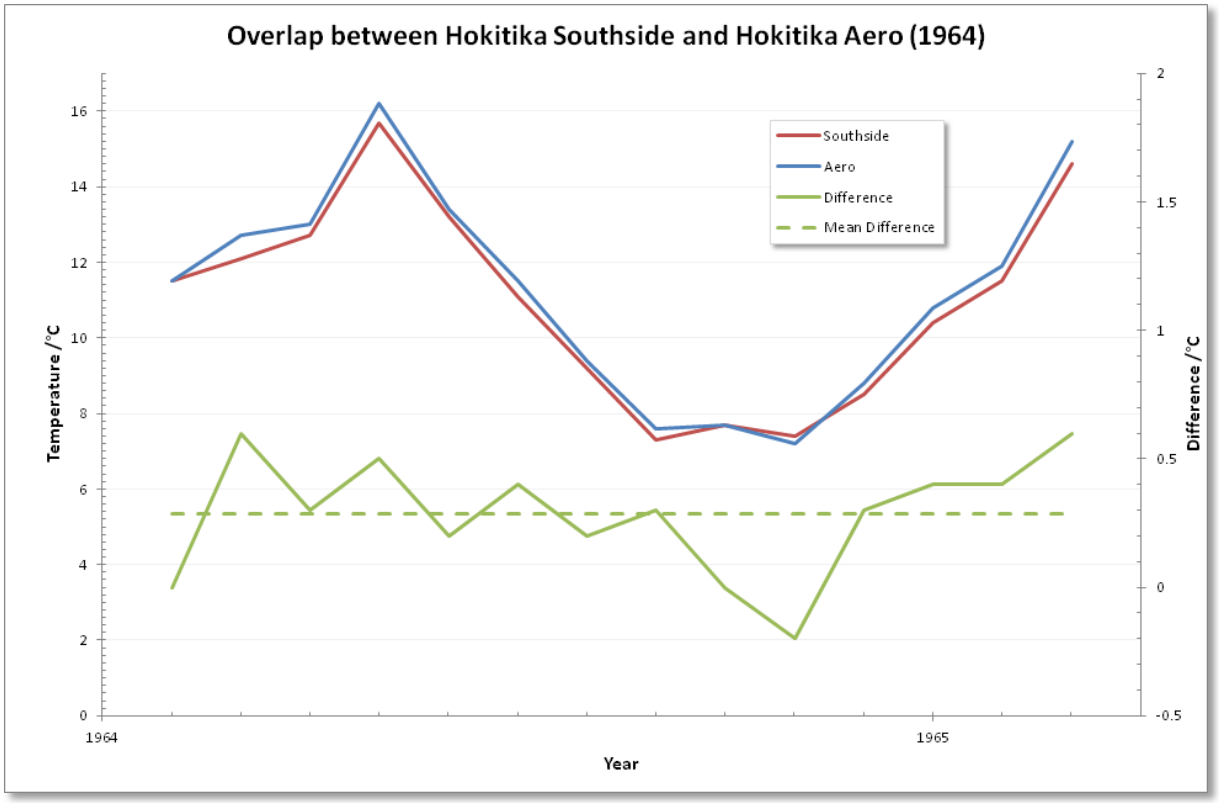


Figure 17: Hokitika Overlap using Monthly Data

Therefore an adjustment of **+0.29°C** should be made for the pre-1964 temperatures.

Site Change in 1945

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Hokitika composite series (pp 9-11)[12]. The adjustment is based on a 30-month overlap analysis between Hokitika Town and Hokitika Southside. NIWA obtain an adjustment result of **-0.68°C** for

[11] "Creating a Composite Temperature Series for Hokitika" http://www.niwa.co.nz/__data/assets/pdf_file/0008/108917/Hokitika_CompositeTemperatureSeries_15Dec2010_FINAL.pdf

[12] "Creating a Composite Temperature Series for Hokitika" http://www.niwa.co.nz/__data/assets/pdf_file/0008/108917/Hokitika_CompositeTemperatureSeries_15Dec2010_FINAL.pdf

pre-1945 values. No confidence limits are published, although the standard deviation of 0.17°C is mentioned.

Overlap Calculation Using Monthly Temperatures

When a significance test is performed, the following result is obtained: -0.68 ± 0.06°C. This confirms the adjustment.

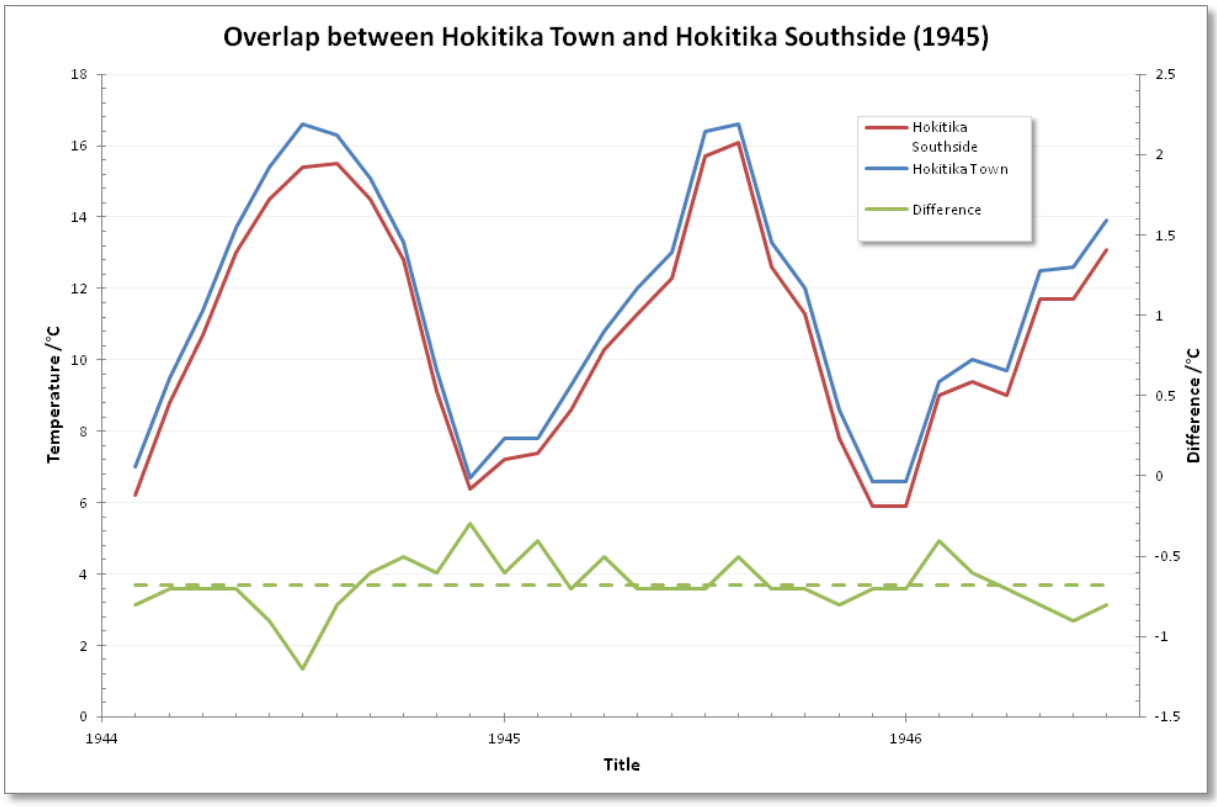


Figure 18: NIWA Hokitika Site Comparisons 1945

Therefore an adjustment of **-0.68°C** should be made for the pre-1945 temperatures.

Instrument Change in 1943

NIWA Result

NIWA appears to have failed to check the effect of the instrument change in 1943, just before the overlap period began between Township and Southside stations. This failure has likely resulted in a large error being introduced into NIWA's Hokitika trend.

Background

According to Fouhy (1992), in July 1943 both minimum and maximum thermometers were replaced:

> 26 July 1943
> The maximum thermometer was replaced. The minimum and grass minimum thermometers had persistent breaks in the columns, which the observer was allowing for. These were replaced.

This would have occurred at the Township site, as the Southside site began only in August 1943. If there was any significant temperature shift due to the replacement of the thermometers, this must be taken into account when the overlap calculation is made, otherwise all pre-1943 values will be reduced incorrectly. This is shown in the figure below.

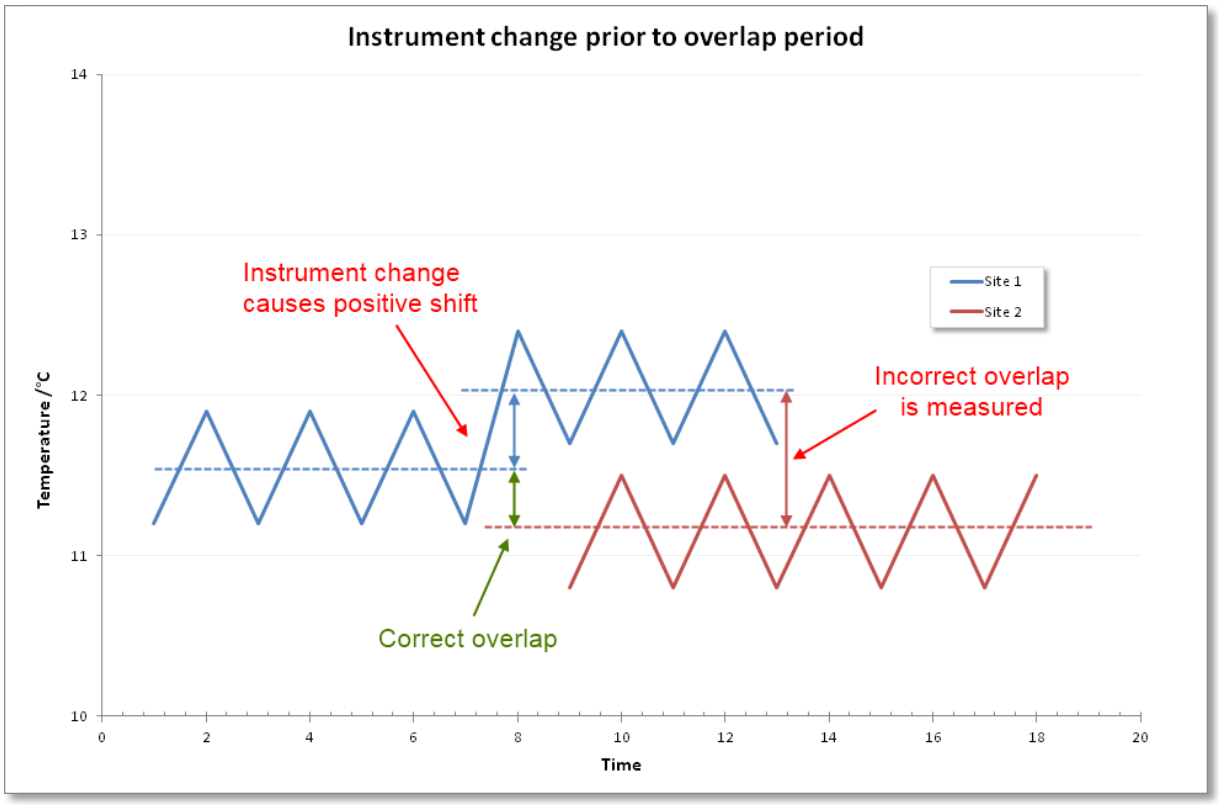


Figure 19: Example illustrating the Hokitika 1943-45 overlap problem.

We shall use the R&S method to check whether a significant shift occurred in July 1943 due to the instrument replacements.

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a largely negative temperature difference at Hokitika Town relative to the other stations. This implies the pre-1943 temperatures may need to be increased, if the shift is significant at the 95% confidence level.

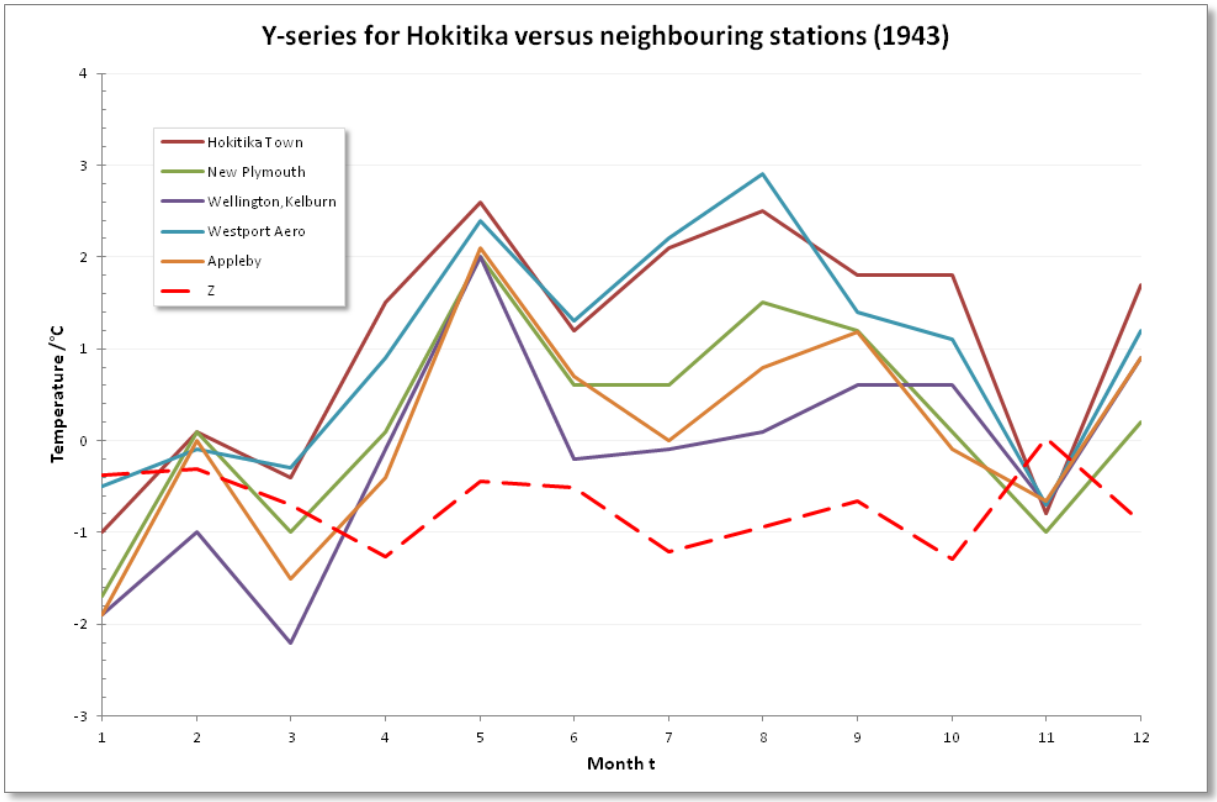


Figure 20: Hokitika temperatures versus neighbouring stations, 1943

The weighting factors were calculated using k=1, and are:

Station	ρ	w
New Plymouth	0.91	0.27
Kelburn	0.84	0.21
Westport Aero	0.95	0.34
Appleby	0.81	0.18

For the case of the 1943 adjustment, the results are:

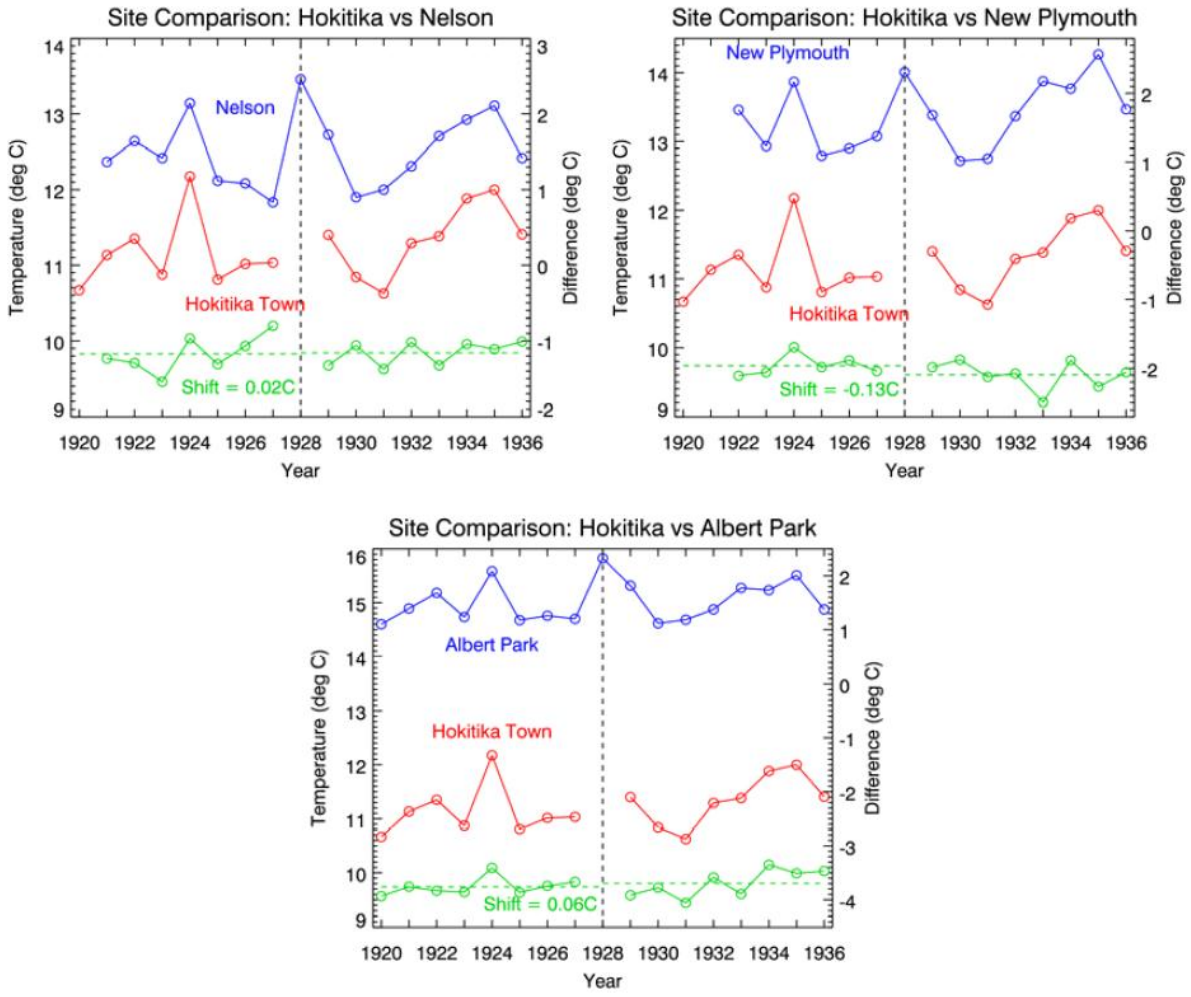
k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.72 ± 0.26 ºC	No	Yes
2	+0.41 ± 0.23 ºC	No	Yes

So the adjustment is: **raise** the pre-July 1943 values by (0.72 + 0.41)/2 = **+0.57°C**.

Site Change in 1928

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Hokitika composite series (pp 11-12)[13]. The Hokitika Town /Hokitika Southside composite is compared with various other stations, using their annual averaging method.



NIWA calculates a value of **-0.02°C** for the 1912 adjustment (0.02 – 0.13 + 0.06)/3 °C.

[13] "Creating a Composite Temperature Series for Hokitika" http://www.niwa.co.nz/__data/assets/pdf_file/0008/108917/Hokitika_CompositeTemperatureSeries_15Dec2010_FINAL.pdf

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a largely zero temperature difference at Hokitika relative to the other stations apart from a few months, with quite high variability.

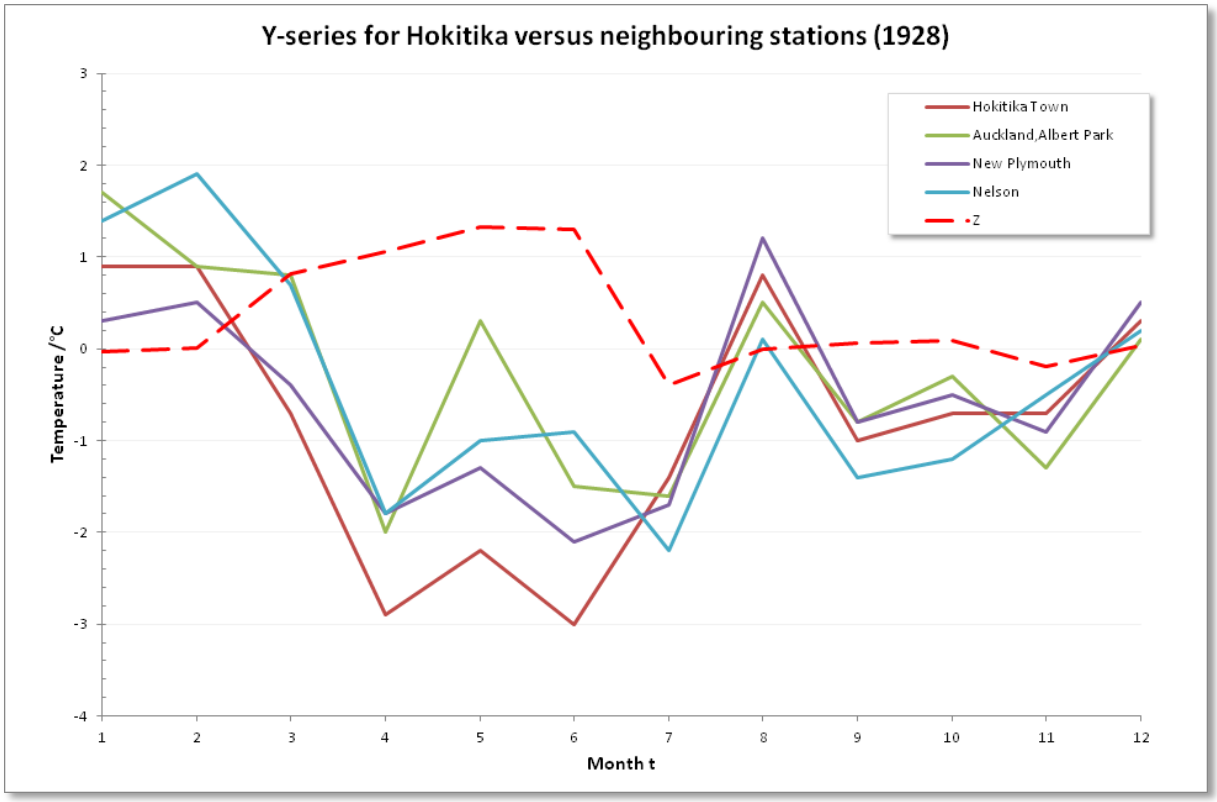


Figure 21: Hokitika temperatures versus neighbouring stations, 1928

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Albert Park	0.75	0.23
New Plymouth	0.94	0.55
Nelson	0.75	0.23

For the case of the 1928 adjustment, the results are:

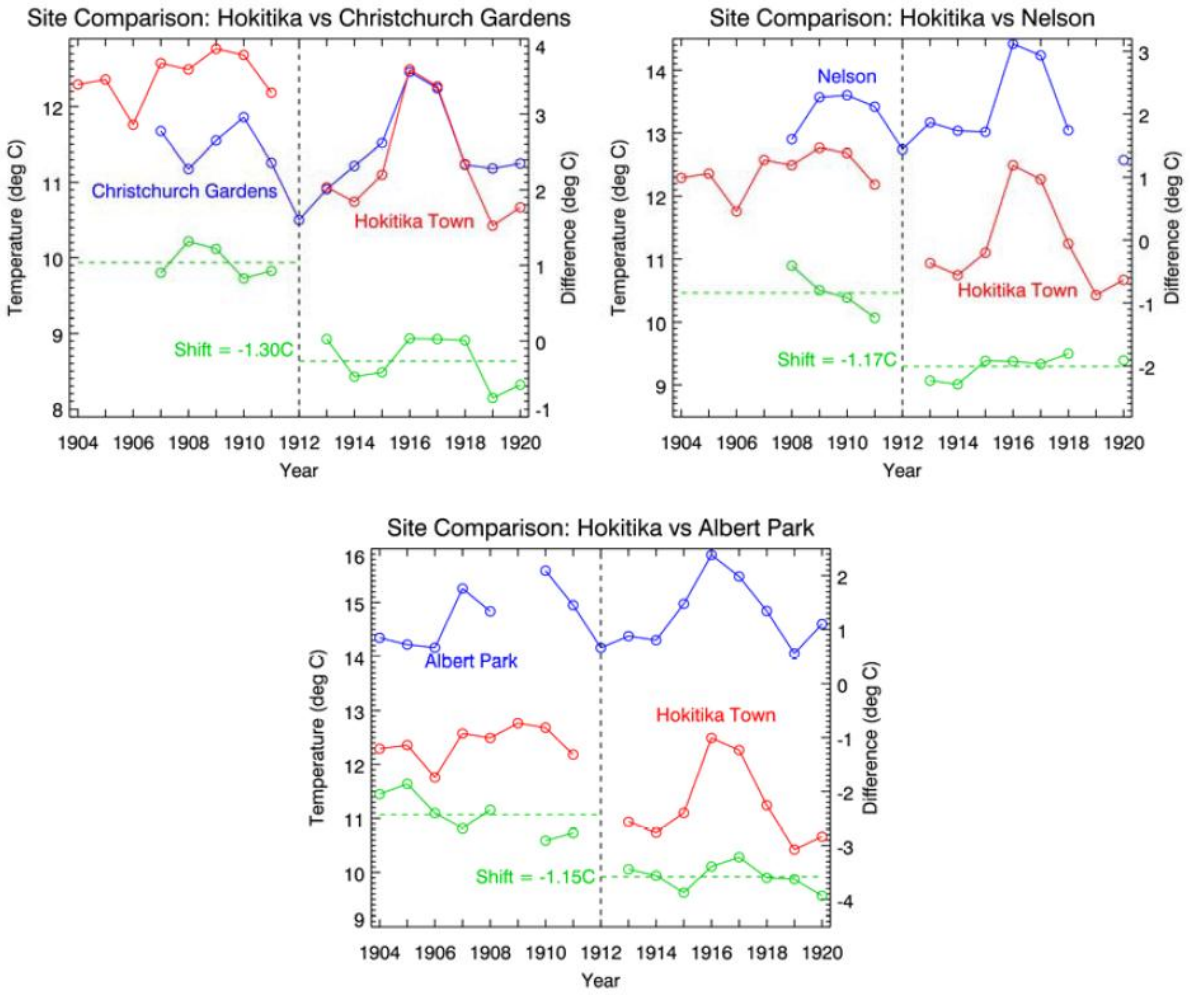
k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.34 ± 0.39 °C	Yes	No
2	-0.18 ± 0.29 °C	Yes	No

So the adjustment is not made.

Site Change in 1912

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Hokitika composite series (pp 12-13)[14]. The Hokitika Town /Hokitika Southside composite is compared with various other stations, using their annual averaging method.



NIWA calculates a value of **-1.21°C** for the 1912 adjustment (-1.30 – 1.17 – 1.15)/3 °C.

Note once again the use of annual instead of monthly values; the asymmetric before and after comparison periods; the long comparison period of 1904-1920; and the lack of any correlation-based weightings (all values are simply averaged).

[14] "Creating a Composite Temperature Series for Hokitika" http://www.niwa.co.nz/__data/assets/pdf_file/0008/108917/Hokitika_CompositeTemperatureSeries_15Dec2010_FINAL.pdf

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a generally positive temperature difference at Hokitika relative to the other stations, with very high variability. However, with only one value over 1°C, the NIWA result of 1.21°C looks doubtful.

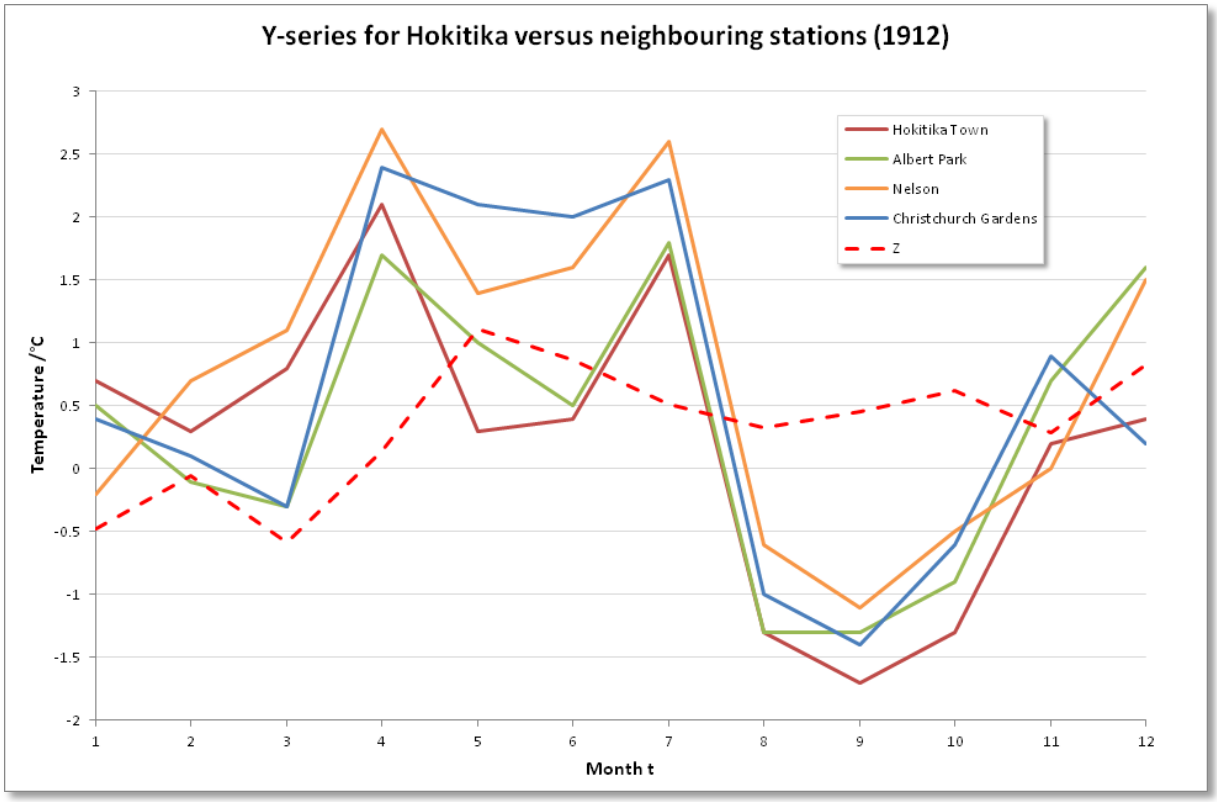


Figure 22: Hokitika Site 1/2 temperatures versus neighbours, 1912

The pre-1912 data is poor. NIWA notes this several times.

The weighting factors were calculated using *k=2*, and are:

Station	ρ	w
Albert Park	0.81	0.39
Nelson	0.80	0.37
Christchurch Gardens	0.72	0.24

For the case of the 1912 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.34 ± 0.33 °C	No	Yes
2	-0.65 ± 0.48 °C	No	Yes

The pre-1913 data is not included in the NIWA 7-station composite, but for completeness the correct adjustment is: **lower** the pre-1912 temperatures by (-0.34 - 0.65)/2 = **-0.50°C**.

Putting the Hokitika Time Series Together

The table below shows a summary of the NIWA versus R&S adjustments.

Table 2: Comparison between NIWA and R&S results

Site Label	Site Name	From	To	NIWA Adj	R&S Adj	NIWA sum	R&S sum
Site 1	Hokitika Town (3907)	Jan 1900	Aug 1912	-1.21	-0.50	-1.57	-0.27
		Sep 1912	Oct 1928	-0.02	0.00	-0.36	+0.23
		Nov 1928	Jul 1943	0.00	+0.57	-0.34	+0.23
		Aug 1943	Dec 1944	-0.68	-0.68	-0.34	-0.34
Site 2	Hokitika Southside (37939)	Jan 1945	Dec 1963	+0.29	+0.29	+0.34	+0.34
Site 3	Hokitika Aero (3909)	Jan 1964	Oct 1967	+0.05	+0.05	+0.05	+0.05
		Nov 1967	present	0.00	0.00	0.00	0.00

The time series from 1909 to 2009 is shown Figure 38 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

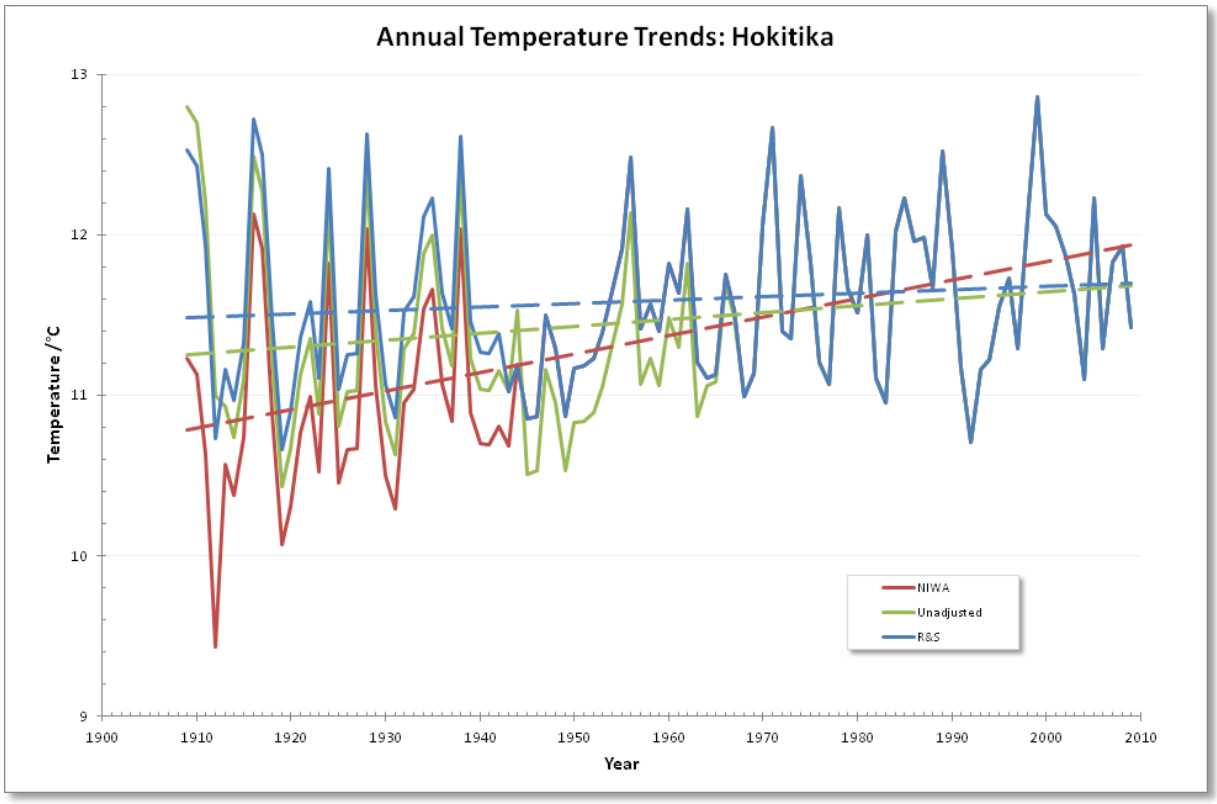


Figure 23: Annual Temperature Trends for Hokitika

The trends over the 1909-2009 period are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.44
NIWA method	1.18
Rhoades & Salinger method	0.21

The difference in trend is 1.18 – 0.21 = 0.97°C/century. This means the NIWA method overstates the Hokitika trend by 0.97/0.21 = 462%.

Nelson

We examine the Nelson temperature series, to determine if there are any differences between the results obtained using the R&S and NIWA methods. The following sections detail this process.

We have used the same station data NIWA used, and the same station shifts have been examined. Similarly, the same neighbouring stations have been used for comparisons.

Site Change in 1997

NIWA Result

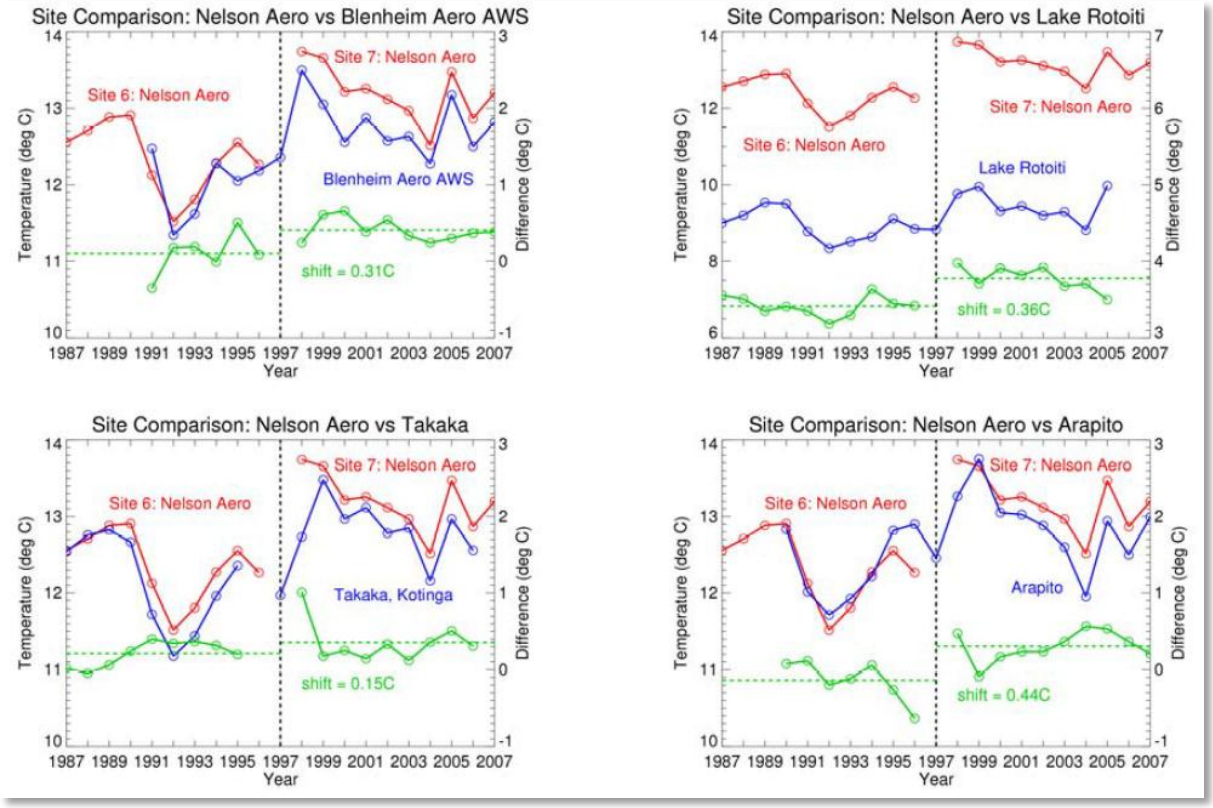


Figure 24: NIWA comparisons with Nelson 1997

The background to the examination of this site change is given in the NIWA document detailing the Nelson composite series (pp 3-7)[15].

NIWA calculates a shift of **+0.31°C** for the 1997 adjustment (0.31 +0.36 +0.15 +0.44)/4 °C.

[15] "Creating a Composite Temperature Series for Nelson" http://www.niwa.co.nz/__data/assets/pdf_file/0006/108888/Nelson_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

A visual check of the y-series for k=1 shows slightly negative temperature differences at Nelson relative to the other stations, but it varies somewhat.

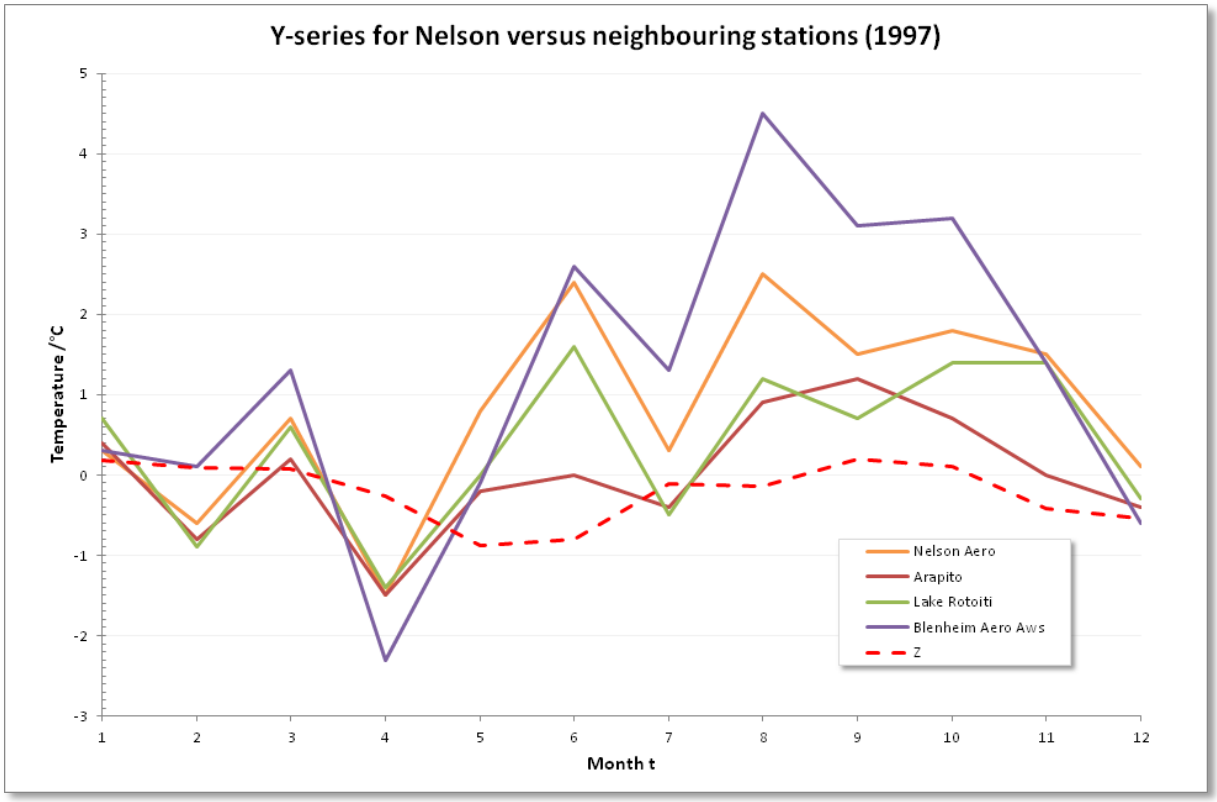


Figure 25: Nelson temperatures versus neighbouring stations, 1997

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Arapito	0.80	0.23
Lake Rotoiti	0.92	0.40
Blenheim Aero AWS	0.90	0.37

For the case of the 1997 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.21 ± 0.24 °C	Yes	No
2	+0.29 ± 0.20 °C	No	Yes
3	+0.26 ± 0.15 °C	No	Yes

In this case, where there is a deadlock between the first two k results, *k=1* should take precedence, as a significant shift should be obvious in the first year. However, since the *k=3* value is significant at the 95% confidence level, it could be used to break the deadlock, and the average of the two significant results is used: (+0.29+0.26)/2 = +0.28°C.

Therefore the Nelson Aero Site 6 temperatures must be raised by **+0.28°C**.

Site Change in 1996

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Nelson composite series (pp 8-9)[16]. The Appleby/Nelson Aero overlap is calculated by NIWA using an annual averaging method.

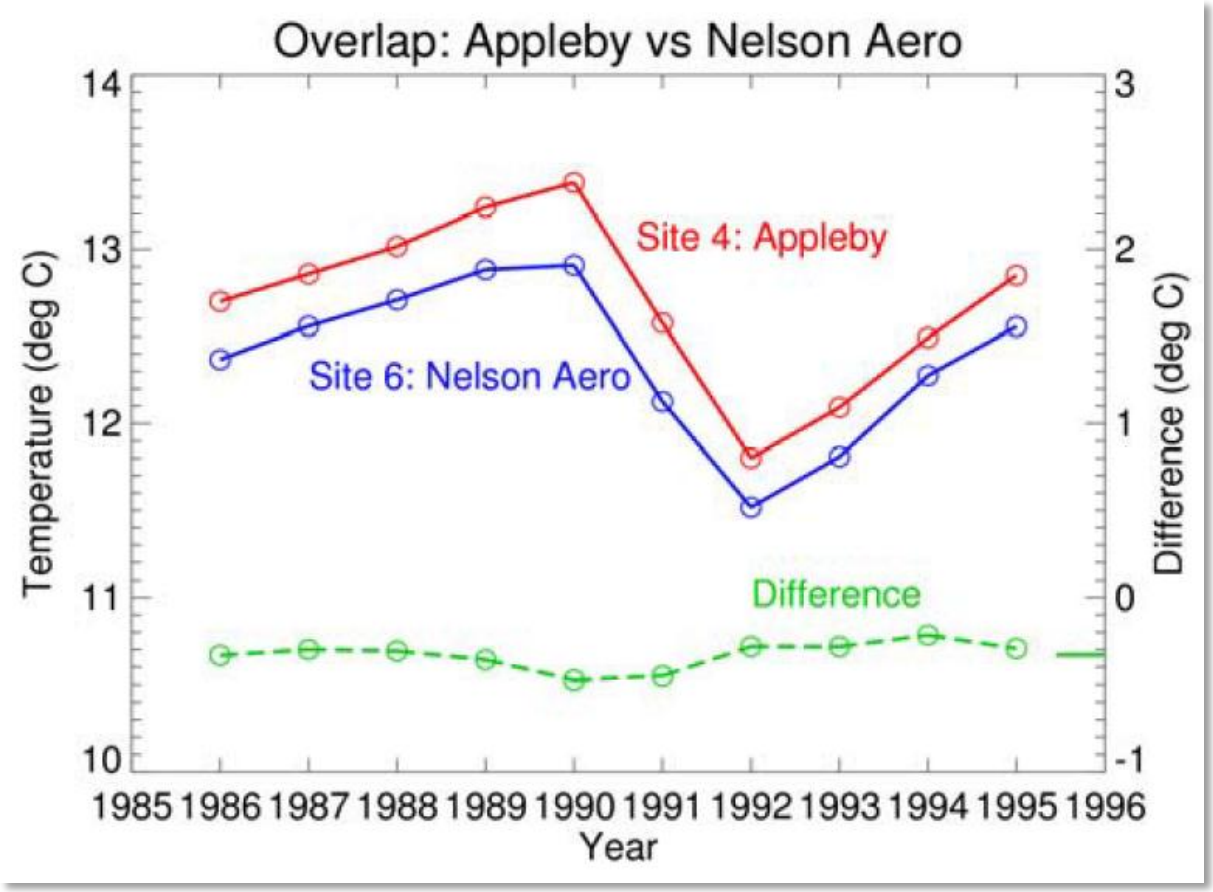


Figure 26: NIWA site comparison – Nelson 1996

NIWA calculates a shift of **-0.33°C** for the 1996 adjustment.

Note the use of annual instead of monthly values and the complete lack of calculation of errors for the purposes of determining confidence limits.

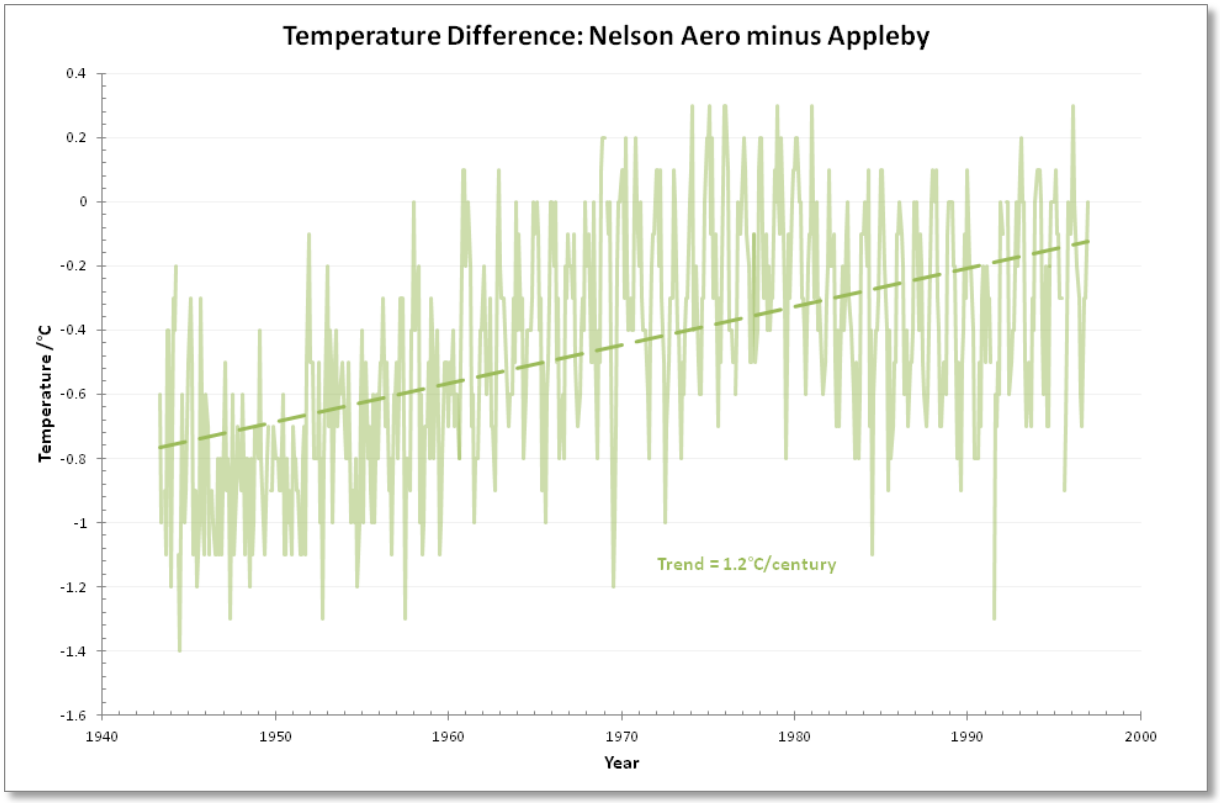
Overlap Calculation Using Monthly Temperatures

A closer look at the overlap period between Appleby (Site 4) and Nelson Aero (Site 6) reveals an interesting effect. NIWA describes Appleby as 13km west of the city and 10km west of the airport. It sounds like an ideal rural setting, surrounded by undulating hills and with the instruments situated on a grassed knoll. Nelson Aero, on the other hand, is sited at an airport, and is therefore more

[16] "Creating a Composite Temperature Series for nelson" http://www.niwa.co.nz/__data/assets/pdf_file/0006/108888/Nelson_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

likely to be influenced by the well-known problems due to urban effects. NIWA describes the Nelson Aero site as "generally an excellent site".

When we plot the differences between Appleby and Nelson Aero however, it is clear that one of the sites is being influenced by non-climatic heating or cooling. Either Nelson Aero is warming relative to rural surroundings, or Appleby is cooling relative to rural surroundings. It is, of course, far more likely that Aero is warming, due to urban heating effects.



Whatever the cause, it's obvious that when calculating overlaps between these two sites one must use the shortest possible overlap period, so as not to skew the results due to the known trend difference.

The table below shows the differences (Nelson Aero minus Appleby) based on monthly values, along with the respective 95% confidence limits.

No. of months of overlap	Difference	Significant at 95%?
12	-0.23±0.21°C	Yes
24	-0.24±0.15°C	Yes
36	-0.23±0.12°C	Yes

It is clear from the above results that a difference of -0.23°C exists at the 95% confidence level. This means that the Appleby (Site 4) temperatures must be decreased by **-0.23°C** relative to Nelson Aero.

Site Change in 1932

NIWA Result

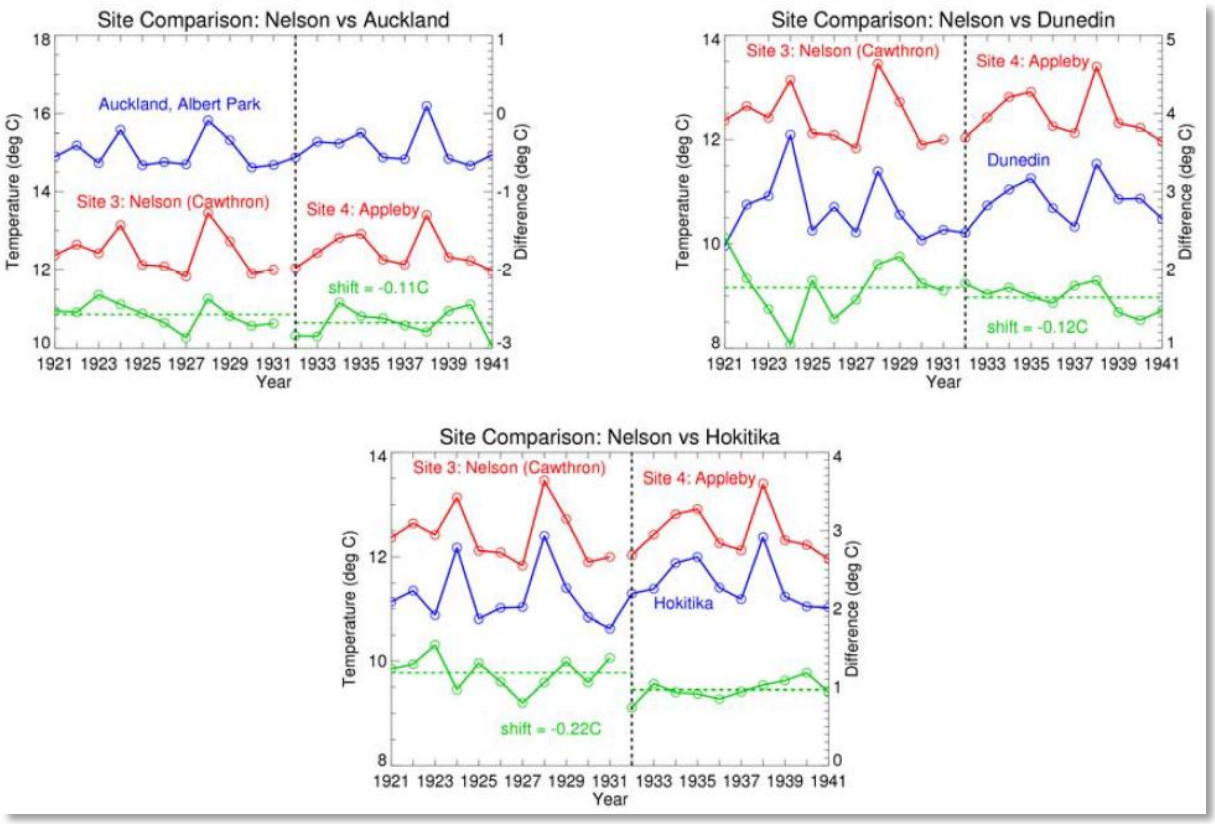


Figure 27: NIWA comparisons with Nelson 1932

The background to the examination of this site change is given in the NIWA document detailing the Nelson composite series (pp 11-12)[17].

NIWA calculates a shift of **-0.17 °C** for the 1932 adjustment (-0.11 -0.12 -0.22)/3 °C.

NIWA, in choosing neighbouring stations, rejects Wellington Kelburn and replaces it with Dunedin. This is because Kelburn has only four years of overlap. However, this is more than enough for the R&S method as it uses monthly, not annual, data.

[17] "Creating a Composite Temperature Series for Nelson" http://www.niwa.co.nz/__data/assets/pdf_file/0006/108888/Nelson_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

NIWA's subsititute (Dunedin) has very poor correlations (<0.1) during this period, and was discarded in favour of Kelburn. A visual check of the y-series for k=1 shows a highly variable temperature difference at Nelson relative to the other stations. The significance test will be important here.

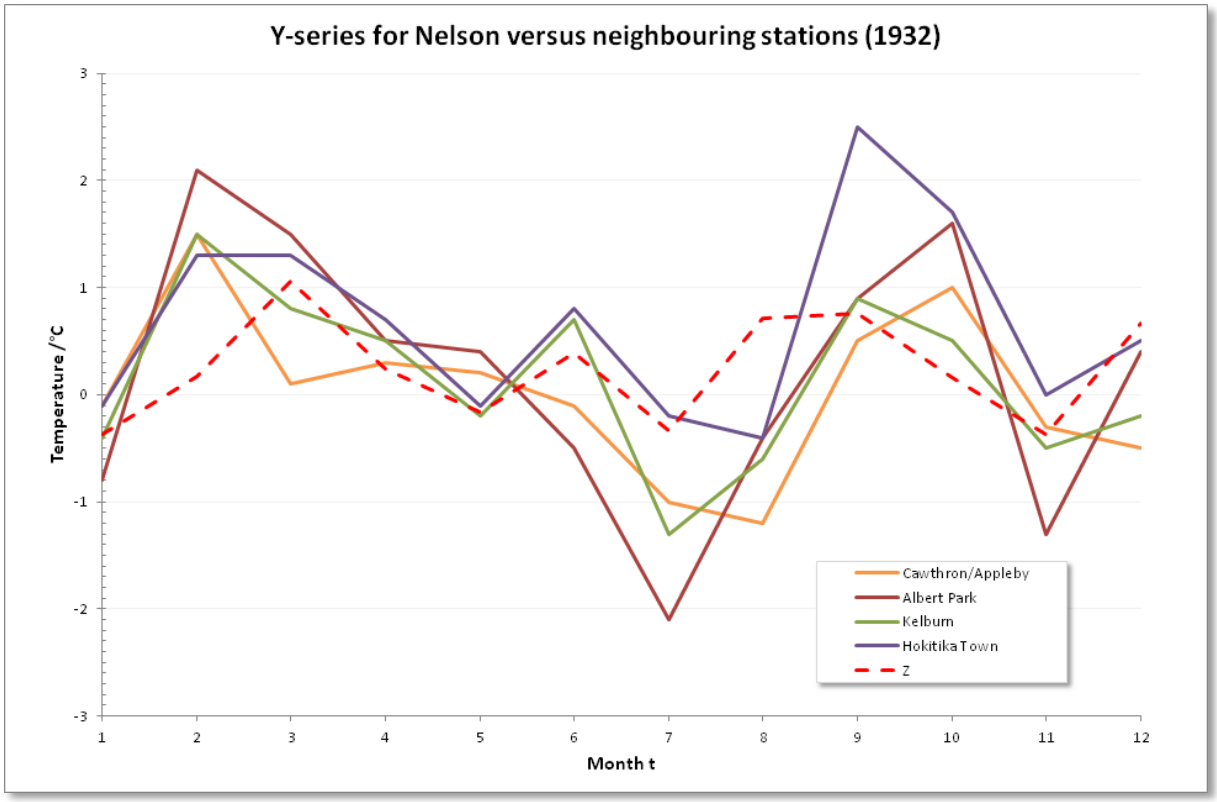


Figure 28: Nelson temperatures versus neighbouring stations, 1932

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Albert Park	0.80	0.36
Kelburn	0.83	0.42
Hokitika Town	0.71	0.22

For the case of the 1932 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.24 ± 0.31 °C	Yes	No
2	+0.21 ± 0.25 °C	Yes	No

Therefore no adjustment is made in this case.

Site Change in 1920

NIWA Result

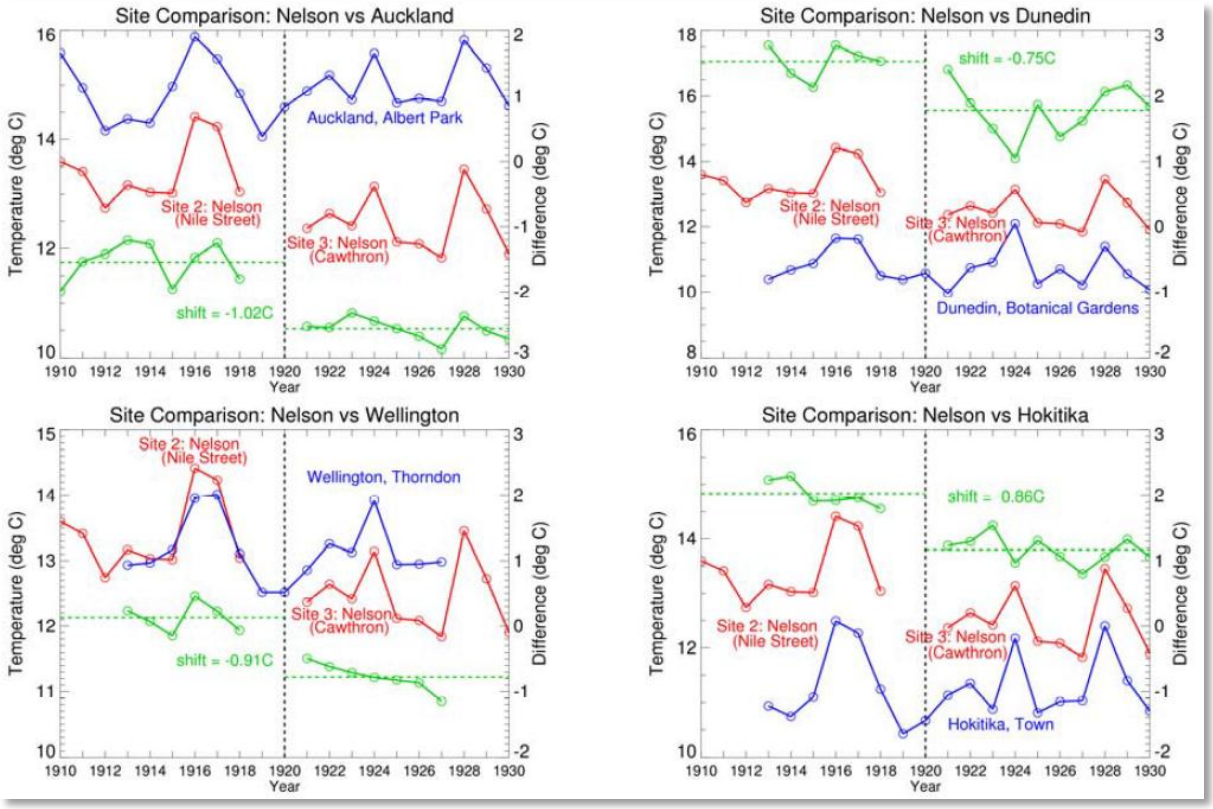


Figure 29: NIWA comparisons with Nelson 1932

The background to the examination of this site change is given in the NIWA document detailing the Nelson composite series (pgs 11-12)[18].

NIWA calculates a shift of **-0.88 °C** for the 1920 adjustment (-1.02 -0.75 -0.91 -0.86)/4 °C.

Note the use of annual instead of monthly values; the long and asymmetric comparison period of 1910-1930; the lack of any applied weightings (all values are simply averaged); and the complete lack of calculation of errors for the purposes of determining confidence limits.

[18] "Creating a Composite Temperature Series for Nelson" http://www.niwa.co.nz/__data/assets/pdf_file/0006/108888/Nelson_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

A visual check of the y-series for k=1 shows positive temperature difference at Nelson relative to the other stations. This implies that pre-1920 temperatures should be lowered, if the difference passes the 95% confidence test.

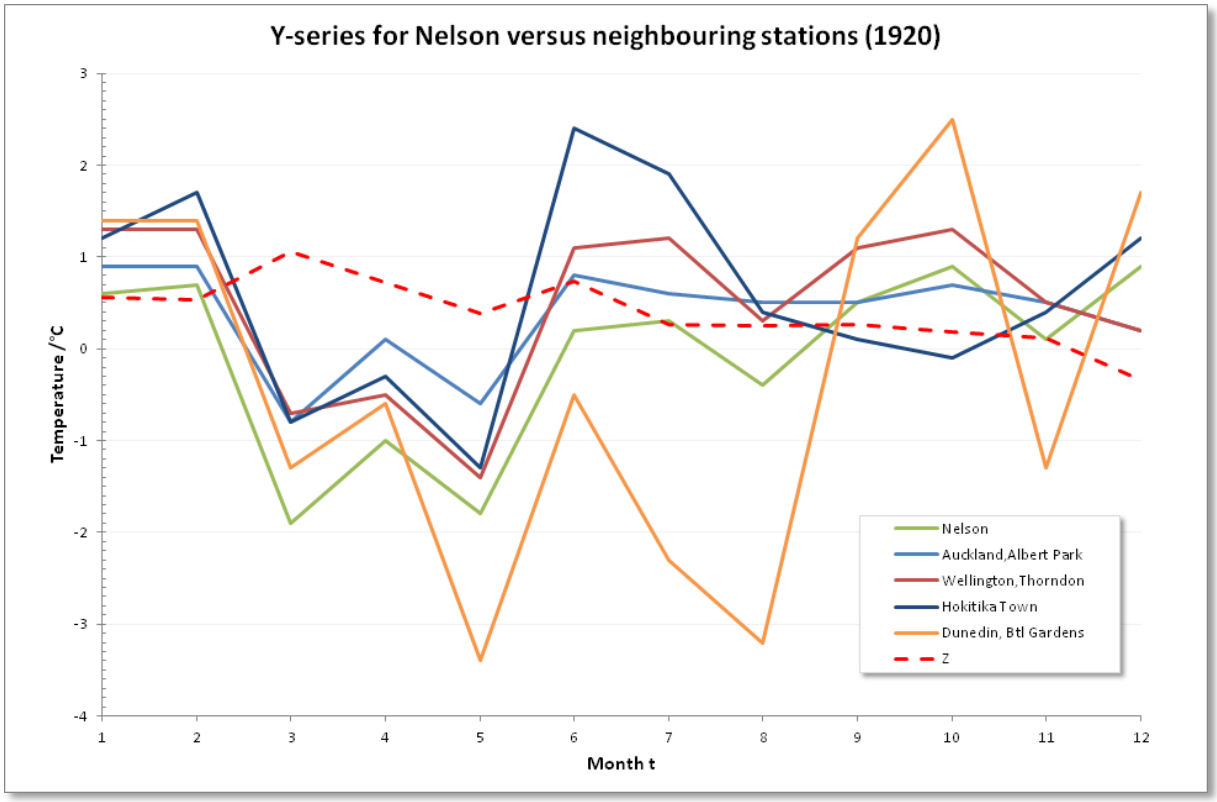


Figure 30: Nelson temperatures versus neighbouring stations, 1920

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Albert Park	0.87	0.34
Thorndon	0.89	0.37
Hokitika Town	0.69	0.14
Dunedin Botanical Gardens	0.71	0.15

For the case of the 1920 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.4 ± 0.23 ºC	No	Yes

The k=2 results were not calculated, as there are 5 months of missing minimum temperatures in 1919. However, k=2 is not necessary, considering that the k=1 result clearly shows a significant result.

Therefore the pre-1920 temperatures must be lowered by **-0.40°C**.

Putting the Nelson Time Series Together

The table below shows a summary of the NIWA versus R&S adjustments.

Table 3: Comparison between NIWA and R&S results

Site Label	Site Name	From	To	NIWA Adj	R&S Adj	NIWA sum	R&S sum
Site 2	Nelson (4244)	Oct 1907	Nov 1920	-0.88	-0.40	-1.05	-0.35
Site 3		Dec 1920	Dec 1931	-0.15	0.00	-0.17	+0.05
Site 4	Appleby (4239)	Jan 1932	Nov 1996	-0.33	-0.23	-0.02	+0.05
Site 6	Nelson Aero (4241)	Dec 1996	May 1997	+0.31	+0.28	+0.31	+0.28
Site 7		Jun 1997	present	0.00	0.00	0.00	0.00

The time series from 1909 to 2009 is shown Figure 38 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

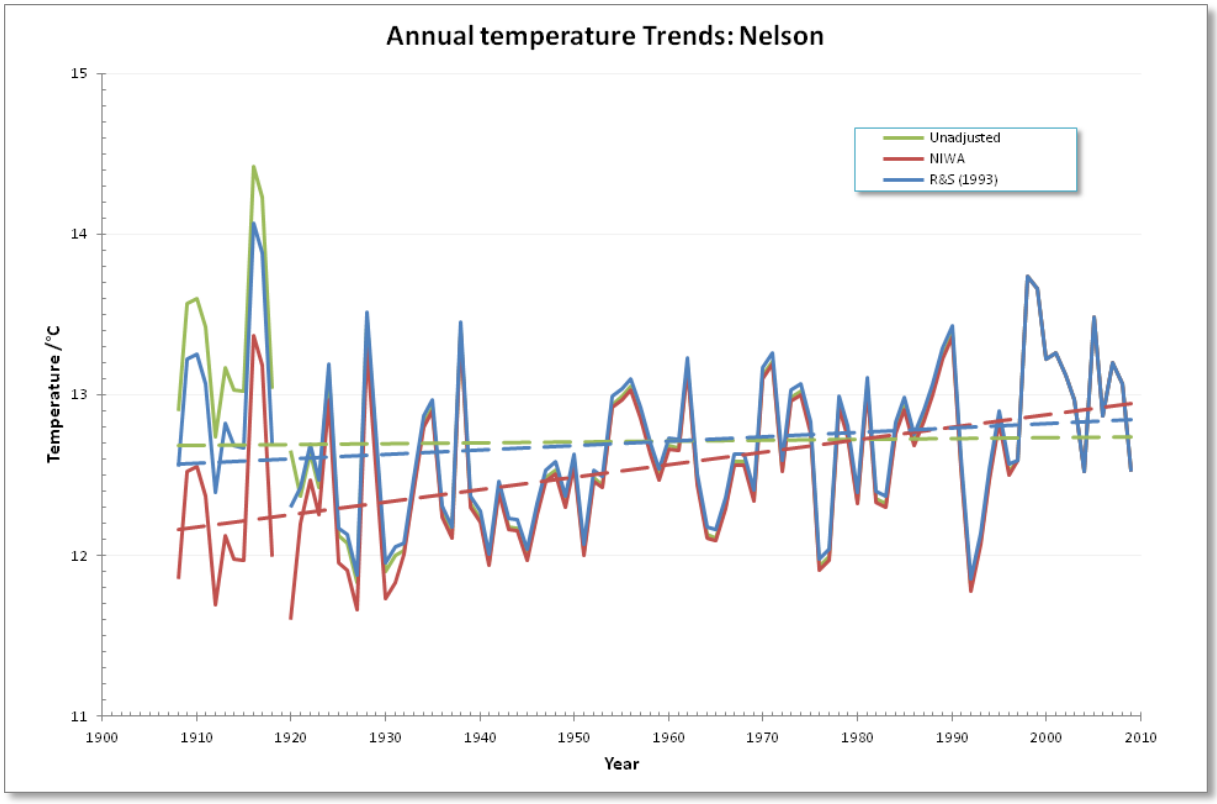


Figure 31: Annual Temperature Trends for Nelson

The trends over the 1909-2009 period are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.07
NIWA method	0.76
Rhoades & Salinger method	0.27

The difference in trend is 0.76 – 0.27 = 0.49°C/century. This means the NIWA method overstates the Nelson trend by 0.49/0.27 = 182%.

Masterton

We examine the Masterton temperature series, to determine if there are any differences between the results obtained using the R&S and NIWA methods. The following sections detail this process.

We have used the same station data NIWA used, and the same station shifts have been examined. Similarly, the same neighbouring stations have been used for comparisons.

Site Change in 1991

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Masterton composite series (pp 6-7)[19]. The Waingawa/East Taratahi overlap is calculated by NIWA using an annual averaging method.

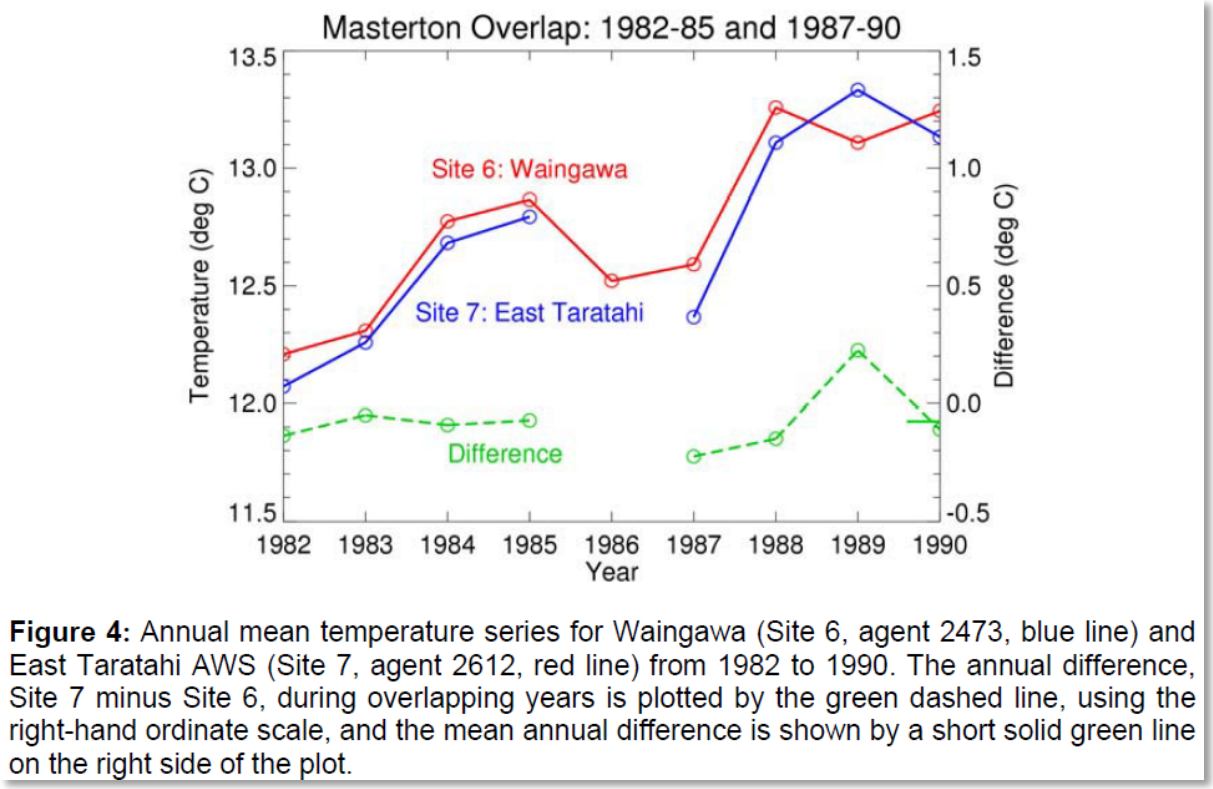


Figure 4: Annual mean temperature series for Waingawa (Site 6, agent 2473, blue line) and East Taratahi AWS (Site 7, agent 2612, red line) from 1982 to 1990. The annual difference, Site 7 minus Site 6, during overlapping years is plotted by the green dashed line, using the right-hand ordinate scale, and the mean annual difference is shown by a short solid green line on the right side of the plot.

Figure 32: NIWA site comparison – Masterton 1991

NIWA calculates a shift of **-0.08°C** for the 1991 adjustment.

NIWA provides no reason why they chose to calculate the overlap using only annual differences, when monthly data is available from both stations. Their annual average approach, as they acknowledge implicitly, has the disadvantage that several years have been eliminated from their analysis simply because some monthly data is missing.

[19] "Creating a Composite Temperature Series for Masterton" http://www.niwa.co.nz/__data/assets/pdf_file/0005/108887/Masterton_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

A far better approach is to compare monthly values, eliminating only those months where data from either site is known to be suspect (e.g. the first half of 1986 where air bubbles were present in the equipment) or simply missing.

Overlap Calculation Using Monthly Temperatures

When a more accurate analysis is performed using monthly data, the following result is obtained:

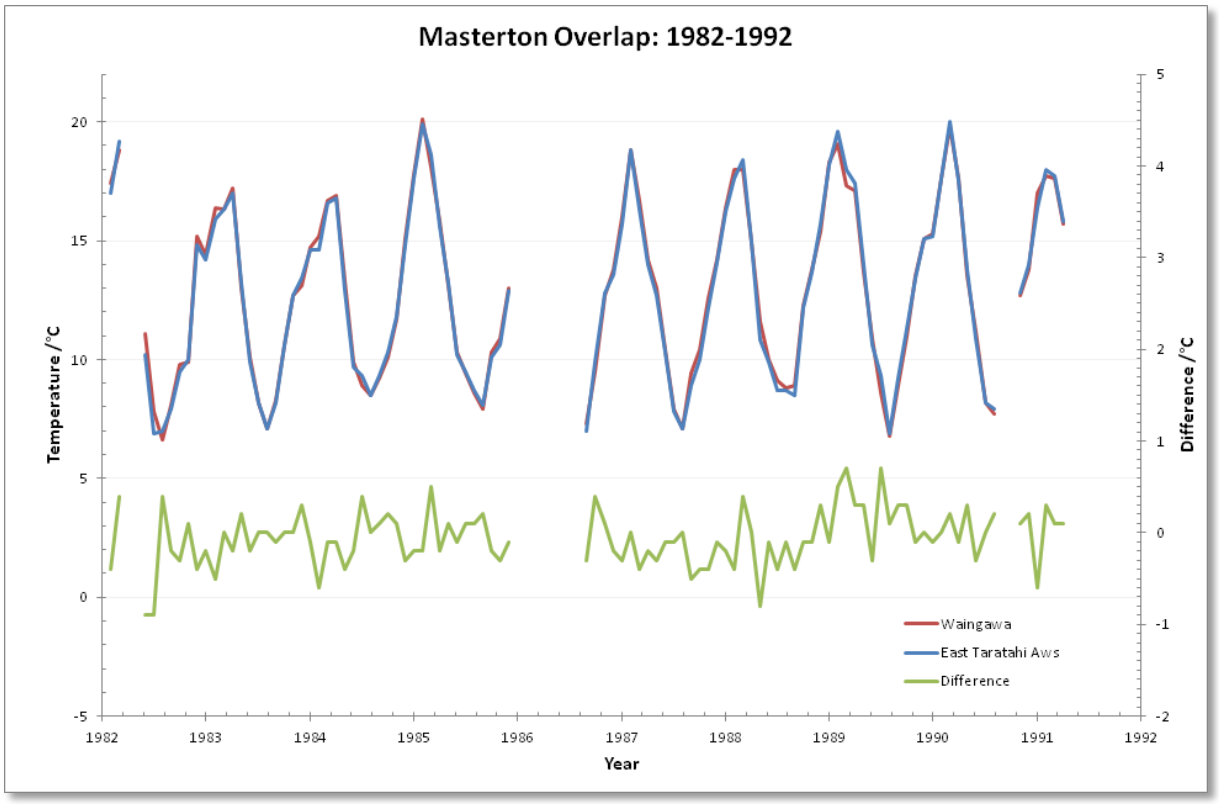


Figure 33: Masterton Overlap using Monthly Data

The analysis reveals that the East Taratahi site is in fact 0.06°C *warmer* than Waingawa during the overlap period. This is opposite to NIWA's finding.

However, when the 95% confidence limits are calculated, it is clear that this result is not statistically significant (0.059 ± 0.062°C).

Therefore no adjustment should be made for the 1991 site change. This result of 0.0°C is the same as the original NIWA (Feb 2010) assessment.

Site Change in 1942

NIWA Result

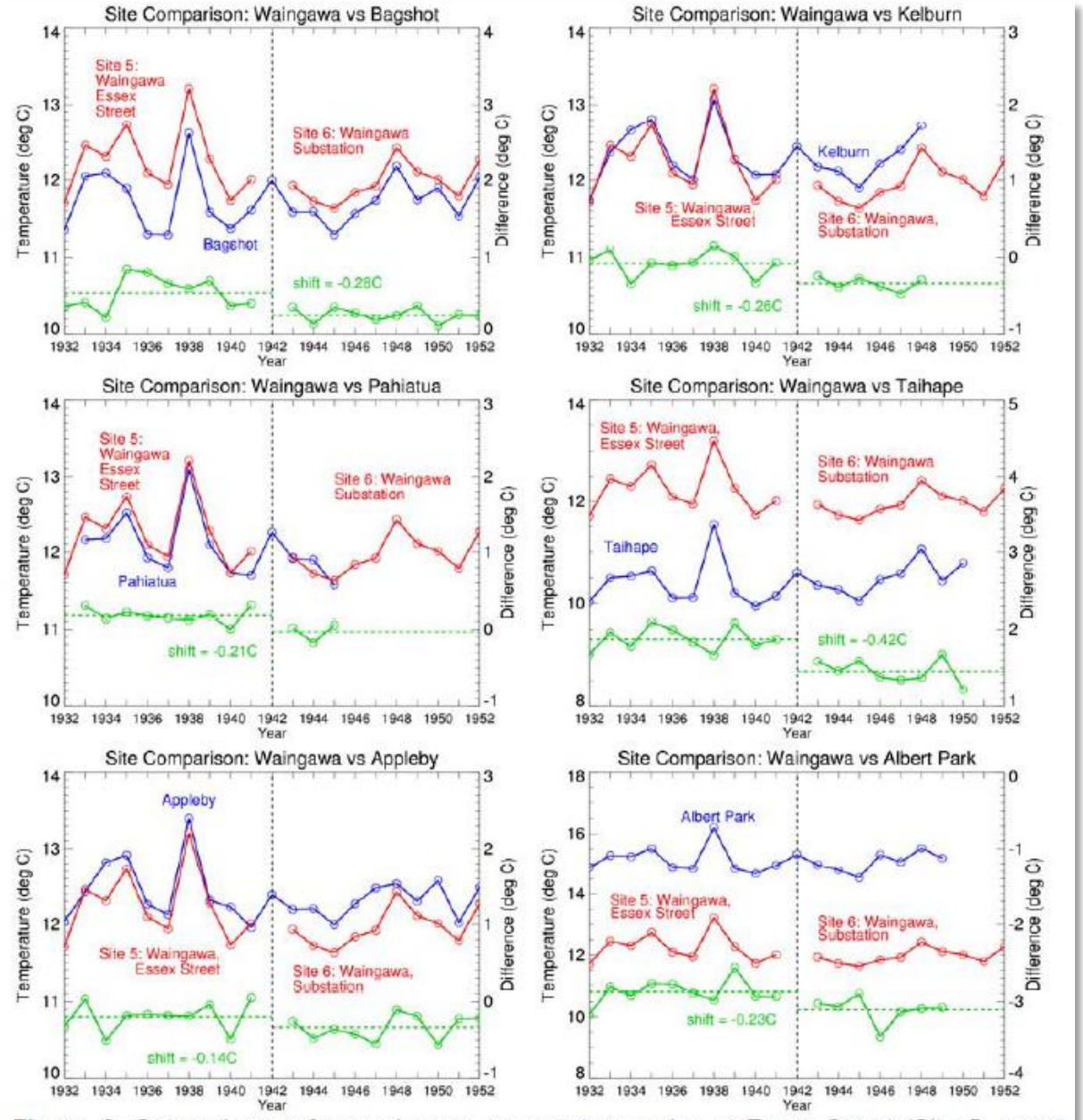


Figure 6: Comparisons of annual mean temperature series at Essex Street (Site 5, agent 2473, red lines on the left of each plot) and Waingawa substation (Site 6, agent 2473, red lines on the right of each plot) with Bagshot Station (agent 2446, blue line in upper left plot), Wellington Kelburn (agent 3385, blue line in upper right plot), Pahiatua (agent 2385, blue line in centre left plot), Taihape (agent 3669, blue line in centre right plot), Appleby (agent 4239, blue line in lower left plot) and Albert Park in Auckland (agent 1427, blue line in lower right plot), from 1932 to 1952. The differences (Waingawa minus each of the other stations) are indicated by the green solid lines, using the right-hand ordinate scale, and the mean differences relative to each Masterton site are shown by the green dashed lines. The magnitude of the mean shift across 1942 is displayed in green, while the year of the site change at Waingawa, 1942, is indicated by the vertical dashed line in the centre of each plot.

Figure 34: NIWA Masterton Site Comparisons 1942

The background to the examination of this site change is given in the NIWA document detailing the Masterton composite series (pp 7-11)[20]. The Essex Street/Substation site changeover series (agent 2473) is compared to Bagshot Station (agent 2446), Wellington Kelburn (agent 3385), Pahiatua (agent 2385), Taihape (agent 3669), Appleby (agent 4239)and Albert Park (agent 1427).

NIWA calculates a shift of **-0.26°C** (-0.28 -0.26 -0.21 -0.42 -0.14 -0.23)/6 °C for the 1942 adjustment.

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a largely zero temperature difference at Waingawa relative to the other stations (6 points above, 6 below – see dashed red line), with high variability.

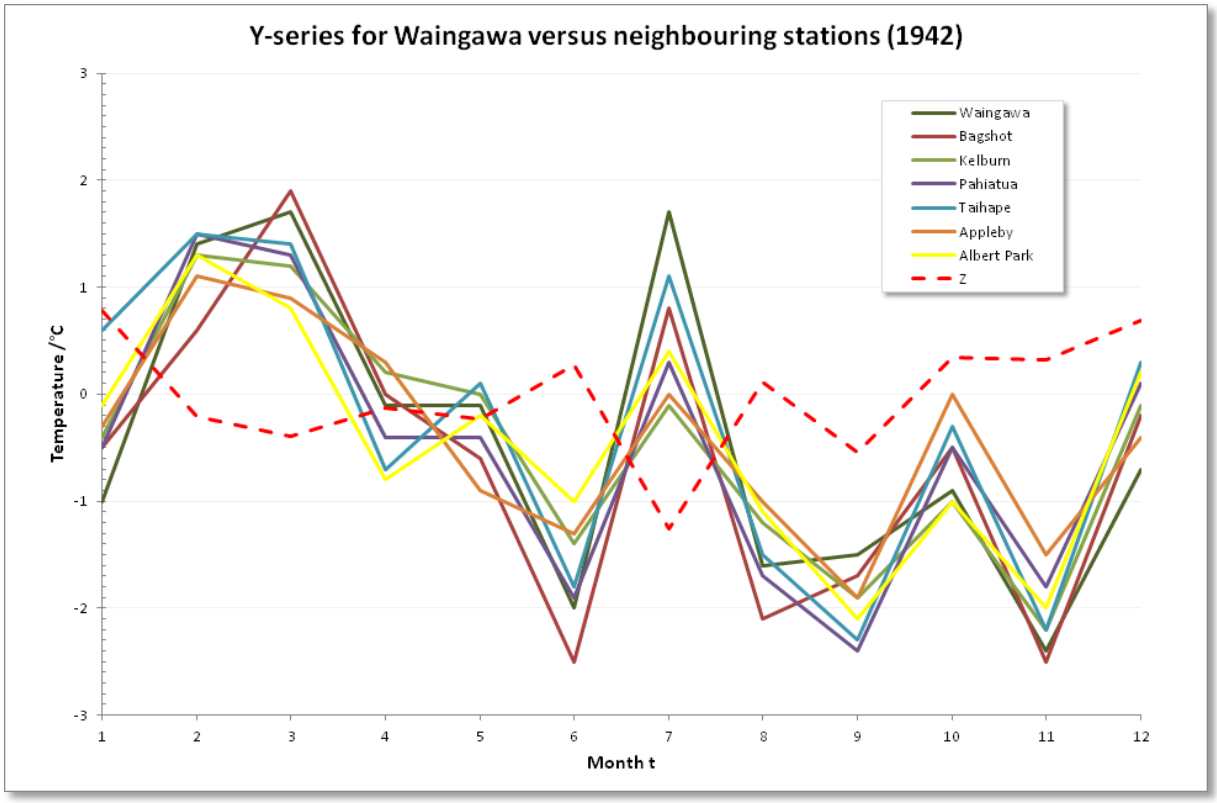


Figure 35: Masterton temperatures versus neighbouring stations, 1942

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Bagshot	0.94	0.21
Kelburn	0.88	0.17
Pahiatua	0.89	0.18
Taihape	0.88	0.16
Appleby	0.83	0.13
Albert Park	0.85	0.14

[20] "Creating a Composite Temperature Series for Masterton" http://www.niwa.co.nz/__data/assets/pdf_file/0005/108887/Masterton_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

For the case of the 1942 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.02 ± 0.36 °C	Yes	No
2	-0.14 ± 0.20 °C	Yes	No

So the adjustment is not made.

Site Change in 1920

NIWA Result

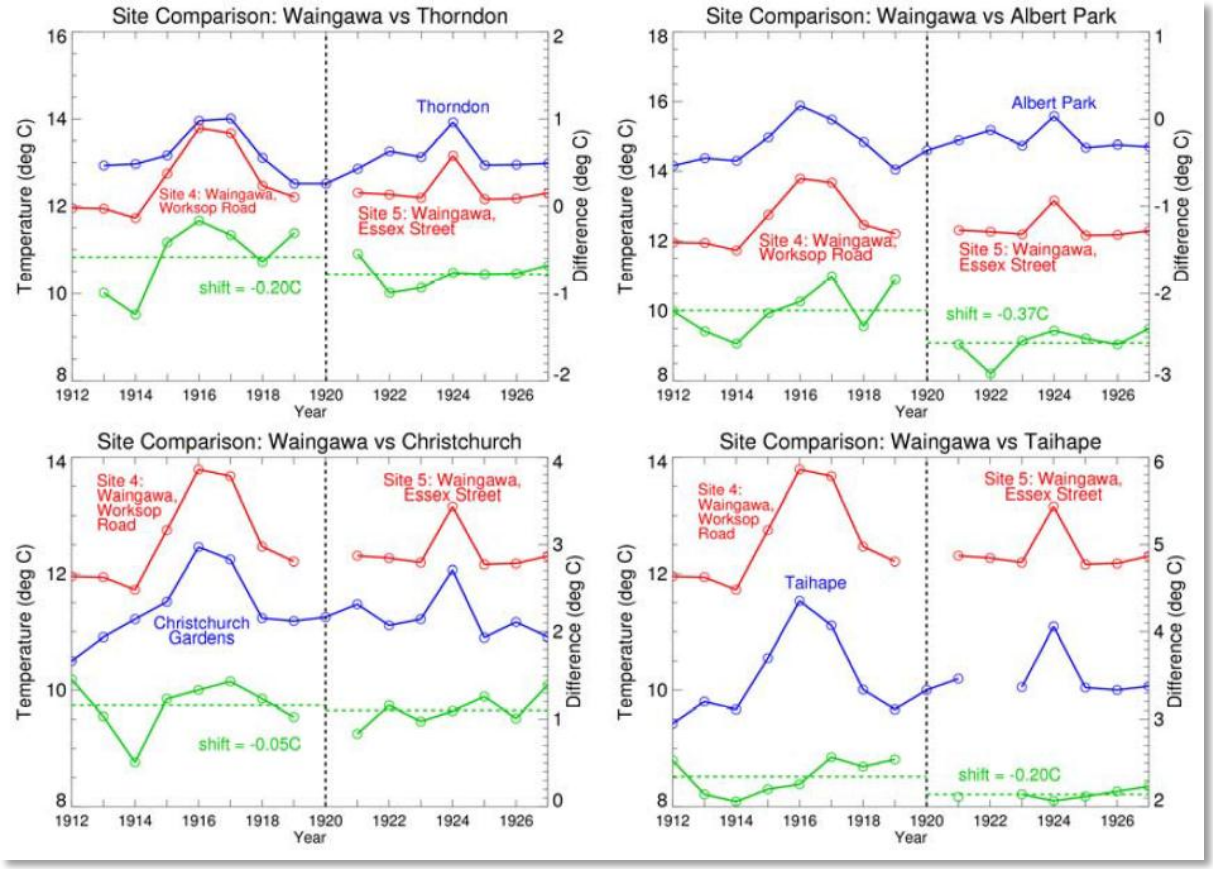


Figure 36: NIWA site comparison - Masterton 1920

The background to the examination of this site change is given in the NIWA document detailing the Masterton composite series (pp 11,12). The Waingawa Worksop Road/Essex Street changeover series (agent 2473) is compared to Thorndon (agent 3391), Albert Park (agent 1427), Christchurch Gardens (agent 4858), and Taihape (agent 3669).

NIWA arrives at a value of **-0.21°C** for the 1920 adjustment (-0.20 - 0.37 – 0.05 - 0.20)/4 °C.

Note also that in the NIWA comments they provide a good example of why the long-term annual comparison method they use is subject to various inaccuracies. In footnote 21 on page 11 they state:

> Technical Comment: In making comparisons with other sites, our approach throughout these station documents is to endeavour to compare 10 years before and 10 years after any site change (subject to additional site changes), as in Figure 6. However, differences between distant stations can be sensitive to atmospheric circulation (prevailing wind flow), and in 1928 there appears to have been a shift in circulation regime: 1928 was a year of anomalous northeasterly flow, and Waingawa recorded its 4th highest annual rainfall in the 65 years of record. Including the additional 3 years 1928-1930 in the comparison of Figure 7 makes no difference with the other 'easterly' site of Christchurch (shift is -0.06 °C instead of -0.05 °C), but causes a large divergence with the Albert Park and Taihape comparisons. (The Thorndon record ends in 1927, so it is not affected.) Since we actually want to know how temperatures at the east coast site of Waingawa varied before and after 1920, it is preferable to avoid comparison with non-east coast sites during a period in which they are responding quite differently; a comparison over such a period would only introduce greater uncertainty into the estimated adjustment.

Strangely, they nevertheless continue to persist with their own method, even though the Rhoades & Salinger method deals with this problem by using only one or two years of comparison before and after, and using correlation-based weightings to exclude sites that vary due to other influences.

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a slightly positive temperature difference at Waingawa relative to the other stations (8 points above, 1 at zero, 3 below – see dashed red line), with high variablility.

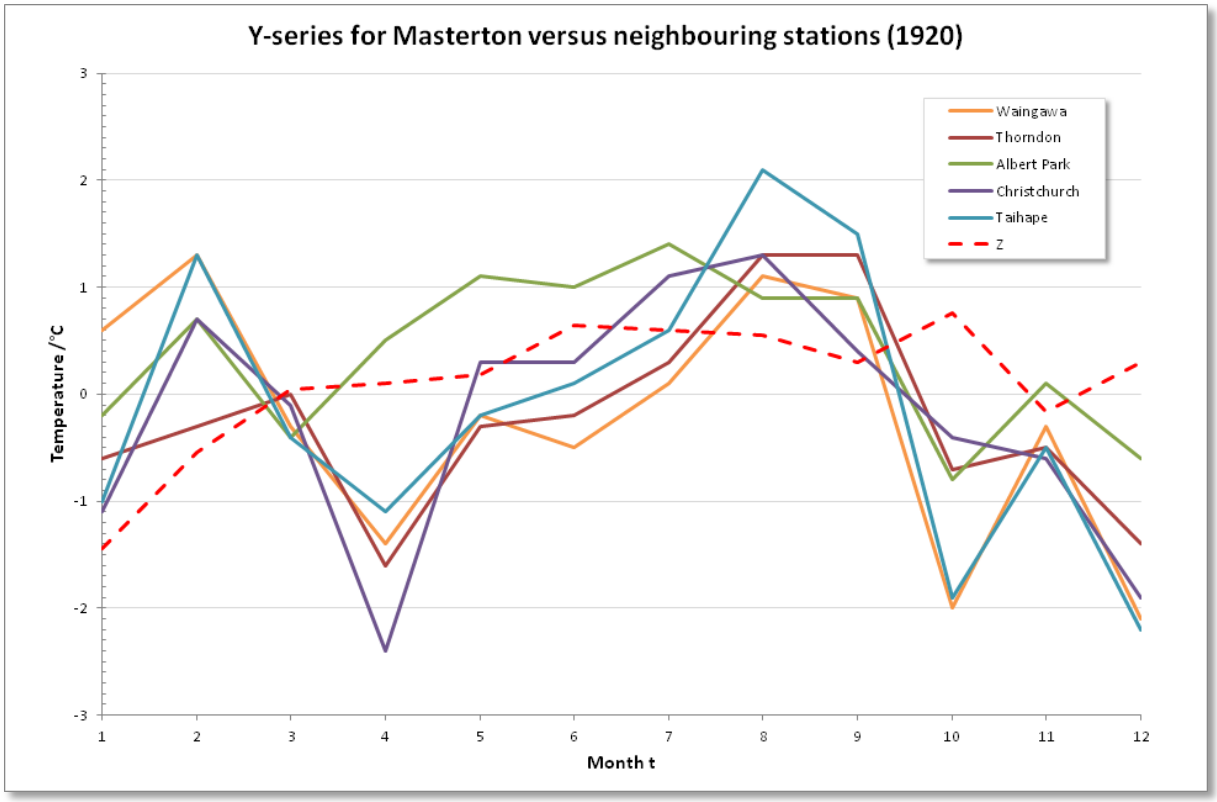


Figure 37: Masterton Waingawa Site 4/5 temperatures versus neighbours, 1920

The pre-1920 data is poor. NIWA notes this, in footnote 20 on page 11:

> Salinger (1981) noted that by comparison to observations at other stations, the Masterton temperature record prior to 1920 was only 'fair' and should be viewed with caution.

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Thorndon	0.73	0.24
Albert Park	0.58	0.09
Christchurch Gardens	0.68	0.18
Taihape	0.88	0.49

For the case of the 1920 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.11 ± 0.39 °C	Yes	No
2	-0.24 ± 0.25 °C	Yes	No

So the adjustment is not made.

Putting the Masterton Time Series Together

The table below shows a summary of the NIWA versus R&S adjustments.

Table 4: Comparison between NIWA and R&S results

Site Label	Site Name	From	To	NIWA Adj	R&S Adj	NIWA sum	R&S sum
Site 4	Waingawa (2473)	Feb 1912	Apr 1920	-0.21	0.00	-0.55	0.00
Site 5	Waingawa (2473)	Jun 1920	Sep 1942	-0.26	0.00	-0.34	0.00
Site 6	Waingawa (2473)	Oct 1942	Dec 1990	-0.08	0.00	-0.08	0.00
Site 7	East Taratahi (2612)	Jan 1991	Oct 2009	0.00	0.00	0.00	0.00

The time series from 1909 to 2009 is shown Figure 38 below. The figure shows the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively. No unadjusted series is shown, as it is identical to the R&S series in this case.

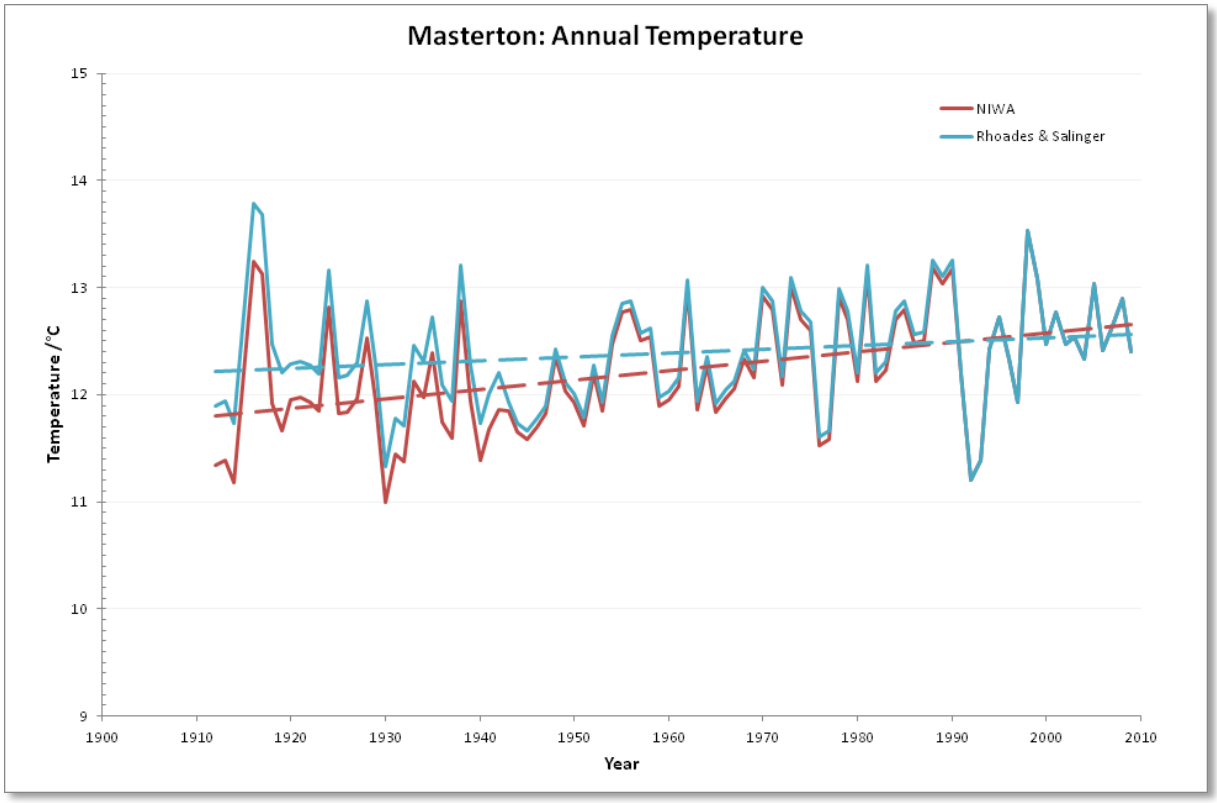


Figure 38: Annual Temperature Trends for Masterton

The trends over the 1909-2009 period are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.36
NIWA method	0.88
Rhoades & Salinger method	0.36

The difference in trend is 0.88 – 0.36 = 0.52°C/century. This means the NIWA method overstates the Masterton trend by 0.52/0.36 = 144%.

Auckland

Most of the Auckland record consists of Albert Park (Agent 1427). This is a station with known urbanisation issues, as discussed in detail in Hessell (1980) and Fouhy (1992). From Fouhy:

> A site description in 1987 notes Albert Park is a large reserve in the centre of Auckland well laid out in lawns and flower beds with a considerable number of trees both around the perimeter and scattered throughout. It is on top of a prominent section of the city and is not sheltered in any direction except by its own trees. The instrumental enclosure was on a piece of level ground at approximately the highest point in the park and the ornamental 2.5m high fence produced a slight sheltering effect. The trees surrounding the enclosure had a considerable effect on wind flow.

Notice the sentence "It is on top of a prominent section of the city and is not sheltered in any direction except by its own trees." In other words, during the early years when the trees were smaller, the cool air flowing in off the ocean would have been cut off over the years as the sheltering increased. This resulted in reducing wind speeds, and higher temperatures over time. This is best shown using Hessell's wind speed graph, which plots the wind run at Albert Park over the period 1916-1974. It is clear that wind speed dropped continually over this period due to tree growth.

Albert Park is classed by Hessell as category "A":

> … assessed to have increased sheltering from trees during the second period and/or significant urbanisation and/or screen changes.

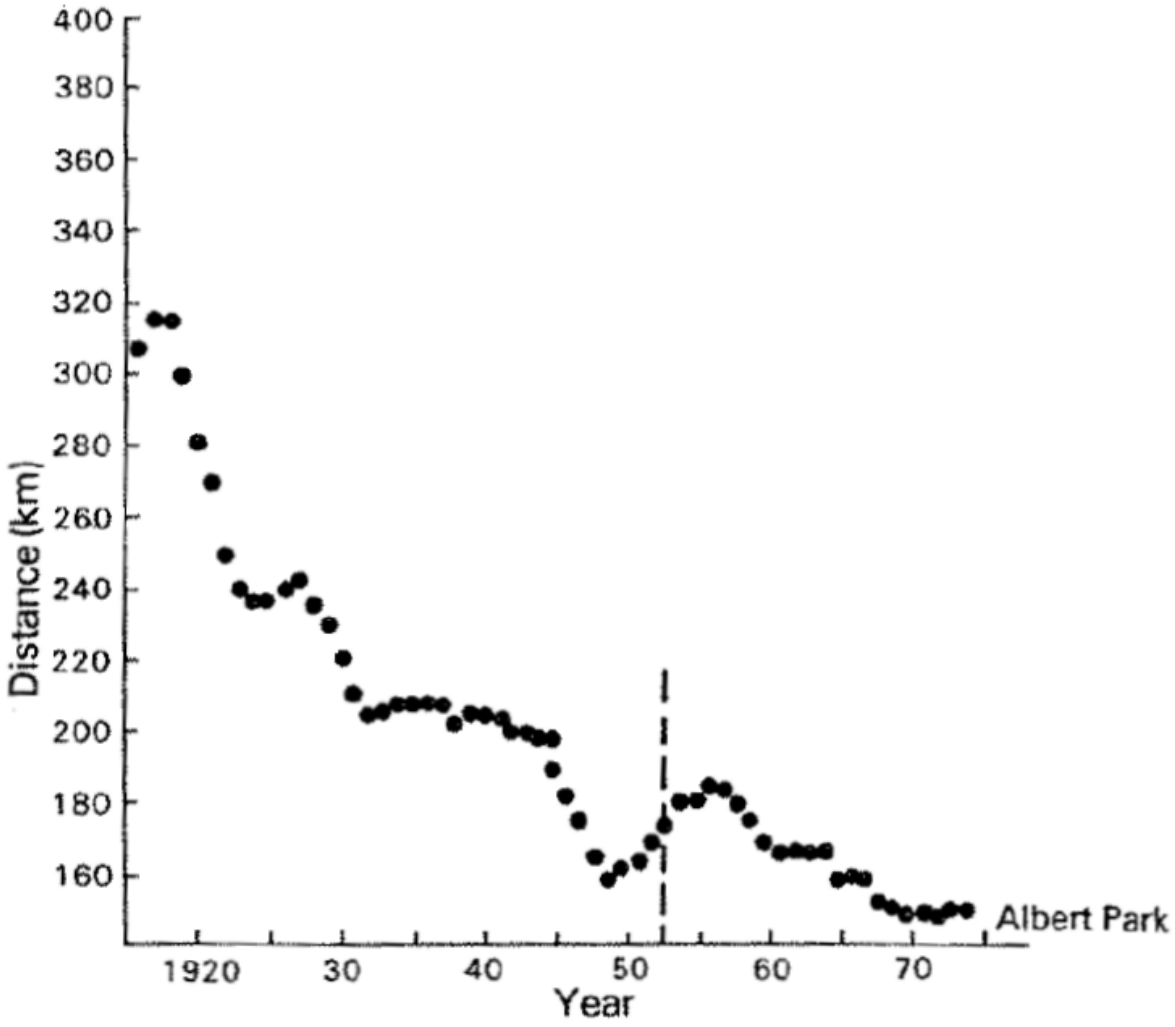


Figure 39: Five-year centred running averages of mean daily wind run at Albert Park (Hessell 1980)

The vertical dashed line represents an anemometer replacement.

As a result the Albert Park record is severely influenced by a non-climatic urban effect (sheltering). According to Rhoades & Salinger, this site must not be used:

> Gradual changes can seldom be assigned with any certainty to non-meteorological causes. Where long-term homogeneous series are required, for example, for studies of climate change, it is best to choose stations that are unlikely to have been affected by gradual changes in shading or ubanization.

In their document on Auckland, NIWA acknowledges this shortcoming (appendix 5):

> This result would suggest a sheltering influence could be affecting the Albert Park record through at least the period 1928-1960. If the Te Aroha differential is taken as an approximate measure of the sheltering effect, then the Albert Park record of mean temperature shows warming by about 0.3 °C more than it 'should' over 1928-1960 (and maximum temperature by twice the amount).

But in their Auckland analysis they effectively ignored this problem, stating:

> Reducing the Auckland warming by 0.3 °C would reduce its century trend and bring it more in line with those at other New Zealand locations. However, further research is required to provide more confident bounds on the correction of the early Auckland record for non-climatic warming.

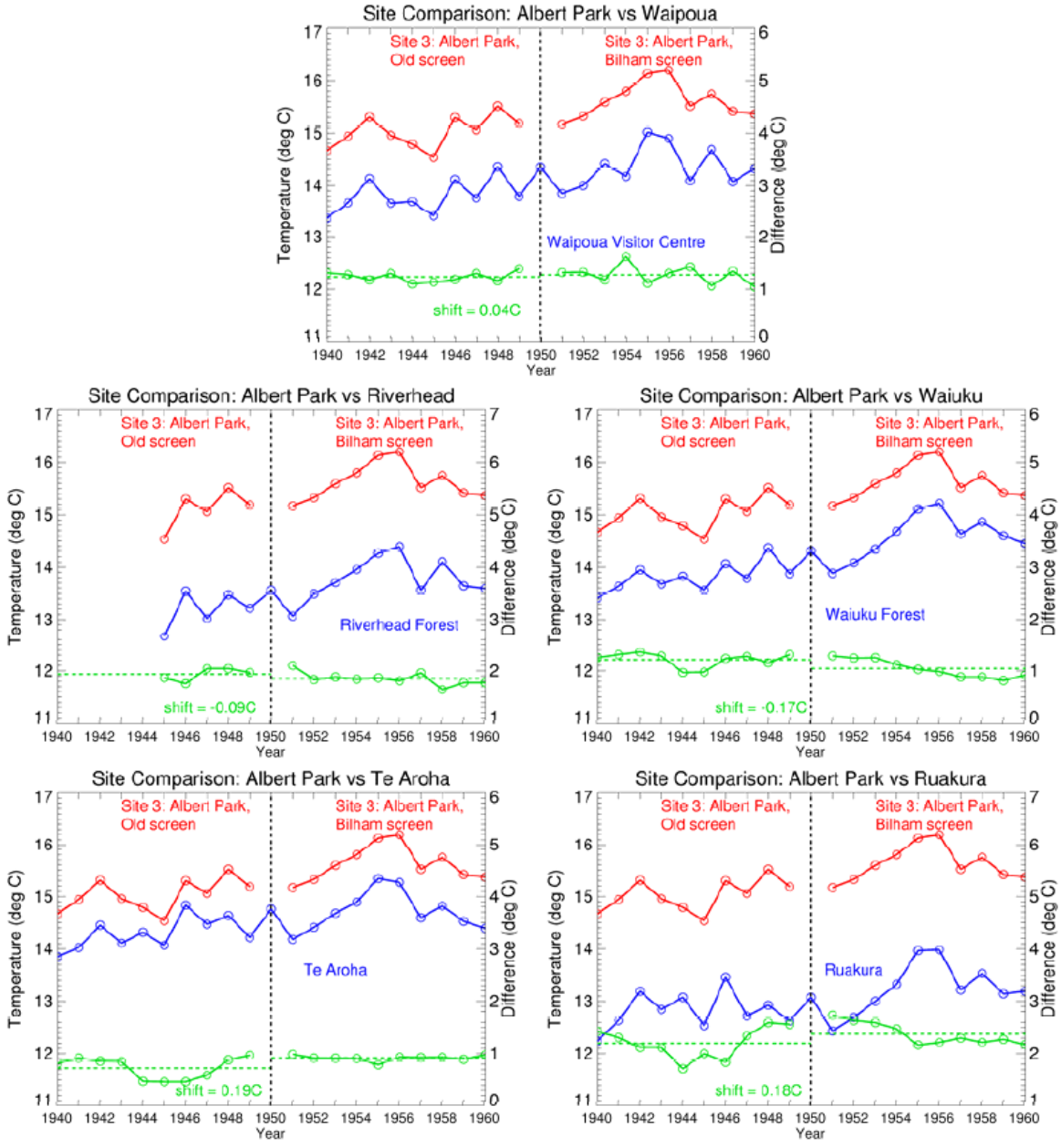
As stated above, the correct R&S approach is to discard this site entirely. However, since NIWA have included it in their composite series, we will attempt to cater for the problems ignored by NIWA. What we will do is try to ascertain the magnitude of the non-climatic sheltering effect by following NIWA's lead and comparing Albert Park with a neighbour station, Te Aroha, which is suitably rural. NIWA claims the effect is limited to 1928-1960, but it's clear from Hessell's wind speed plot that the sheltering problem continued well beyond 1960. In fact we know for certain that Albert Park experienced a known wind speed reduction from 1916 to 1974.

We shall then attempt to adjust for this artificial warming trend before joining the Albert Park and Auckland Aero sites together.

Screen Change in 1950

NIWA Result

First of all, the screen change in 1950 at Albert Park must be dealt with. The background to the examination of this site change is given in the NIWA document detailing the Auckland composite series (pp 8-11)[21]. The Albert Park site is compared with various other stations, using their annual averaging method.



NIWA calculates a nominal **+0.03°C** difference due to the screen change.

[21] "Creating a Composite Temperature Series for Auckland" http://www.niwa.co.nz/__data/assets/pdf_file/0011/108884/Auckland_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a slightly positive temperature difference at Albert Park relative to the other stations, but with high variability.

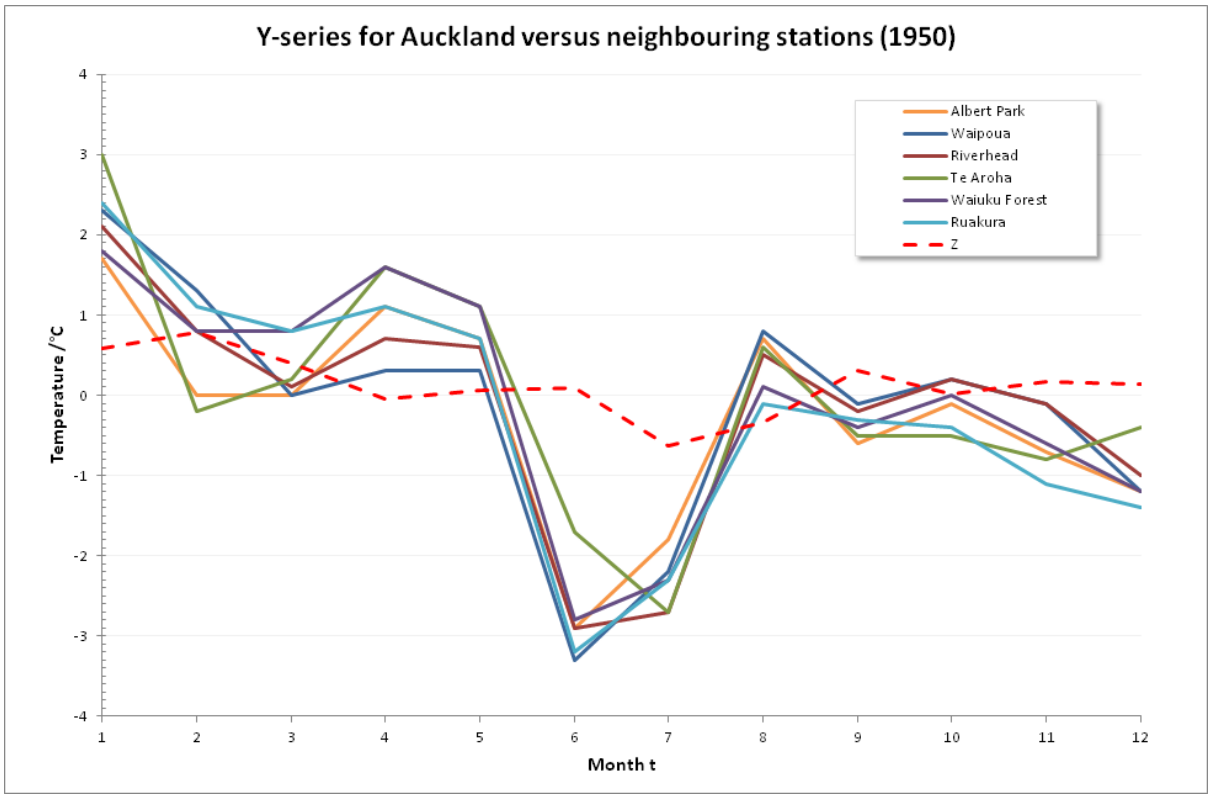


Figure 40: Auckland (Albert Park) Site temperatures versus neighbours, 1950

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Waipoua	0.92	0.19
Riverhead	0.95	0.21
Te Aroha	0.90	0.17
Waiuku Forest	0.96	0.22
Ruakura	0.94	0.20

For the case of the 1950 screen change, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.13 ± 0.24 °C	Yes	No
2	-0.03 ± 0.18 °C	Yes	No

So the adjustment is not made.

NIWA's Error in Dealing with the Sheltering Problem at Albert Park

The first step when dealing with the sheltering problem is to compare Albert Park with a nearby rural site. Unfortunately there are few very near neighbours during this period that do not have sheltering problems of their own. The nearest good rural site is Te Aroha. This site was examined by Hessell in his 1980 paper, and declared to be a good rural site unaffected by any known sheltering or urbanization effects.

When the temperature differences are calculated over the period 1928 to 1974 (the pre-1928 values are apparently unusable at Te Aroha), there is an obvious and persistent trend of 0.91°C/century. In other words, Albert Park is warming by an extra 0.91°C per century due to non-climatic effects such as sheltering due to tree growth. It is assumed that the same rate applies in the 1916-1928 period.

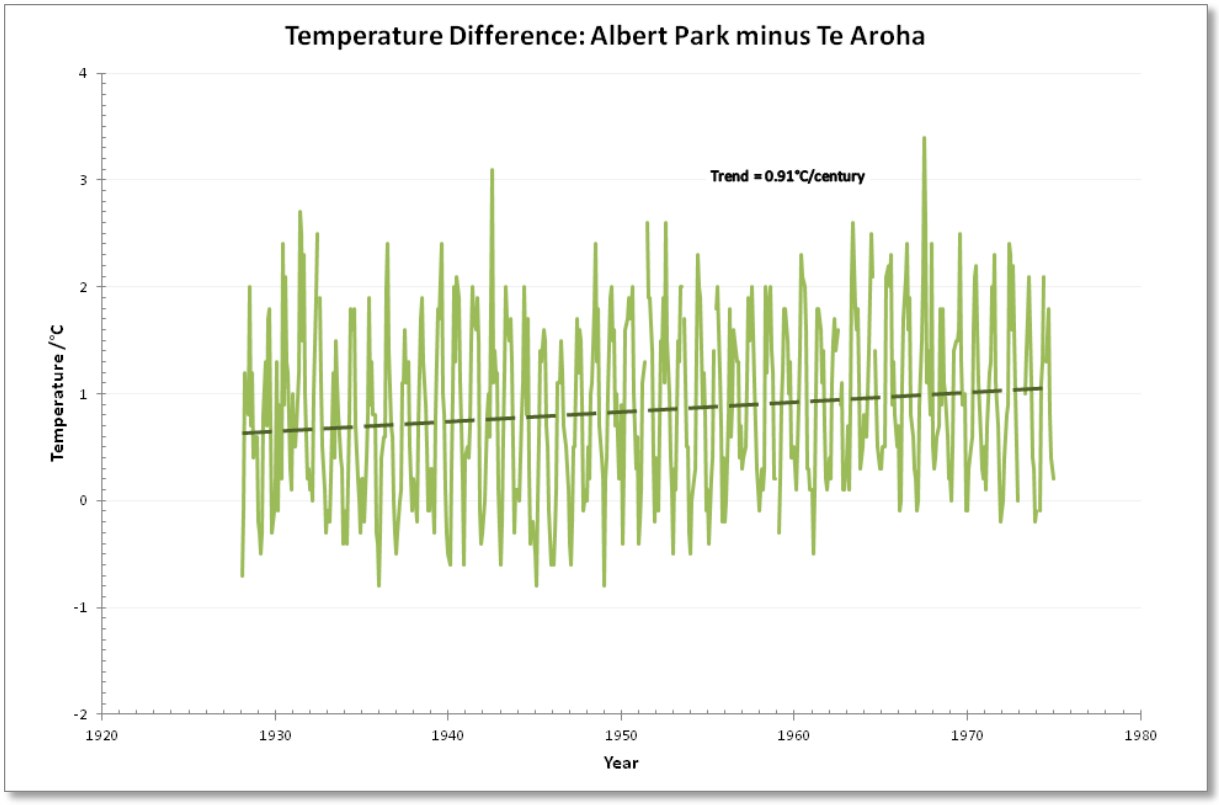


Figure 41: Albert Park warming relative to Te Aroha

This warming trend must therefore be subtracted from the raw Albert Park data; otherwise the end point in 1974 will effectively be about 0.53°C higher (0.0091 x 58 years) than it should be, had the sheltering not occurred.

If this reduction in trend is not carried out, it would invalidate any overlap comparison performed on the series, and would in fact compound the already existing warming trend even further by lowering the entire site record by the erroneous overlap amount.

This is exactly the error NIWA have made when assembling the Auckland series. The error is best illustrated using a diagram from Hansen et al. (2001)[22]:

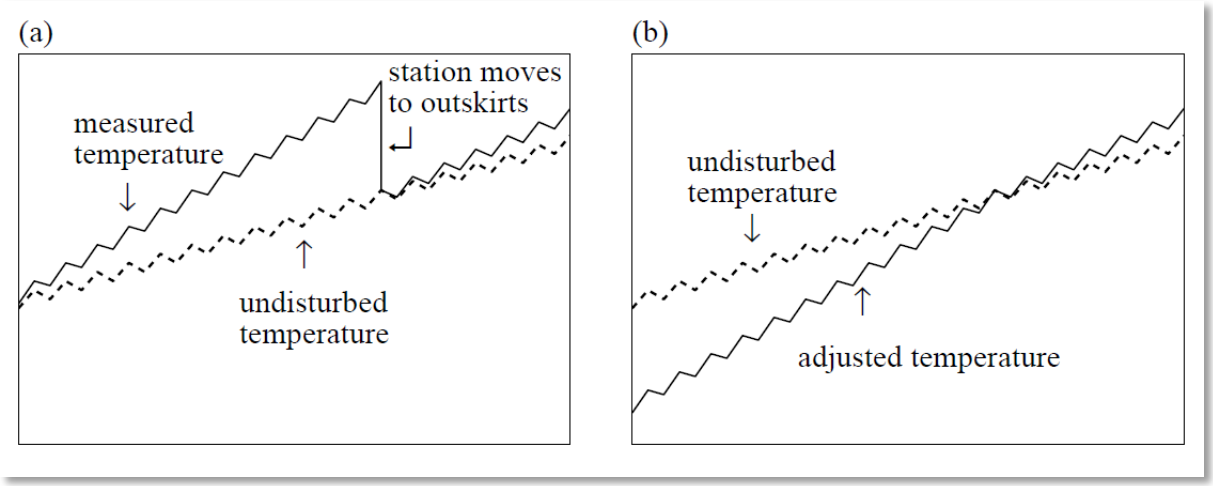


Figure 42: Schematic illustration of a temperature record at a site experiencing urban warming

The full caption for this figure from Hansen (2001) reads:

> (a) Schematic illustration of a temperature record at a site experiencing urban warming and a station move from the urban center to the urban outskirts.
> (b) The temperature record adjusted for the discontinuity has a stronger warming trend than that in the undisturbed environment.

Imagine in the Fig 42 (a) above that the first station is Albert Park, and the second is Mangere, and Albert Park is warming anomalously due to an urban sheltering effect, as is well known. NIWA does not adjust for this effect, and then calculates an overlap between Albert Park and Mangere of 0.66°C. They then reduce the Albert Park series by 0.66°C (see the second picture (b)). This is shown below.

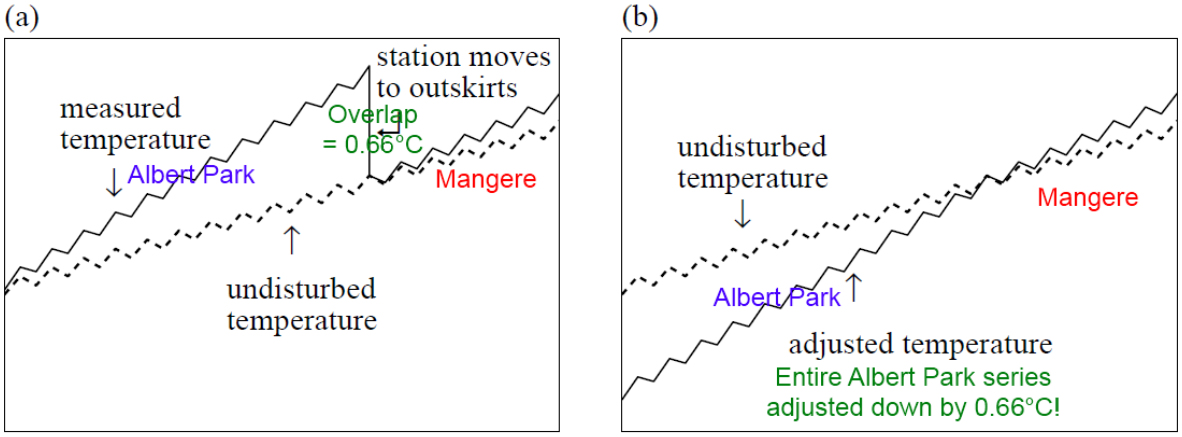


Figure 43: Erroneous adjustment by NIWA

It is obvious from Fig 43 above that this is a serious error. Where the adjustment should have produced the dashed line labelled "undisturbed temperature", it has instead greatly exacerbated the warming trend.

[22] Hansen, J.; Ruedy, R.; Sato, M.; Imhoff, M.; Lawrence, W.; Easterling, D.; Peterson, T.; Karl, T., 2001: A closer look at United States and global surface temperature change. *J. Geophys. Res*., 106, 23 947–23 963

This explains why NIWA's Auckland record has a trend much higher than any of the other sites they use in their seven-station composite series, and has nothing to do, as they claim, with anomalous warming in the Auckland region.

Adjusting for the Sheltering Problem at Albert Park

The simplest approach to take is to reduce the trend at Albert Park by the known non-climatic trend of 0.91°C/century. This has the effect of dropping the Albert park record in Figure 43 back down to the correct "undisturbed temperature" line, before any overlaps are calculated.

The non-climatic trend was calculated above by comparing Albert Park to Te Aroha, a site known to be free of urban effects, and was found to be 0.91°C/century, or 0.0091°C/year.

To reduce the trend, one starts at 1916 (the first year of provable wind speed reduction) and then one subtracts temperatures from the Albert Park series using the equation $\Delta T = m\Delta t$ where m is the trend reduction rate (-0.0091°C/year) and Δt is the number of years measured from January 1916.

By the time the end of the known sheltering period is reached in 1974, the shift is -0.53°C. This constant shift of -0.53°C is then applied for the remainder of the Albert Park temperature series.

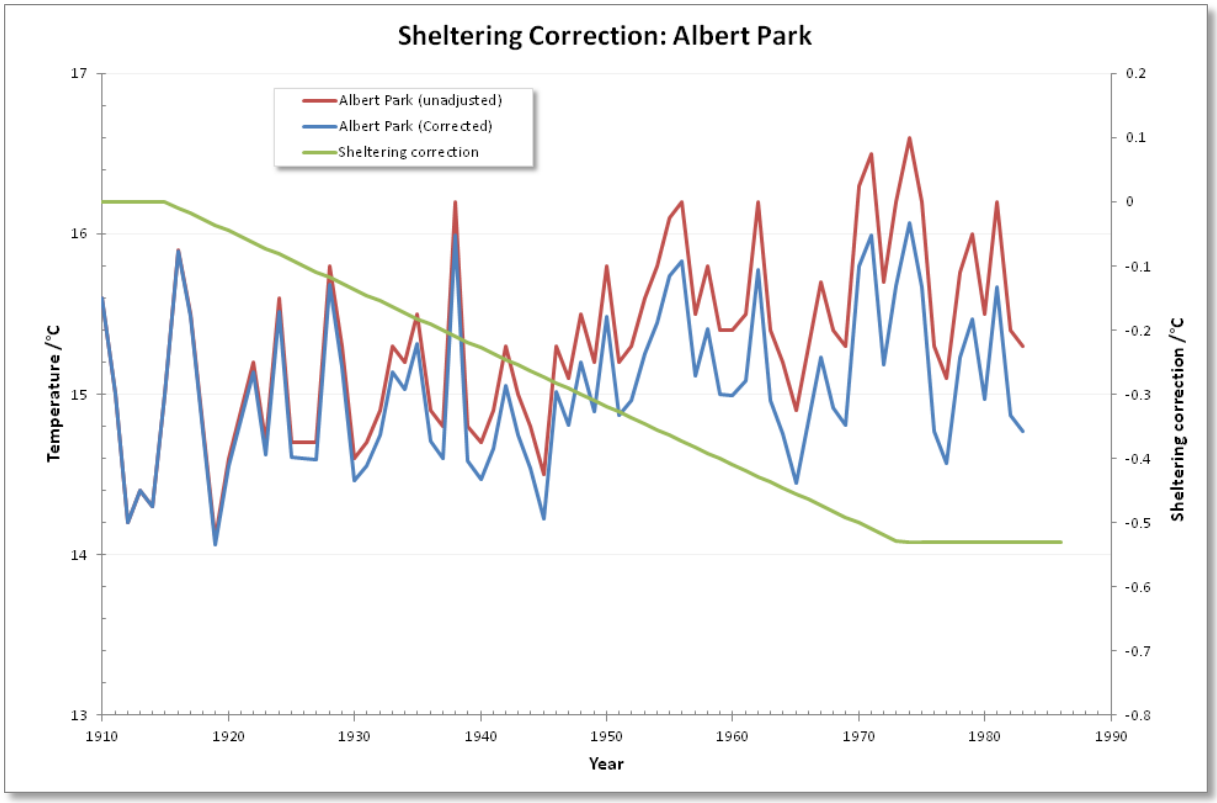


Figure 44: Removal of the sheltering trend: Albert Park (1910-1983)

Adjusting for UHI Problems

Albert Park is not the only site in Auckland with non-climatic problems. Both Mangere and nearby Auckland Aero, which are both used in the NIWA series from 1976 to the present, have obvious urban heat island issues that NIWA failed to address. The urban heat island (UHI) effect is well known. It occurs due to the urban build-up of heat-absorbing surfaces such as asphalt and concrete around a weather station. It also occurs due to heat-generating activities developing near stations. These build-ups are usually by-products of a city's growth, and are the reason that Rhoades & Salinger specifically mention that stations contaminated in this way must be excluded from climatic studies.

Both Mangere and Auckland Aero sites are situated in Manukau, one of the fastest-growing urban centres within the Auckland region. The population here has grown by 1200% since the 1950s, from 15,700 in 1951 to 190,000 in 1981. With that growth has come associated non-climatic warming. A recent study by the Australian Bureau of Meteorology (BoM) has estimated that the urban heat island effect in Australian cities accounts for increases in maximum temperatures of 0.8°C/century, in the case of Sydney[23]. This finding is consistent with Torok[24] (2001) who found that even small towns with populations less than 10,000 experience significant UHI effects.

We check Mangere and Auckland Aero against two other airport sites situated within 50 km: Ardmore airport and Whenuapai airport. Both these airports are relatively (but not completely) free of the urbanisation effects suffered by the Mangere and Aero sites. See the figure below for a geographical layout of the stations.

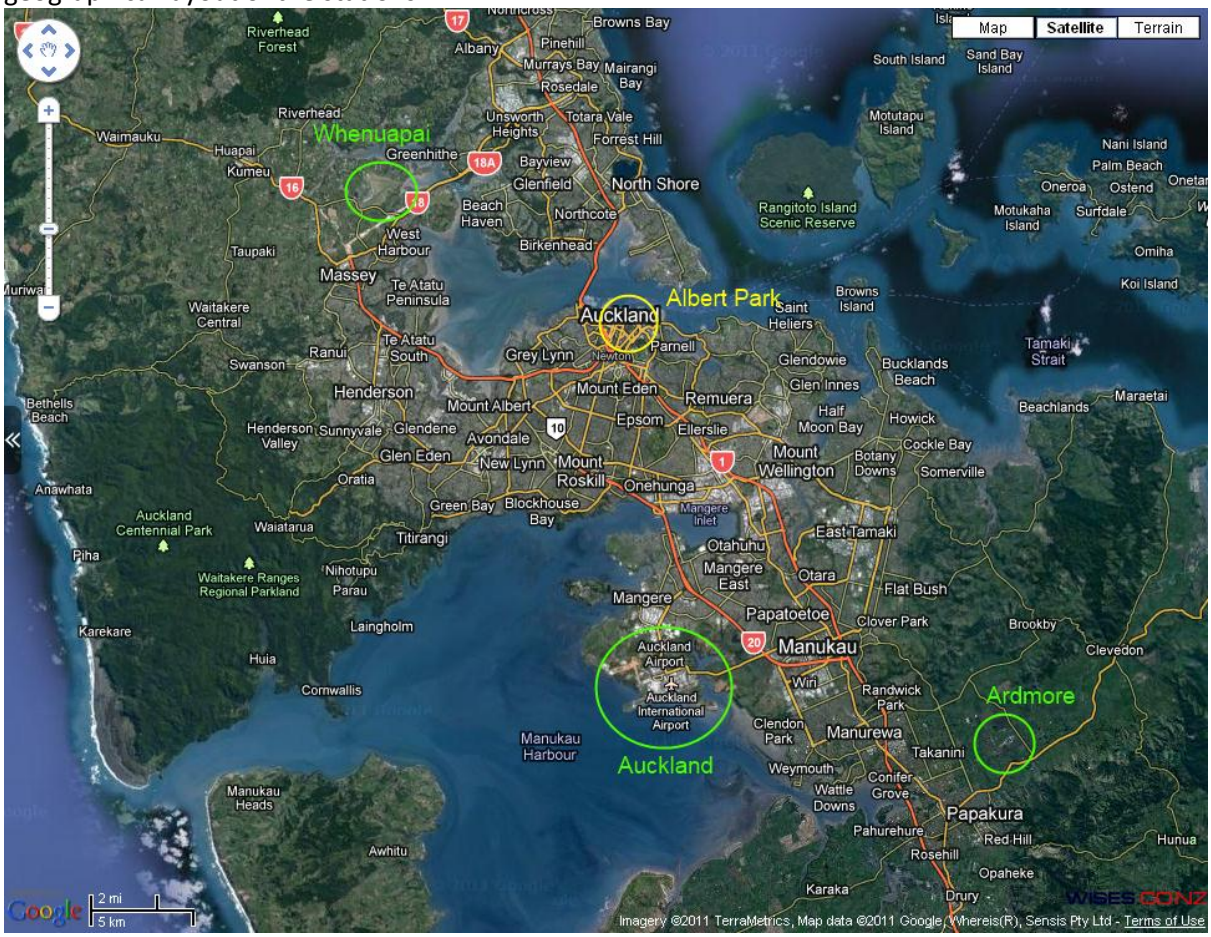


Figure 45: Map of Auckland showing stations

[23] H. Stern et al., "Urbanisation and maximum temperature", *American Meteorological Society*, 2011

[24] S. Torok et al. "Urban heat island features of southeast Australian towns", *Aust. Met. Mag*. 50 (2001) 1-13

The results are summarized below.

Stations	From	To	Trend difference (°C/century)
Mangere minus Whenuapai	1959	1993	0.92
Mangere minus Ardmore	1969	1998	0.94
Auckland Aero minus Whenuapai	1962	1993	0.96
Auckland Aero minus Ardmore	1969	1993	0.97

It is clear from these results that the Mangere/Aero region was subject to an obvious urban heat island effect. If these stations are to be used, as NIWA has done, the artificial non-climatic UHI trends must first be removed. To do so, we follow the same method as Albert Park above.
Of course, it's entirely possible that Whenuapai and Ardmore are *themselves* subject to UHI warming. This is quite likely, in which case the Mangere/Aero series should be reduced even more. However, we lack the resources to follow this further. Suffice it to say that these issues are precisely why Rhoades & Salinger (and the Austalian BoM) recommend that urban sites like these should not be included in climatic series.

Adjusting for UHI at Mangere

The simplest approach to take is to reduce the trend at Mangere by the known non-climatic trend of (0.92+0.94)/2 = 0.93°C/century. This has the effect of dropping the Mangere record in Figure 43 back down to the correct "undisturbed temperature" line, before any overlaps are calculated.
To reduce the trend, one starts at 1962 (the first year of the Mangere record) and then one subtracts temperatures from the Mangere series using the equation $\Delta T = m\Delta t$ where m is the trend reduction rate (-0.0093°C/year) and Δt is the number of years measured from January 1962.
By the end of the Mangere station record in 1998, the shift ΔT is -0.33°C.

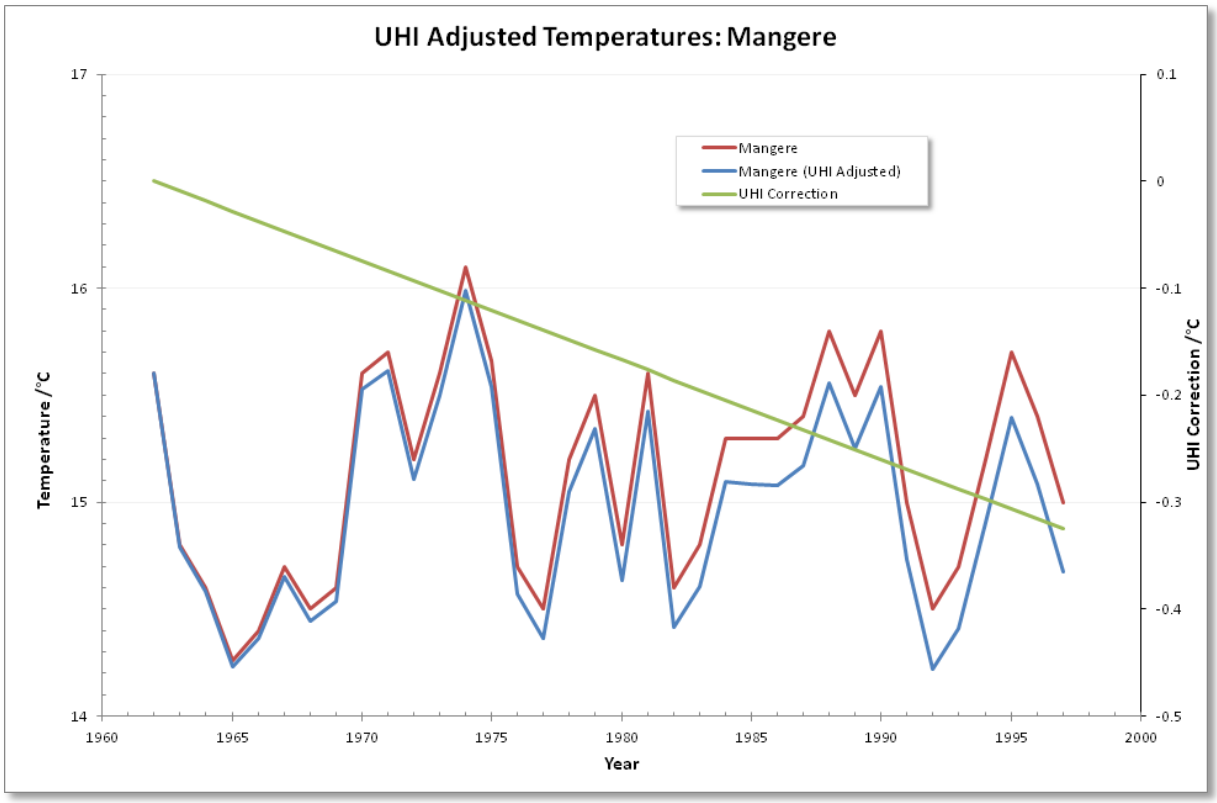


Figure 46: Removal of the UHI trend: Mangere (1962-1997)

Adjusting for UHI at Auckland Aero

We follow the same approach as Mangere above, and reduce the trend at Auckland Aero by the known non-climatic trend of (0.96+0.97)/2 = 0.965°C/century. This has the effect of dropping the Auckland Aero record in Figure 43 back down to the correct "undisturbed temperature" line, before any overlaps are calculated.

To reduce the trend, one starts at 1963 (the first year of the Aero record) and then one subtracts temperatures from the Aero series using the equation $\Delta T = m\Delta t$ where m is the trend reduction rate (-0.00965°C/year) and Δt is the number of years measured from January 1963.

By the end of the Auckland Aero station record in 2010, the shift ΔT is -0.46°C.

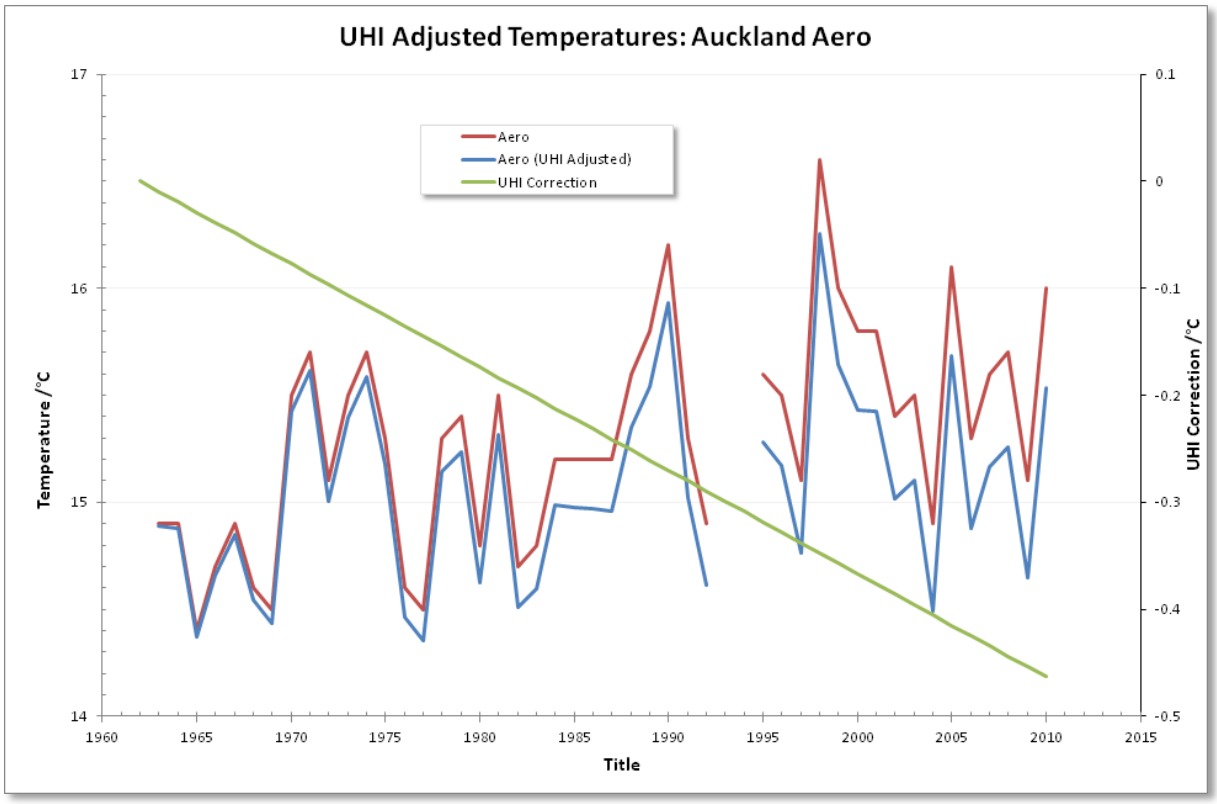


Figure 47: Removal of the UHI trend: Auckland Aero (1963-2010)

Site Change in 1976

NIWA splices the Mangere station in between the Albert Park and Auckland Aero sites from 1976 to 1998. For the 36 month period prior to the joining of the Albert Park and Mangere series in April 1976, the temperature difference between the two sites was -0.12°C, with the UHI-corrected Albert Park series being warmer. This suggests that the UHI-corrected Albert Park temperature series should be reduced by **-0.12°C** to bring it in line with Mangere.

Site Change in 1998

The Mangere station is joined to the Auckland Aero site in 1998. For the 36 month period prior to the joining of the Albert Park and Mangere series in August 1998, the temperature difference between the two sites was **+0.02°C**, with the UHI-corrected Aero series being warmer. This suggests that the UHI-corrected Mangere temperature series should be increased by +**0.02°C** to bring it in line with Auckland Aero.

Putting the Auckland Time Series Together

The table below shows a summary of the NIWA versus R&S adjustments.

Table 5: Comparison between NIWA and R&S results

Site Label	Site Name	From	To	NIWA Adj	R&S Adj	NIWA sum	R&S sum
Site 3	Albert Park (1427)	Sep 1909	Dec 1950	+0.03	0.00	-0.62	-0.10
		Jan 1951	Mar 1976	-0.66	-0.12	-0.65	-0.10
Site 4	Mangere (1945)	Apr 1976	Jul 1998	+0.01	+0.02	0.01	+0.02
Site 5	Auckland Aero (1962)	Aug 1998	Present	0.00	0.00	0.00	0.00

The time series from 1910 to 2009 is shown Figure 38 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

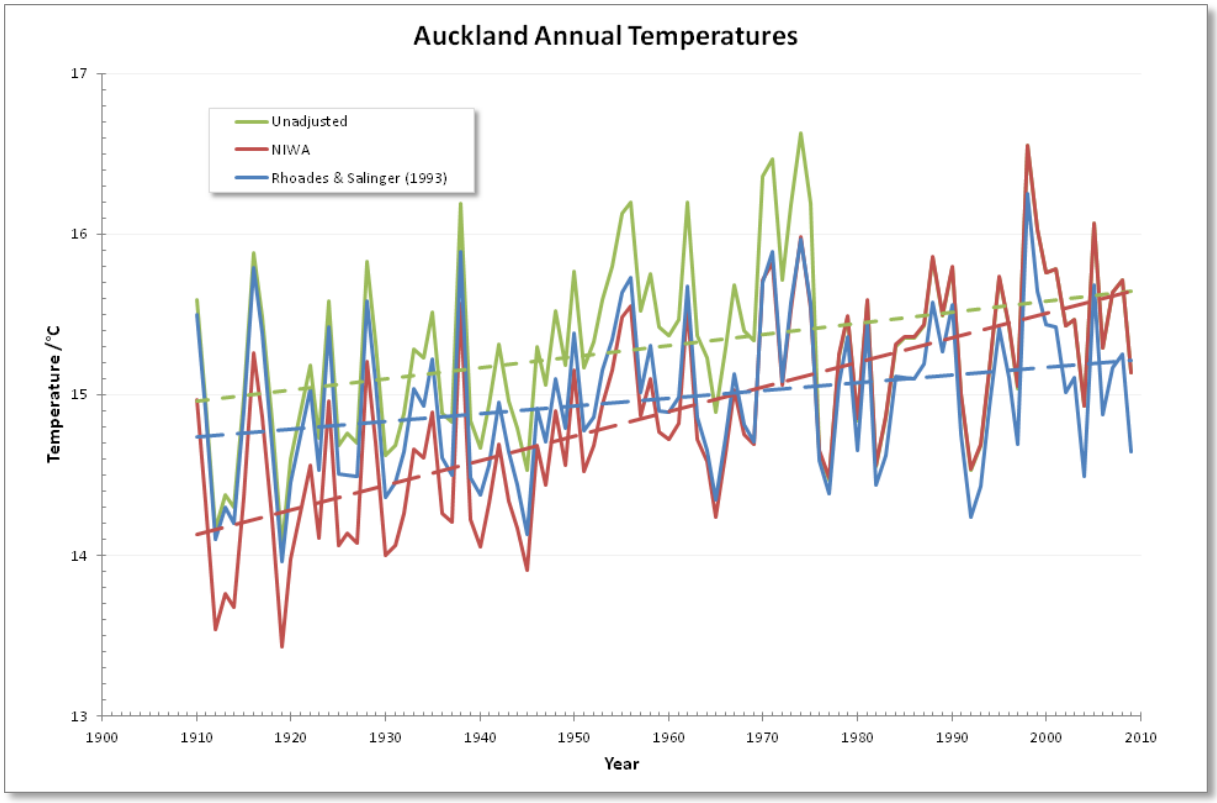


Figure 48: Annual Temperature Trends for Auckland

The trends over the 1910-2009 period are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.69
NIWA method	1.53
Rhoades & Salinger method	0.48

The difference in trend is 1.53 – 0.48 = 1.05°C/century. This means the NIWA method overstates the Auckland trend by 1.05/0.48 = 219%.

Wellington

Most of the Wellington record consists of Kelburn (Agent 3385). This is a station with known urbanisation issues, as discussed in Hessell (1980). The sheltering issue is also mentioned in Fouhy (1992). From Fouhy:

July 1949	The trees and bushes were cut back.
August 1959	The trees and bushes were cut back.
1969	The trees and bushes were cut back.

And when discussing wind:

> 1948 From about 1948 when additional rooms were built on the top floor of the office, the exposure of the anemometer began to deteriorate. This was further aggravated by the growth of pine trees, 15-20m high, about 20m to the north of the office.

Sheltering was not the only problem. Fouhy also mentions the presence of asphalt surfaces very close to the site (it's unclear when these were built):

> Except for the southern side, tar sealed paths surround the enclosure, with a tar sealed car park extending about 10m from the enclosure on the northeast side.

Hessell (1980) specifically mentions that Kelburn is a site with known urbanisation and sheltering issues:

> These effects are to be found, though less easily demonstrable, at a third major city site, Kelburn in Wellington. This site lies in the Botanical Gardens near the crest of a hill and has a high mean wind speed of about 12kt. Although shelter is periodically removed from the immediate surroundings, of the enclosure, tree growth in the Gardens generally appears to be providing more shelter to the site.

Kelburn is classed by Hessell as category "A":

> … assessed to have increased sheltering from trees during the second period and/or significant urbanisation and/or screen changes.

So the Kelburn record is clearly influenced by non-climatic effects. According to Rhoades & Salinger, this site must not be used:

> Gradual changes can seldom be assigned with any certainty to non-meteorological causes. Where long-term homogeneous series are required, for example, for studies of climate change, it is best to choose stations that are unlikely to have been affected by gradual changes in shading or ubanization.

NIWA makes no mention of any urbanisation or sheltering issues in their document.

As stated above, the correct R&S approach is to discard this site entirely. However, since NIWA have included it in their composite series, we will attempt to cater for the problems ignored by NIWA.

What we will do is try to ascertain the magnitude of the non-climatic sheltering effect by following NIWA's lead with Albert Park and comparing Kelburn with a neighbour station, Appleby, which is suitably rural and free of site changes. The overlap period between Kelburn and Appleby is 1932 to 1996.

Unlike NIWA, we shall then attempt to adjust for this artificial warming trend before joining Kelburn with other sites.

Adjusting for non-climatic warming at Kelburn

The difference between Kelburn and Appleby trends over the period 1932-1996 is 0.4°C/century. In other words, Kelburn warmed at a rate of 0.004°/year higher than a rural site free of non-climatic influences. There is no reason to conclude that the relative warming trend only ran from 1932 to 1996 (the coincidental period of the overlap).

The simplest approach to take is to reduce the trend at Kelburn by the known non-climatic trend of 0.4°C/century. This has the effect of dropping the Kelburn record back down to the correct "undisturbed temperature" line, before any overlaps are calculated.
To reduce the trend, one starts at 2005 (the last year of the Kelburn record) and then one adds temperatures to the Kelburn monthly series using the equation $\Delta T = m\Delta t$ where m is the trend reduction rate (-0.004°C/year) and Δt is the number of years measured backwards from 2005.[25]
By the start of the Kelburn station record in 1928, the shift ΔT is +0.31°C.

Site Change in 2005

NIWA Result

The shift between Kelburn and Kelburn AWS is calculated by means of the 16-month overlap. It is found to be **-0.06°C**. This is a very small amount, and will be accepted as is.

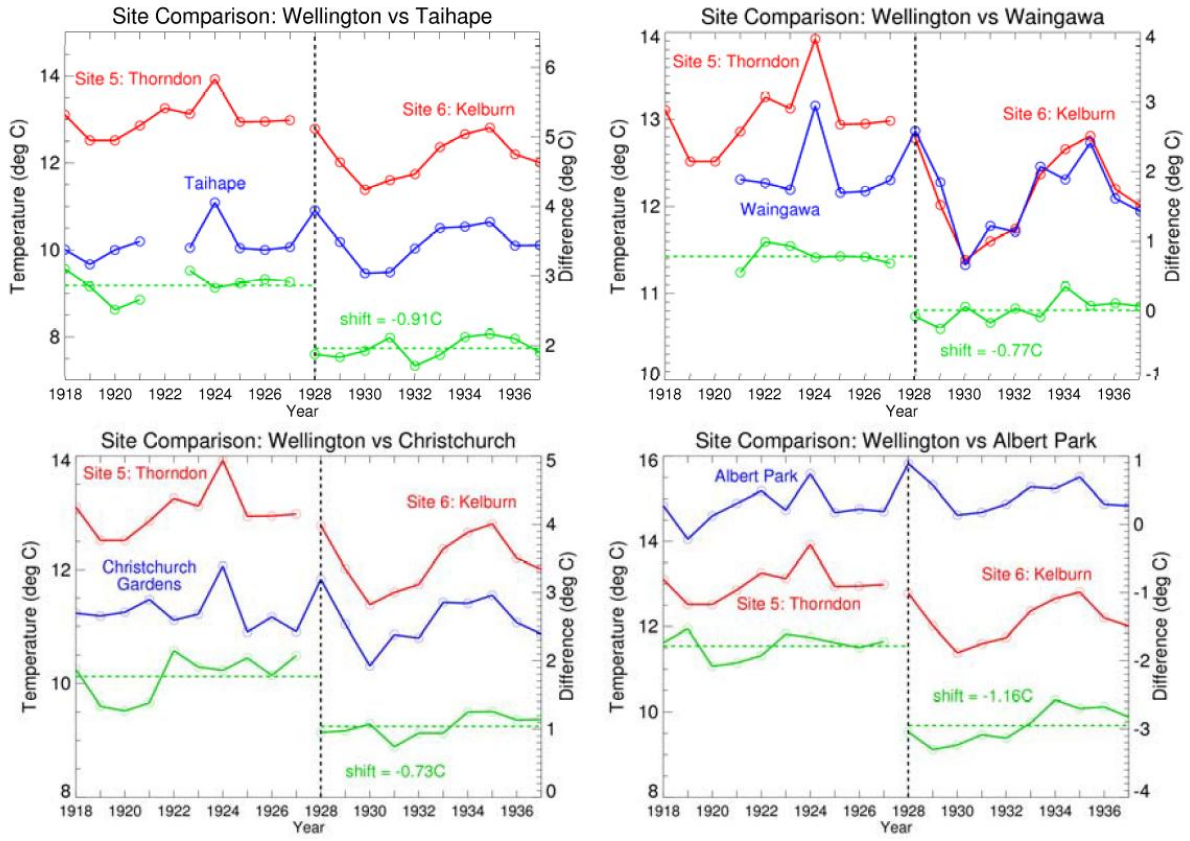
Screen Change in 1928

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Wellington composite series (pp 7-10)[26]. The Kelburn site is compared with various other stations, using their annual averaging method.

[25] Note that this approach is the opposite of the one applied to Albert Park above. It make no difference mathematically whether the trend is reduced going forwards or backwards. But since Kelburn is a reference site, it is easier in this case to fix the right-hand side and go backwards.

[26] "Creating a Composite Temperature Series for Wellington"
http://www.niwa.co.nz/__data/assets/pdf_file/0007/108889/Wellington_CompositeTemperatureSeries_13Dec2010_FINAL.pdf



NIWA calculates a **-0.89°C** difference due to the site change. This makes sense, as Thorndon is lower than Kelburn, and is much more sheltered.

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a positive temperature difference at Kelburn relative to the other stations.

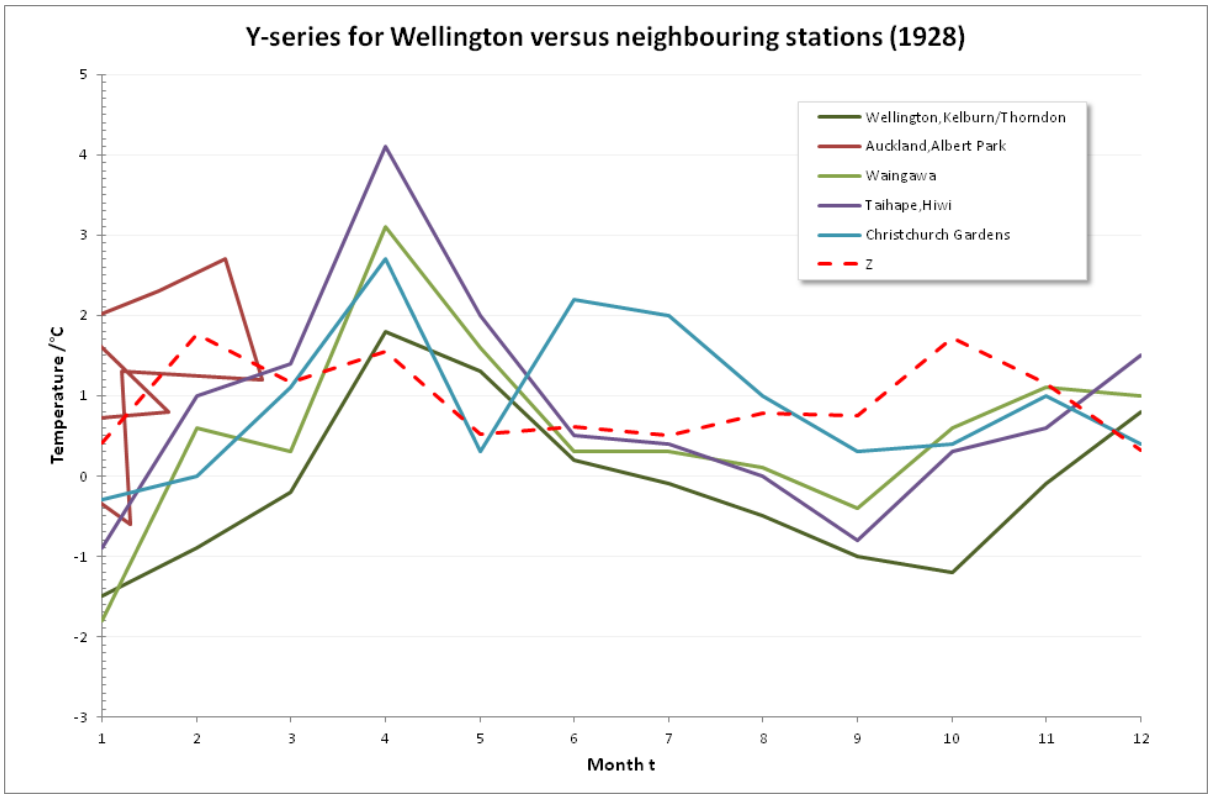


Figure 49: Wellington temperatures versus neighbours, 1928

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Albert Park	0.77	0.23
Waingawa	0.84	0.33
Taihape	0.87	0.37
Christchurch Gardens	0.57	0.07

For the case of the 1928 site change, the results are:

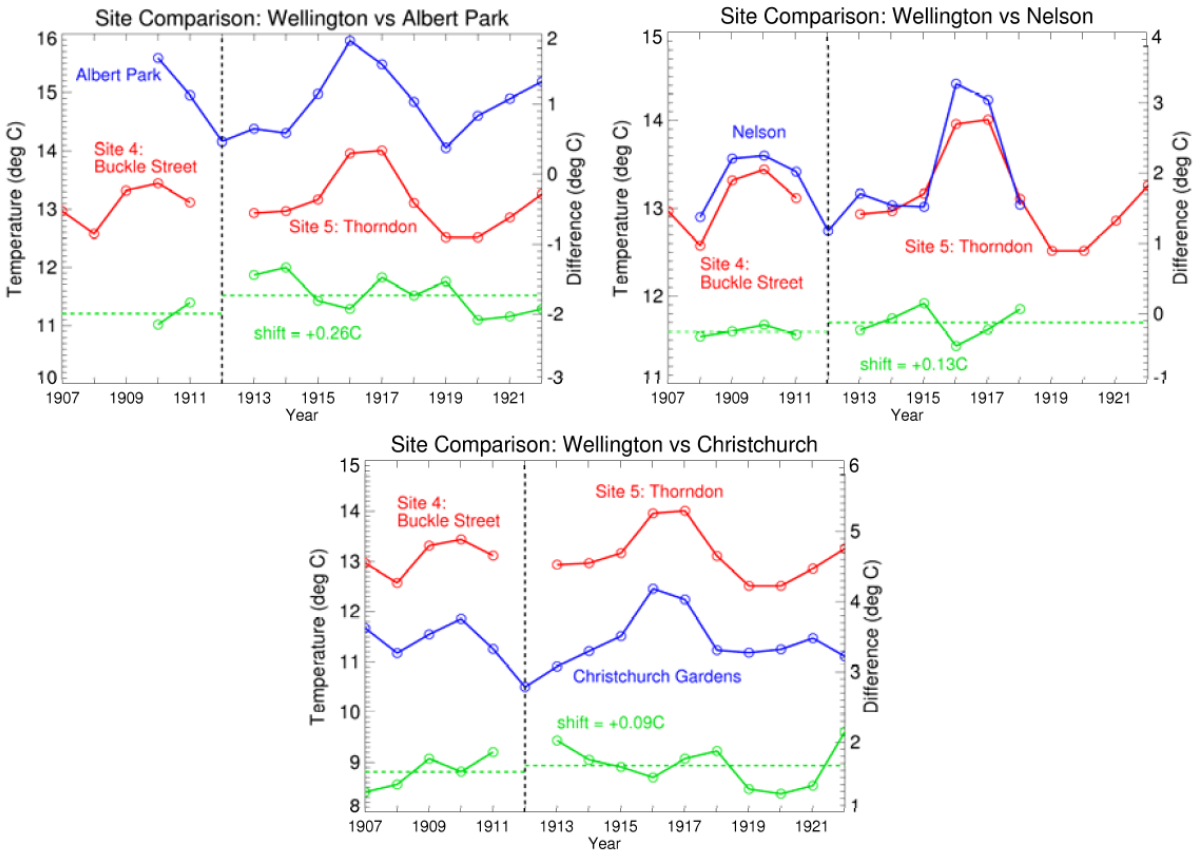
k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.94 ± 0.33 °C	No	Yes
2	-1.05 ± 0.28 °C	No	Yes

So the adjustment is to lower the pre-1928 values by (0.94 + 1.05)/2 = **-1.0°C**.

Screen Change in 1912

NIWA Result

The background to the examination of this site change is given in the NIWA document detailing the Wellington composite series (pp 11-12)[27]. The Kelburn site is compared with various other stations, using their annual averaging method.



NIWA calculates a (+0.26 +0.13 +0.09)/3 = **+0.16°C** difference due to the site change.

[27] "Creating a Composite Temperature Series for Wellington" http://www.niwa.co.nz/__data/assets/pdf_file/0007/108889/Wellington_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S Analysis

A quick visual check of the y-series for k=1 shows a negative temperature difference at Wellington relative to the other stations.

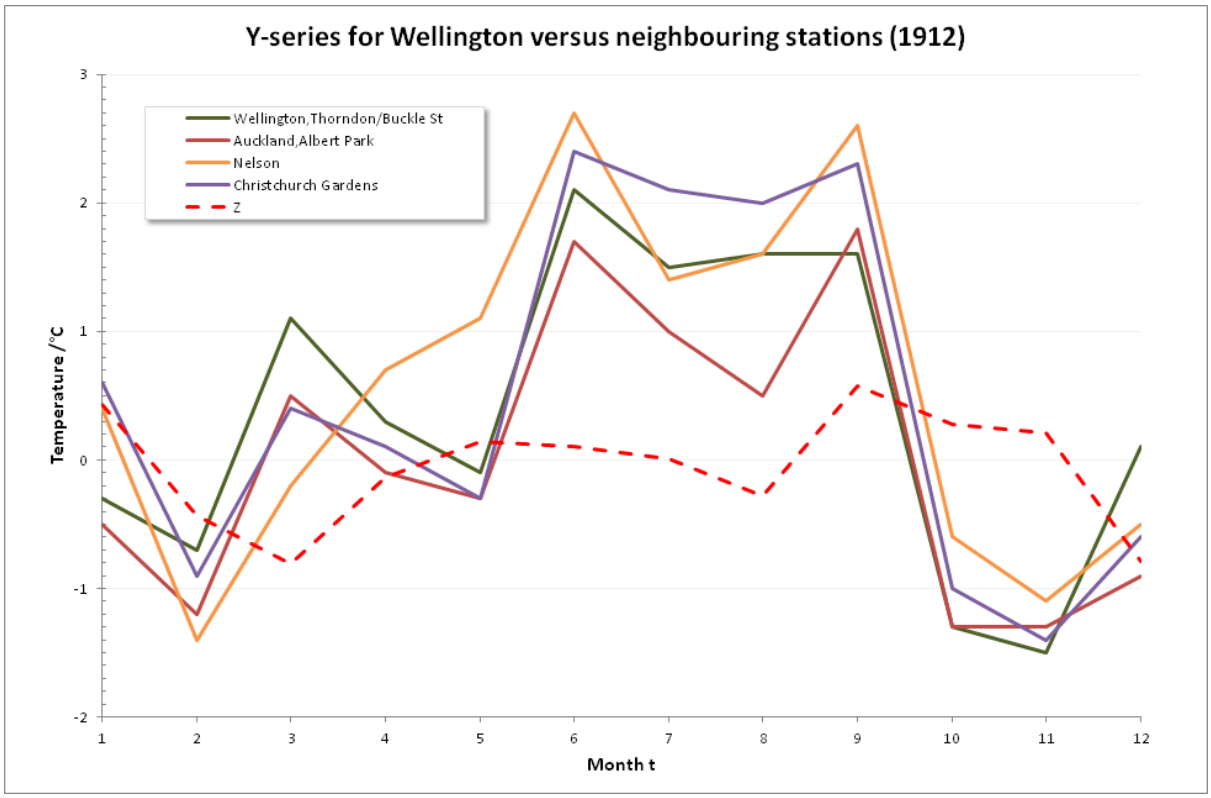


Figure 50: Wellington temperatures versus neighbours, 1912

The weighting factors were calculated using k=1, and are:

Station	ρ	w
Albert Park	0.94	0.39
Nelson	0.84	0.24
Christchurch Gardens	0.93	0.37

For the case of the 1912 site change, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	+0.06 ± 0.28 °C	Yes	No
2	+0.19 ± 0.16 °C	No	Yes
3	+0.22 ± 0.16 °C	No	Yes

So the adjustment is to raise the pre-1912 values by (0.19 + 0.22)/2 = **+0.21°C**.

Putting the Wellington Time Series Together

The table below shows a summary of the NIWA versus R&S adjustments.

Table 6: Comparison between NIWA and R&S results

Site Label	Site Name	From	To	NIWA Adj	R&S Adj	NIWA sum	R&S sum
Site 4	Buckle Street (3431)	Jun 1906	Jun 1912	+0.16	+0.21	-0.73	-0.48
Site 5	Thorndon (3391)	Jul 1912	Dec 1927	-0.89	-1.00	-0.89	-0.69
Site 6	Kelburn (3385)	Jan 1928	Aug 2005	0.00	0.00	0.00	0.00
Site 7	Kelburn AWS (25354)	Sep 2005	Present	-0.06	-0.06	-0.06	-0.06

The time series from 1909 to 2009 is shown Figure 38 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

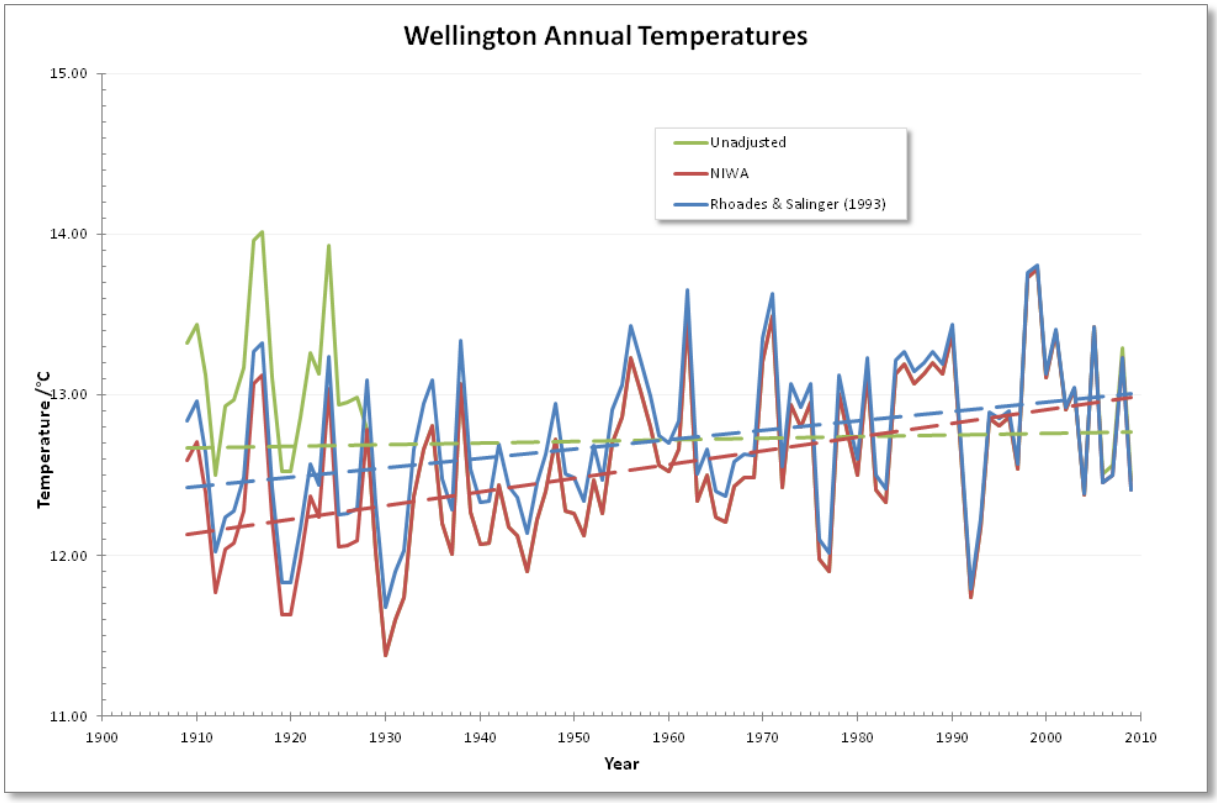


Figure 51: Annual Temperature Trends for Wellington

The trends over the 1909-2009 period are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.01
NIWA method	0.86
Rhoades & Salinger method	0.59

The difference in trend is 0.86 – 0.59 = 0.27°C/century. This means the NIWA method overstates the Wellington trend by 0.27/0.59 = 46%.