THE NEW ZEALAND CLIMATE SCIENCE COALITION

Statistical Audit of the NIWA 7-Station Review

July 2011

In 2010, NIWA published their review of their 7-station temperature series for New Zealand. The review was based upon the statistically-based adjustment method of Rhoades & Salinger (1993) for neighbouring stations. In this report, we examine the adjustments in detail, and show that NIWA did not follow the Rhoades & Salinger method correctly. We also show that had NIWA followed Rhoades & Salinger correctly, the resultant trend for the 7-station temperature series for New Zealand would have been significantly lower than the trend they obtained.

Background

The New Zealand Meteorological Service, with its forebears, has been measuring and recording our weather since 1861. In 1992, it published a booklet containing a detailed history of all its weather stations[1], along with 130 years of climate data. In that year, the National Institute of Water and Atmospheric Research ("NIWA") came into being and has now published most of the Met Service data online.

Two other events occurred in 1992:

(1) NIWA adopted a time series for average New Zealand temperatures over the 1861-1990 period called the "Seven-station Series" ("7SS")[2] which was then published in its monthly digests. The 7SS claimed a 0.92°C warming trend during the 20th century.

(2) A paper describing statistical techniques for adjusting historical weather data was written by Rhoades (a statistician) and Salinger (a scientist). This paper was subsequently peer-reviewed, published by a learned journal, and received some international recognition.

After criticism[3] of the 7SS adjustments by the New Zealand Climate Science Coalition ("NZCSC") in 2009, NIWA contended[4] that its 1992 adjustments applied the internationally-accepted techniques described in Rhoades & Salinger (1993)[5] ("R&S"). At the same time, however, it admitted that most of the adjustments had been taken from a 1981 Salinger thesis – which did not apply the R&S techniques – and these thesis calculations had been lost in a computer mishap.

NIWA agreed to undertake a comprehensive review of the 7SS, which would include publication of confidence levels and a journal paper describing its techniques.

A review document[6] ("the Review") released on 17 December 2010, describes a replacement set of 7SS adjustments which also show a warming trend of 0.91°C/century. This document claims that all the 1992 adjustments at all seven stations used the methodology of R&S. The Review also claims to use the same techniques, although it "revisits and describes in greater detail" the process.

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[1] Fouhy, E.; Coutts, L.; McGann, R. P.; Collen, B.; Salinger, M. J., 1992: *South Pacific Historic Climatological Network Climate Station Histories. Part 2: New Zealand and Offshore Islands.* NZ Meteorological Service, Wellington, ISBN 0-477-01583-2.

[2] Salinger et al. (1992),

[3] "Are We Feeling Warmer Yet?" www.climateconversation.wordshine.co.nz/docs/awfw/are-we-feeling-warmer-yet.htm

[4] In many forums, including answers to Parliamentary Questions

[5] Rhoades, D. A., and Salinger, M. J., 1993: Adjustment of temperature and rainfall records for site changes. *International Journal of Climatology*, **13**, 899—913.

[6] http://www.niwa.co.nz/__data/assets/pdf_file/0007/108934/Report-on-the-Review-of-NIWAas-Seven-Station-Temperature-Series_v3.pdf

The NIWA references to the R&S method are many. It is the only reference given on their website under Methodology[7], and it was given in answer to Parliamentary questions[8]. It is also repeated in each of the seven individual station sub-sections of their Review (emphasis added):

> *These adjustments to the multiple sites comprising the 'seven-station' series were calculated by Salinger et al. (1992),* ***using the methodology of Rhoades and Salinger (1993)****, which extended the early work on New Zealand temperatures by Salinger (1981).*

The NIWA Review document was peer-reviewed by the Australian Bureau of Meteorology (BoM) before publication.

[7] http://www.niwa.co.nz/our-science/climate/news/all/nz-temp-record/seven-station-series-temperature-data/references

[8] Eg: 9274 (2010). John Boscawen to the **Minister of Research Science and Technology** (20 May 2010)

The Rhoades & Salinger Method

Neighbouring Station Comparisons

The technique NIWA has used for all their adjustments (excepting overlaps) is the “neighbouring stations” method.

It is important to note that in reality NIWA seldom uses truly neighbouring stations. In most cases the stations chosen are from some distance away, especially for the earlier records. For example, Dunedin is compared against Albert Park in Auckland. For the purposes of this document, we shall however refer to all station comparisons as “neighbouring”, even though many are not.

The correct way to implement the neighbouring station method, according to R&S, is described in detail in Section 2: ‘*Adjustment of Stations with Neighbours*’ (see extract below - emphasis added).

> The method proposed here, unlike that of Karl and Williams (1987), is to use a **symmetric interval** before and after the site change and select only those neighbouring stations that have no site changes over the period of comparison. The standard error is based on the variation of a set of differences (between the target station and its neighbours) of **monthly** differences (before and after the site change). The use of monthly differences means that the t-statistic has relatively high degrees of freedom, even when computed from a short time interval of **only 1 or 2 years** before and after the site change. The period of comparison is kept relatively short in order to avoid contamination by gradual effects, or sudden but unrecognized effects, at one or more of the neighbouring stations. If no such effects are present it is optimal to use as long a period of comparison as possible. However, in this case, the usual concern to maximize the power of the test is balanced by an opposing concern that the modelling assumptions are likely to be more **seriously invalidated** as the period of comparison is lengthened.

Section 3 of R&S deals with adjustments for *isolated* stations, and is not relevant in this context since all NIWA adjustments made use of neighbouring stations, except on a few occasions where an overlap occurred.

Basically, the R&S method for comparing a station with neighbouring stations involves the use of

- Monthly data
- Symmetric interval centred on the shift
- A 1-2 year period before and after the shift
- Weighted averages based on correlations with neighbouring stations
- Adjustments only performed if results are significant at the 95% confidence level

The R&S method is explained in more detail in Appendix A.

The NIWA Method

The method NIWA actually employed in their Review is loosely based on the R&S method, but varies in several important points. An example of the NIWA method is shown in Figure 1 below.

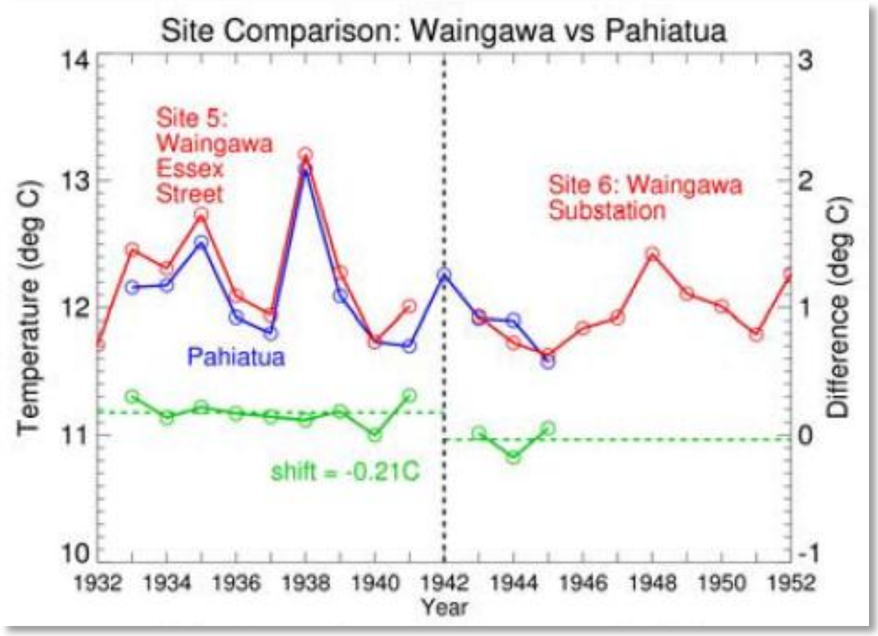

Figure 1: Example of NIWA's asymmetric, annual averages comparison method

The NIWA method uses:

- Annual data
- Asymmetric intervals
- Varying periods of up to 11 years before and after the shift
- No weighted averages
- No evidence of significance tests - adjustments are always applied.

In the review reports, NIWA gives no reason for not implementing the R&S method correctly, nor is the matter discussed.

See Appendix B for further comments on the NIWA method.

UHI

It is clear from reading the NIWA review papers that at no point has any adjustment been made for urban heat island (UHI) effects, even though the peer-reviewed literature explicitly states that New Zealand urban temperature records suffer from significant UHI and sheltering problems (Hessell, 1980; Fouhy, 1992). In the Auckland document (Appendix 5, page 24), NIWA states that:

> 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).

However, NIWA then ignores the issue, concluding that:

> 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.

In our analyses (see Supplementary Information document), the issue of UHI and sheltering has been dealt with in the cases of Auckland (Albert Park, Mangere), and Wellington (Kelburn). We have found that the urbanisation and sheltering problems have a significant effect on the temperature trends at these sites, and adjustments have been made accordingly.

It is of course extremely likely that other stations suffer from similar non-climatic warming due to these effects. It is therefore likely that the overall trend for New Zealand as shown in the next section is an upper limit.

The New Zealand Composite Series

The graph below summarizes the findings of this report. Each station was examined in detail, and the R&S method was applied to each adjustment performed by NIWA. When all seven stations are combined, the result is as follows.

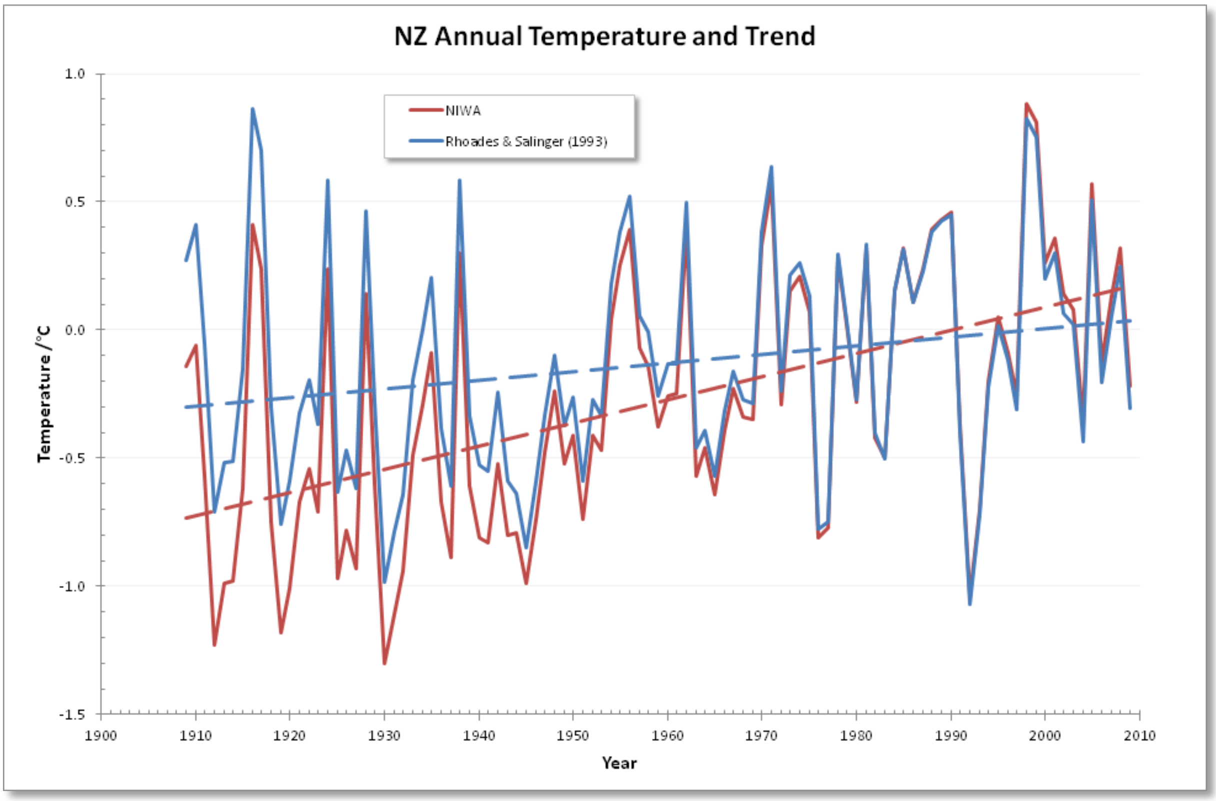

Figure 2: Composite New Zealand Temperature Series

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

Series	Trend (°C/century)
Unadjusted	0.23
NIWA method	0.91
Rhoades & Salinger method	0.34

The difference in trend is 0.91 – 0.34 = 0.57°C/century. This means the NIWA method overstates the New Zealand trend by 0.57/0.34 = 168%. Expressed another way, the R&S trend is only 0.34/0.91 = 37% of the NIWA trend.

In the sections below, we set out the findings from each station. One example will be dealt with in detail (Dunedin) while summary results will be presented for the other stations.

A Single Station Example: Dunedin

We examine the Dunedin 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

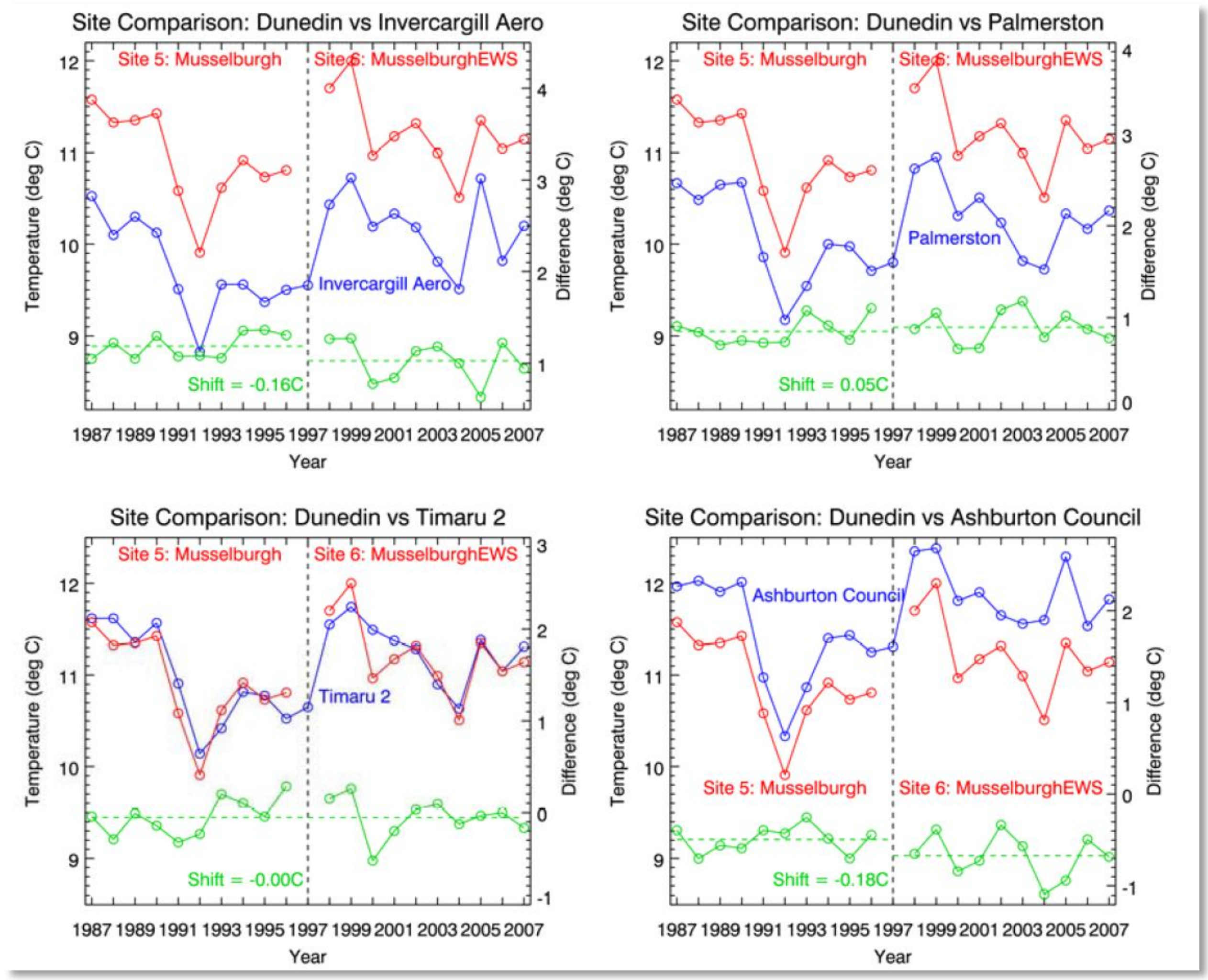

Figure 3: NIWA comparisons with Dunedin 1997

The background to the examination of this site change is given in the NIWA document detailing the Dunedin composite series (pgs 3-7)[9]. The Musselburgh (agent 5402) / Musselburgh EWS (agent 15752) changeover series is compared to Invercargill Aero (agent 5814), Palmerston (agent 5323), Timaru 2 (agent 5095), and Ashburton Council (agent 4778).

NIWA calculates a shift of **-0.07°C** for the 1997 adjustment (-0.16 +0.05 +0.00 -0.18)/4 °C.

[9] "Creating a Composite Temperature Series for Dunedin" http://www.niwa.co.nz/__data/assets/pdf_file/0003/108885/Dunedin_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis[10]

A visual check of the y-series for *k=1* (i.e. one year after compared with one year before) shows slightly positive temperature differences at Dunedin Musselburgh relative to the other stations. Four months are positive, three negative, and the rest show no change.

Note that using the R&S nomenclature, the sign of *z* is opposite to the sign for the eventual adjustment δ. If *z* is positive, the adjustment δ for the pre-change data is *downwards*. If *z* is negative, the adjustment δ is *upwards*.

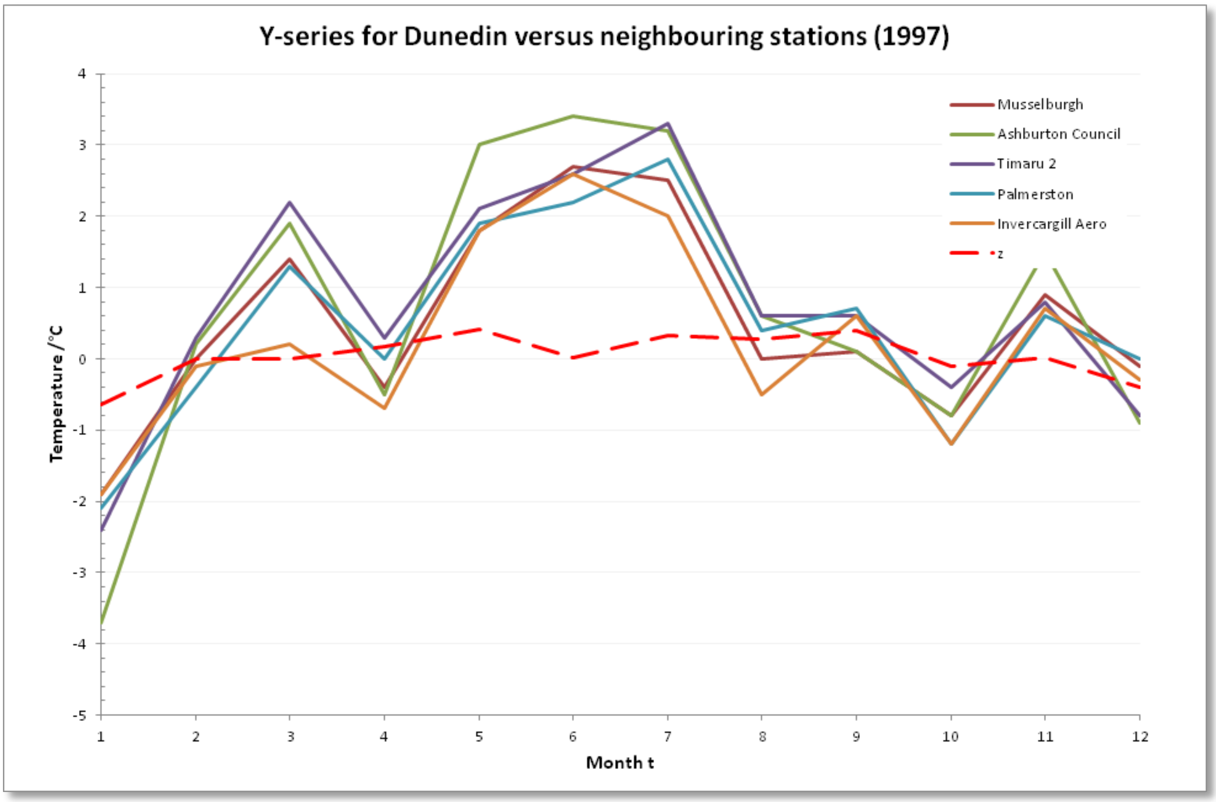

Figure 4: Dunedin temperatures versus neighbouring stations, 1997

The R&S weighting factors were calculated using *k=1*, and are:

Station	ρ	w
Ashburton Council	0.97	0.26
Timaru 2	0.95	0.24
Palmerston	0.97	0.25
Invercargill Aero	0.96	0.24

For the case of the 1997 shift, the R&S results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.04 ± 0.20 °C	Yes	No
2	-0.04 ± 0.20 °C	Yes	No

The calculated shift δ is not significant at the 95% confidence level (i.e. the 95% confidence limit ±0.20 is greater than the shift -0.04 itself), and so the adjustment is not made.

[10] See Appendix A for a description of the Rhoades & Salinger (R&S) method.

Site Change in 1960

NIWA Result

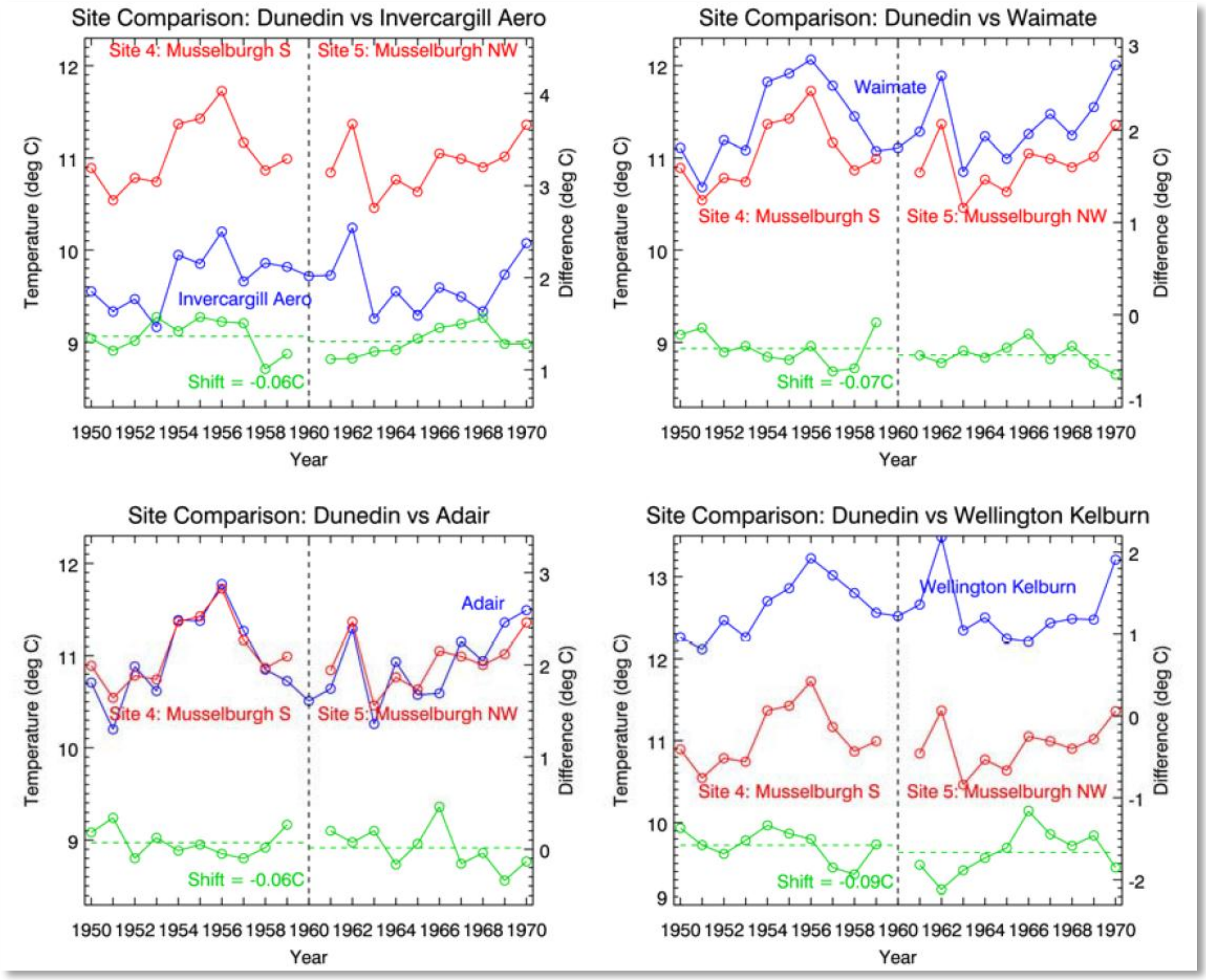

Figure 5: NIWA comparisons with Dunedin 1960

The background to the examination of this site change is given in the NIWA document detailing the Dunedin composite series (pgs 7,8)[11]. The Musselburgh S (agent 5402) / Musselburgh NW (agent 5402) changeover series is compared to Invercargill Aero (agent 5814), Waimate (agent 5102), Adair (agent 5088), and Wellington Kelburn (agent 3385).

NIWA calculates a shift of **-0.07°C** for the 1960 adjustment (-0.06 +0.07 -0.06 -0.09)/4 °C.

[11] "Creating a Composite Temperature Series for Dunedin" http://www.niwa.co.nz/__data/assets/pdf_file/0003/108885/Dunedin_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

A visual check of the y-series for *k=1* shows slightly positive temperature differences at Dunedin relative to the other stations, but with high variability.

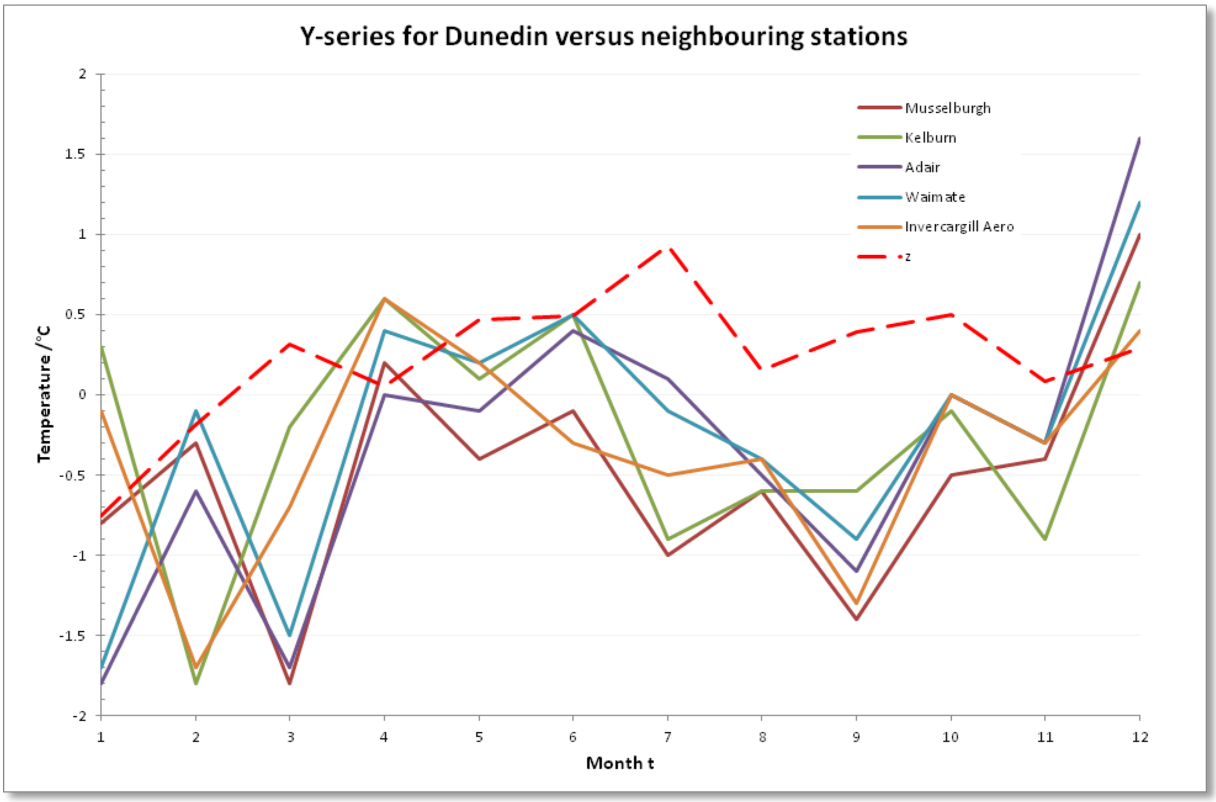

Figure 6: Dunedin temperatures versus neighbouring stations, 1960

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

Station	ρ	w
Kelburn	0.41	0.02
Adair	0.82	0.42
Waimate	0.85	0.47
Invercargill Aero	0.55	0.08

The two poorly correlated sites (Kelburn and Invercargill) are automatically given low weights, due to the 4th power weighting method employed by R&S.

For the case of the 1960 adjustment, the results are:

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.23 ± 0.27 °C	Yes	No
2	-0.24 ± 0.24 °C	Yes	No

So the adjustment is not made.

Site Change in 1947

NIWA Result

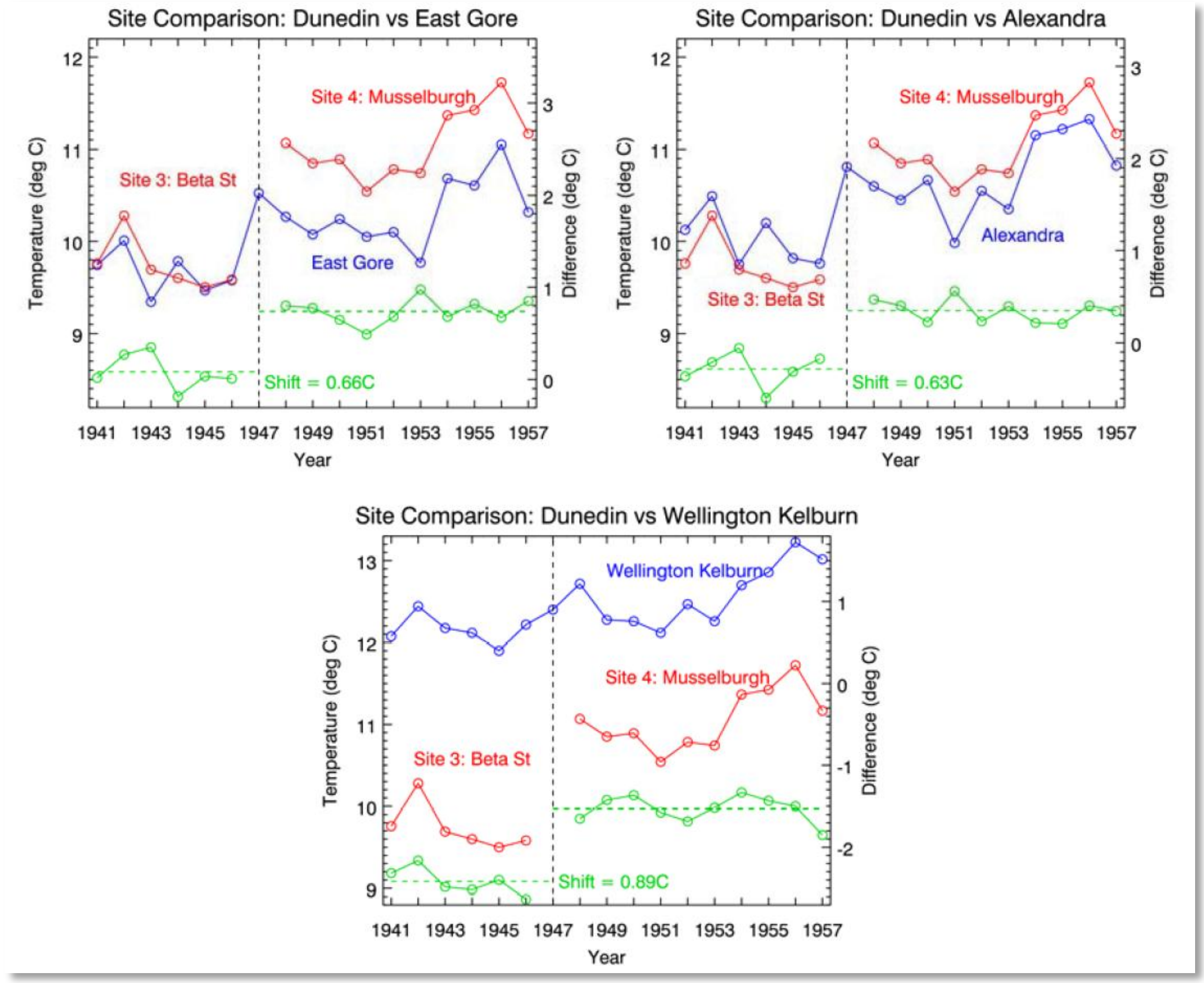

Figure 7: NIWA comparisons with Dunedin 1947

The background to the examination of this site change is given in the NIWA document detailing the Dunedin composite series (pgs 9-11)[12]. The Musselburgh Beta St (agent 5402) / Musselburgh S (agent 5402) changeover series is compared to East Gore (agent 5759), Alexandra (agent 5576), and Wellington Kelburn (agent 3385).

NIWA calculates a shift of **+0.73°C** for the 1947 adjustment (+0.66 +0.63 +0.89)/3 °C.

[12] "Creating a Composite Temperature Series for Dunedin" http://www.niwa.co.nz/__data/assets/pdf_file/0003/108885/Dunedin_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

A visual check of the y-series for *k=1* shows negative temperature differences at Dunedin relative to the other stations, with moderate variability.

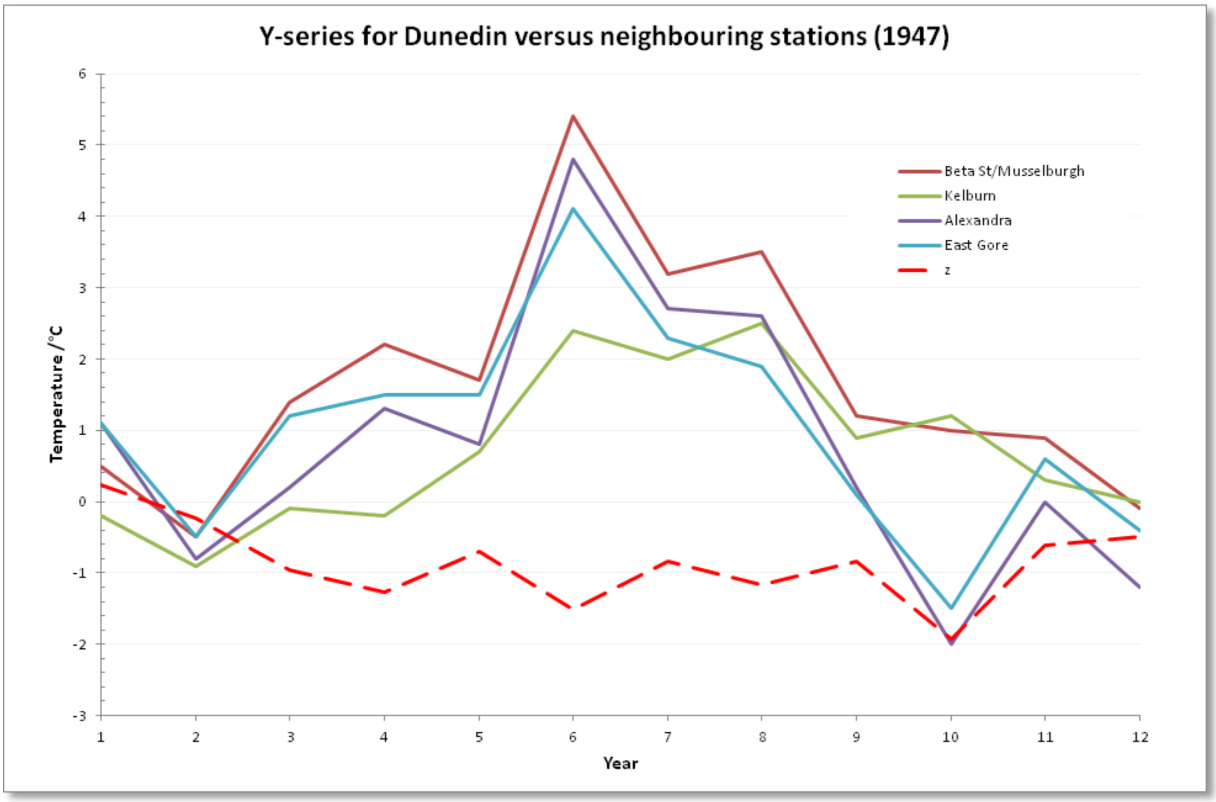

Figure 8: Dunedin y-series versus neighbouring stations, 1947

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

Station	ρ	w
Kelburn	0.84	0.29
Alexandra	0.90	0.38
East Gore	0.87	0.33

For the case of the 1947 adjustment, the results are:

k	Adjustment *δ*	Contains zero?	Valid adjustment?
1	+0.86 ± 0.36 °C	No	Yes
2	+0.84 ± 0.26 °C	No	Yes

So the adjustment is: **raise** the pre-June 1947 values by (0.86 + 0.84)/2 = **+0.85°C**.

Site Change in 1942

NIWA Result

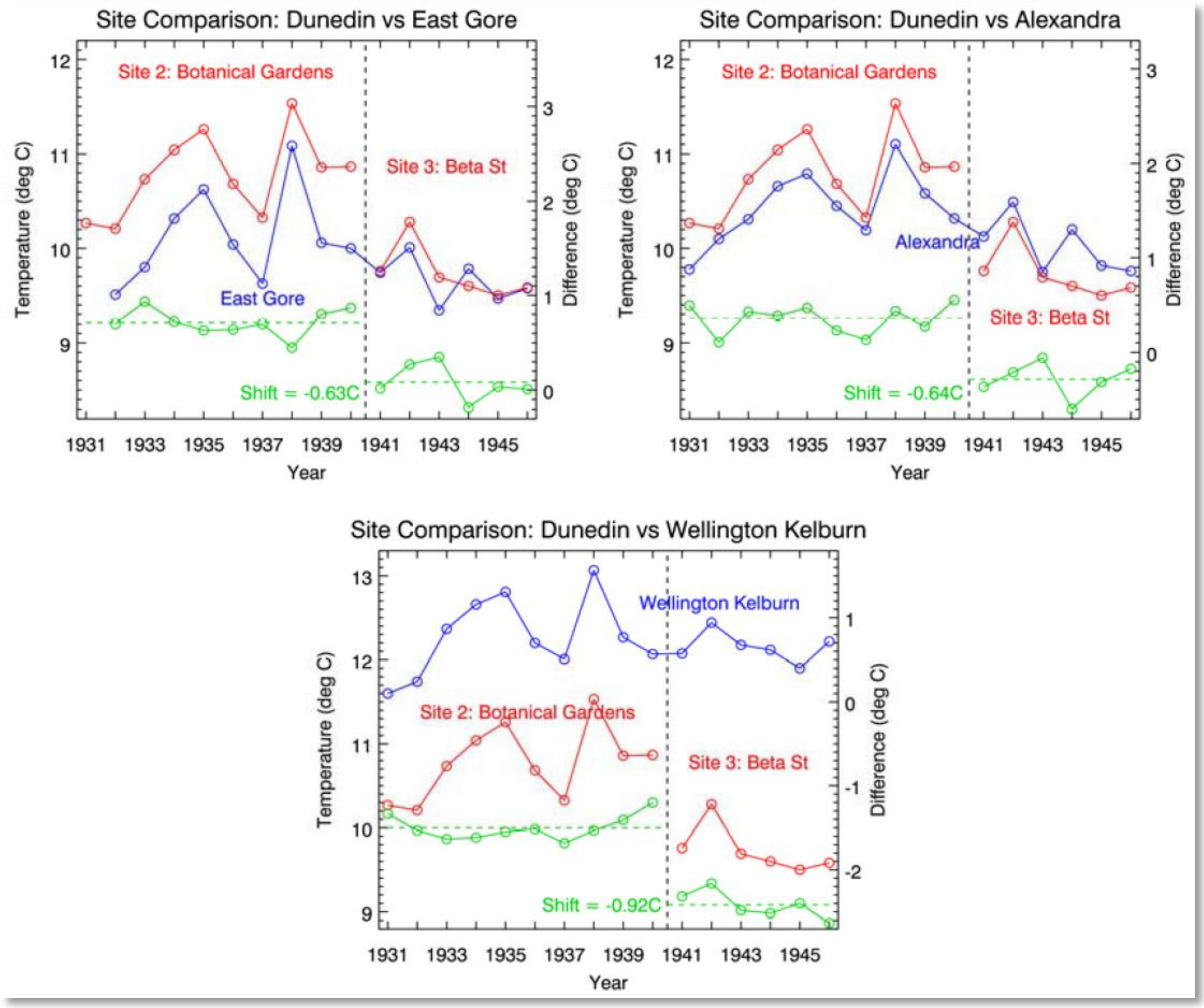

Figure 9: NIWA comparisons with Dunedin 1942

The background to the examination of this site change is given in the NIWA document detailing the Dunedin composite series (pgs 11,12)[13]. The Botanical Gardens (agent 5375) / Beta St (agent 5379) changeover series is compared to East Gore (agent 5759), Alexandra (agent 5576), and Wellington Kelburn (agent 3385).

NIWA calculates a shift of **-0.73°C** for the 1947 adjustment (-0.63 -0.64 -0.92)/3 °C.

[13] "Creating a Composite Temperature Series for Dunedin" http://www.niwa.co.nz/__data/assets/pdf_file/0003/108885/Dunedin_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

A visual check of the y-series for *k=1* shows positive temperature differences at Dunedin Botanical Gardens relative to the other stations.

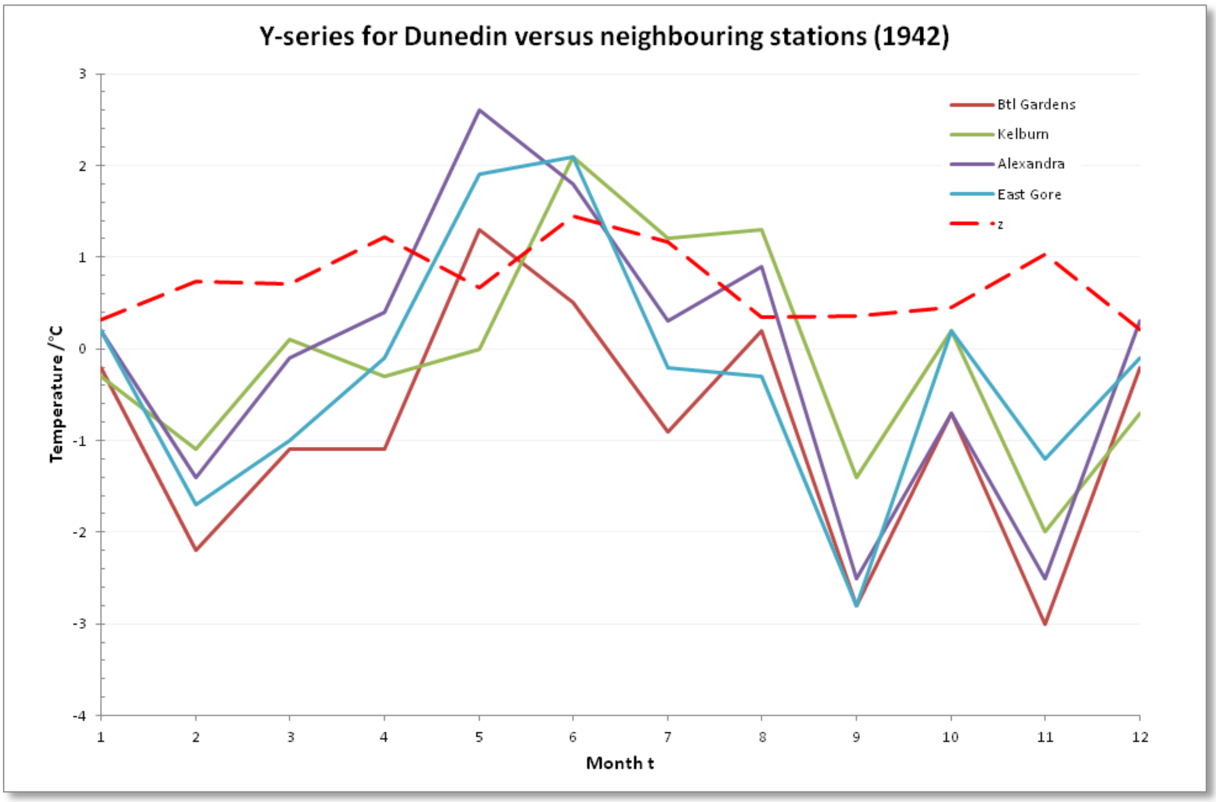

Figure 10: Dunedin y-series versus neighbouring stations, 1942

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

Station	ρ	w
Kelburn	0.71	0.15
Alexandra	0.96	0.50
East Gore	0.89	0.35

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

k	Adjustment δ	Contains zero?	Valid adjustment?
1	-0.72 ± 0.26 °C	No	Yes
2	-0.65 ± 0.35 °C	No	Yes

So the adjustment is: **lower** the pre-December 1942 values by (-0.72 -0.65)/2 = **-0.69°C**.

Site Change in 1913

NIWA Result

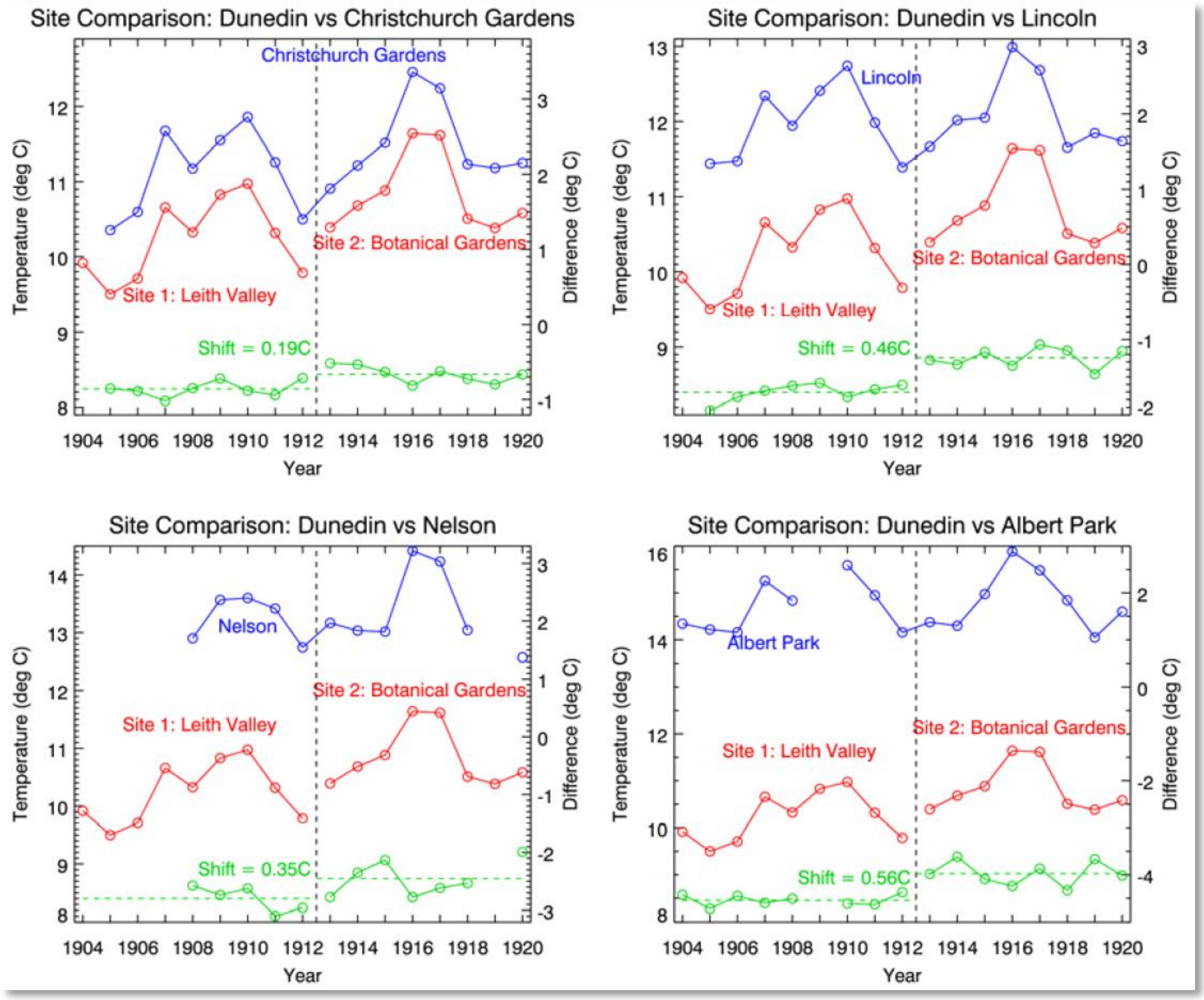

Figure 11: NIWA comparisons with Dunedin 1913

The background to the examination of this site change is given in the NIWA document detailing the Dunedin composite series (pgs 13-15)[14]. The Leith Valley (agent 5380) / Musselburgh Botanical Gardens (agent 5375) changeover series is compared to Christchurch Gardens (agent 4858), Lincoln (agent 4881), Nelson (agent 4244), and Albert Park (agent 1427).

NIWA calculates a shift of **-0.39°C** for the 1913 adjustment (-0.19 -0.46 -0.35 -0.56)/4 °C.

[14] "Creating a Composite Temperature Series for Dunedin" http://www.niwa.co.nz/__data/assets/pdf_file/0003/108885/Dunedin_CompositeTemperatureSeries_13Dec2010_FINAL.pdf

Results from R&S analysis

A visual check of the y-series for *k=1* shows generally negative temperature differences at Dunedin relative to the other stations, but high variation.

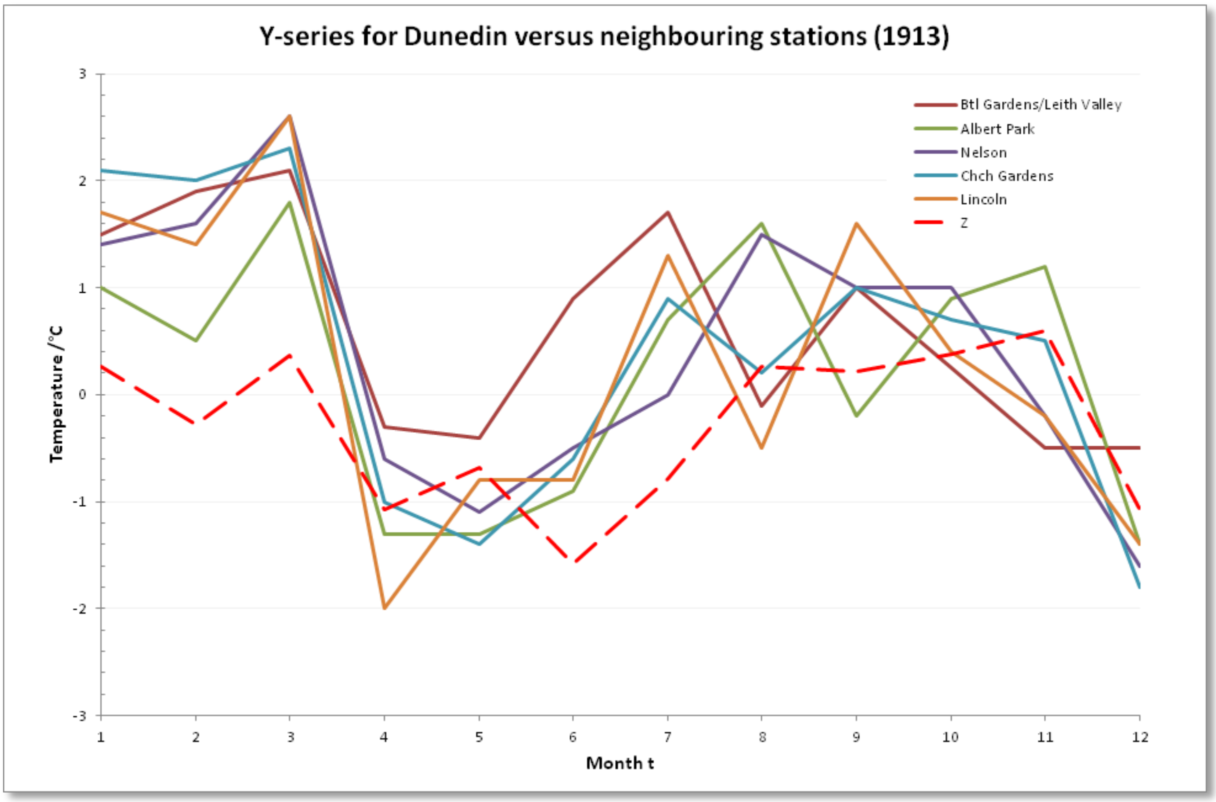

Figure 12: Dunedin y-series versus neighbouring stations, 1913

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

Station	ρ	w
Albert Park	0.45	0.03
Nelson	0.68	0.18
Christchurch Gardens	0.81	0.36
Lincoln	0.86	0.44

For the case of the 1913 adjustment, the results are:

k	Adjustment *δ*	Contains zero?	Valid adjustment?
1	+0.28 ± 0.46 °C	Yes	No
2	+0.37 ± 0.37 °C	Yes	No

So no adjustment is made for 1913.

Putting the Dunedin 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	Leith Valley (5380)	Jan 1900	Dec 1912	+0.39	0.00	+0.25	+0.16
Site 2	Botanical Gardens (5375)	Jan 1913	Nov 1942	-0.73	-0.69	-0.14	+0.16
Site 3	Beta Street (5379)	Dec 1942	May 1947	+0.73	+0.85	+0.59	+0.85
Site 4	Musselburgh (5402)	Jun 1947	Oct 1960	-0.07	0.00	-0.14	0.00
Site 5	Musselburgh (5402)	Nov 1960	Aug 1997	-0.07	0.00	-0.07	0.00
Site 6	Musselburgh EWS (15752)	Sep 1997	present	0.00	0.00	0.00	0.00

The time series from 1913 to 2009 is shown Figure 13 below[15]. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the R&S methods respectively.

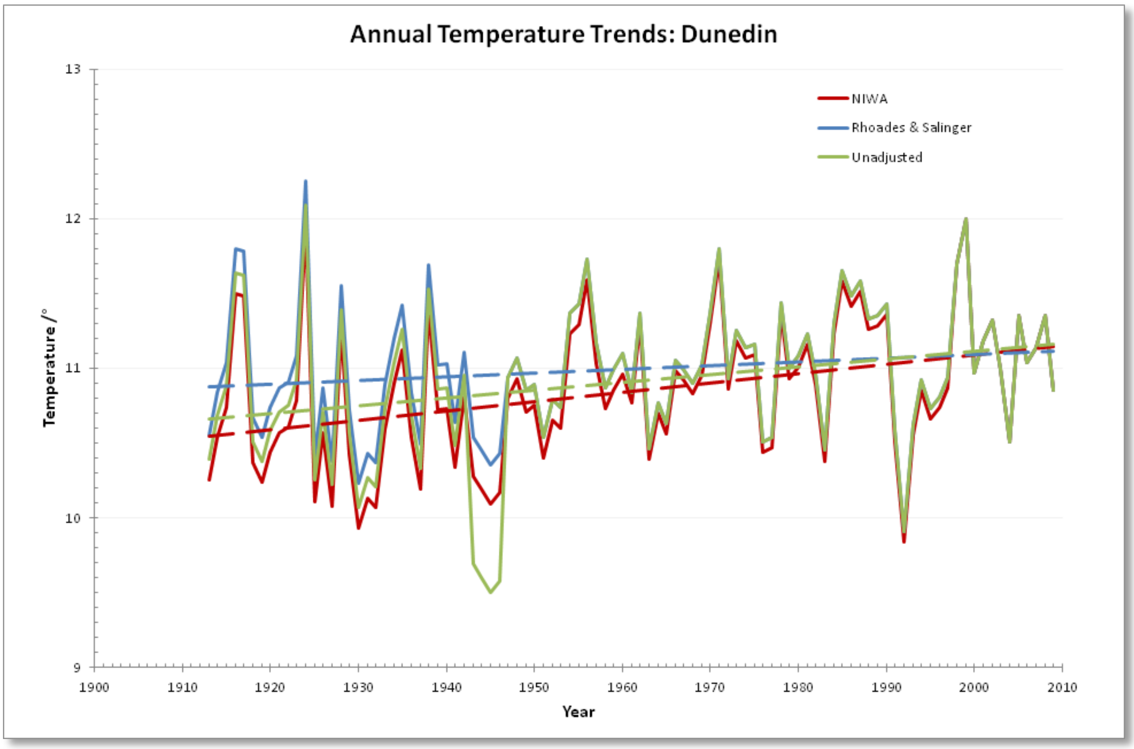

Figure 13: Annual Temperature Trends for Dunedin

The trends over the period 1913-2009 are shown in the table below.

Series	Trend (°C/century)
Unadjusted	0.53
NIWA method	0.62
Rhoades & Salinger method	0.24

The difference in trend is 0.62 – 0.24 = 0.38°C/century. This means that for Dunedin, the NIWA method trend is greater than the R&S trend by 0.38/0.24 = 158%.

[15] Note that NIWA uses the 1913 start point for their Dunedin trend, not 1909. We have done the same.

Other Stations

Each of the other six stations was examined in the same manner as Dunedin. As the volume of work is too great to present here in detail, a summary of the results for each station will be given in the following sections.

A full breakdown of the work for these six stations is available however in a Supplementary Information document.

Auckland

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 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 in Figure 14 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

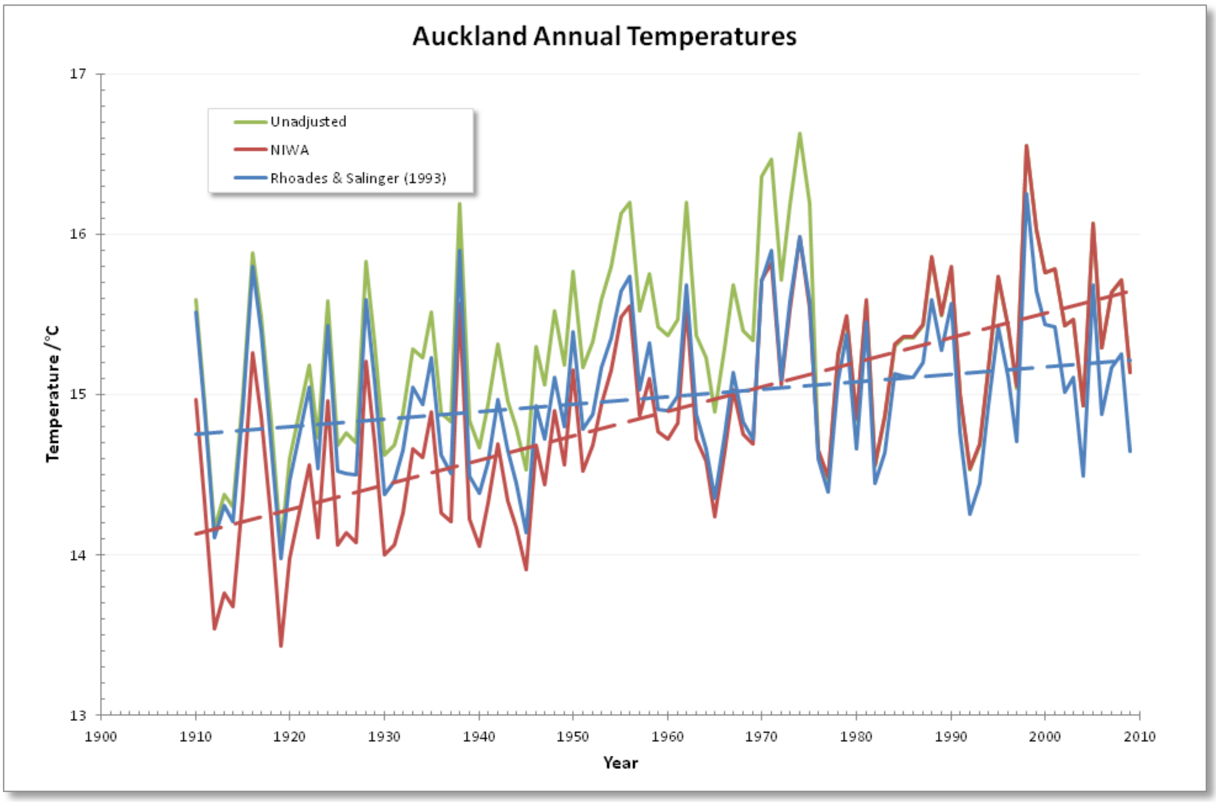

Figure 14: Annual Temperature Trends for Auckland

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%.

Masterton

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 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 1912 to 2009 is shown Figure 15 below. The figure shows the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively. The unadjusted is not shown, as it is identical to the R&S series in this case.

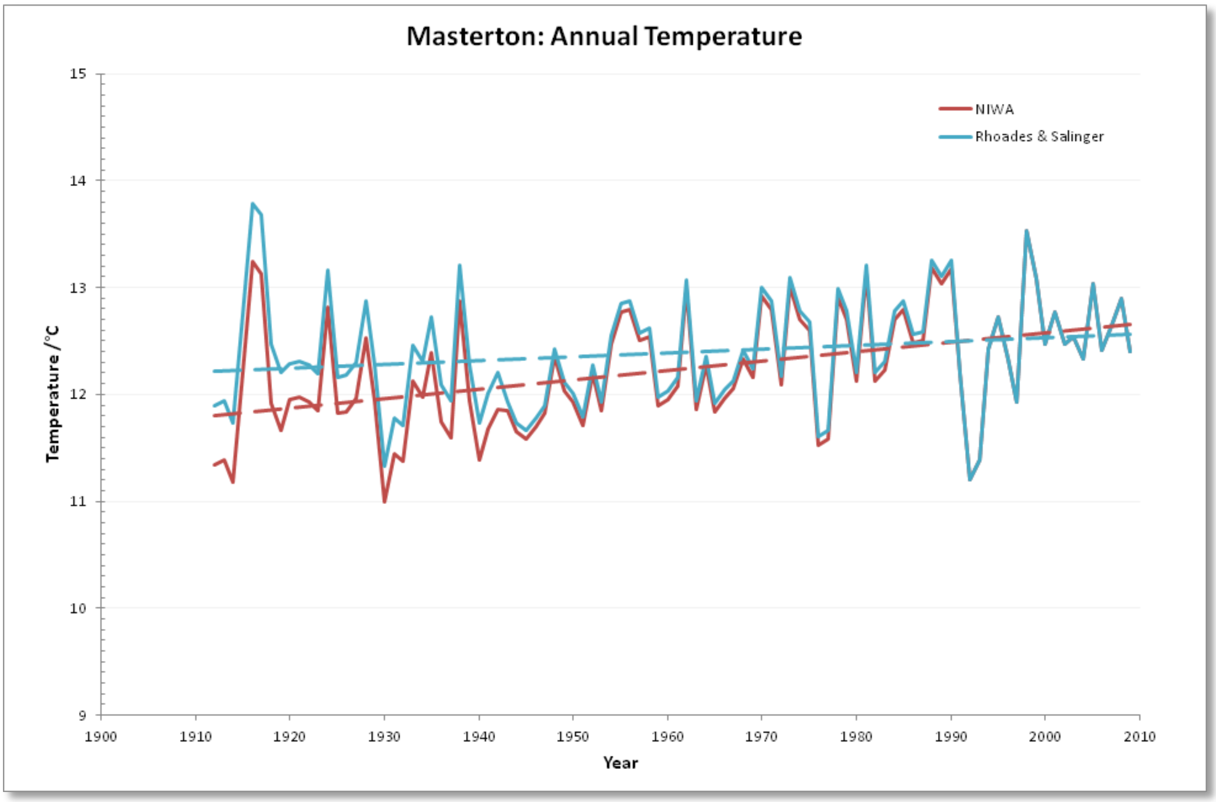

Figure 15: Annual Temperature Trends for Masterton

The trends over the 1912-2009 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%.

Wellington

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	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 15 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

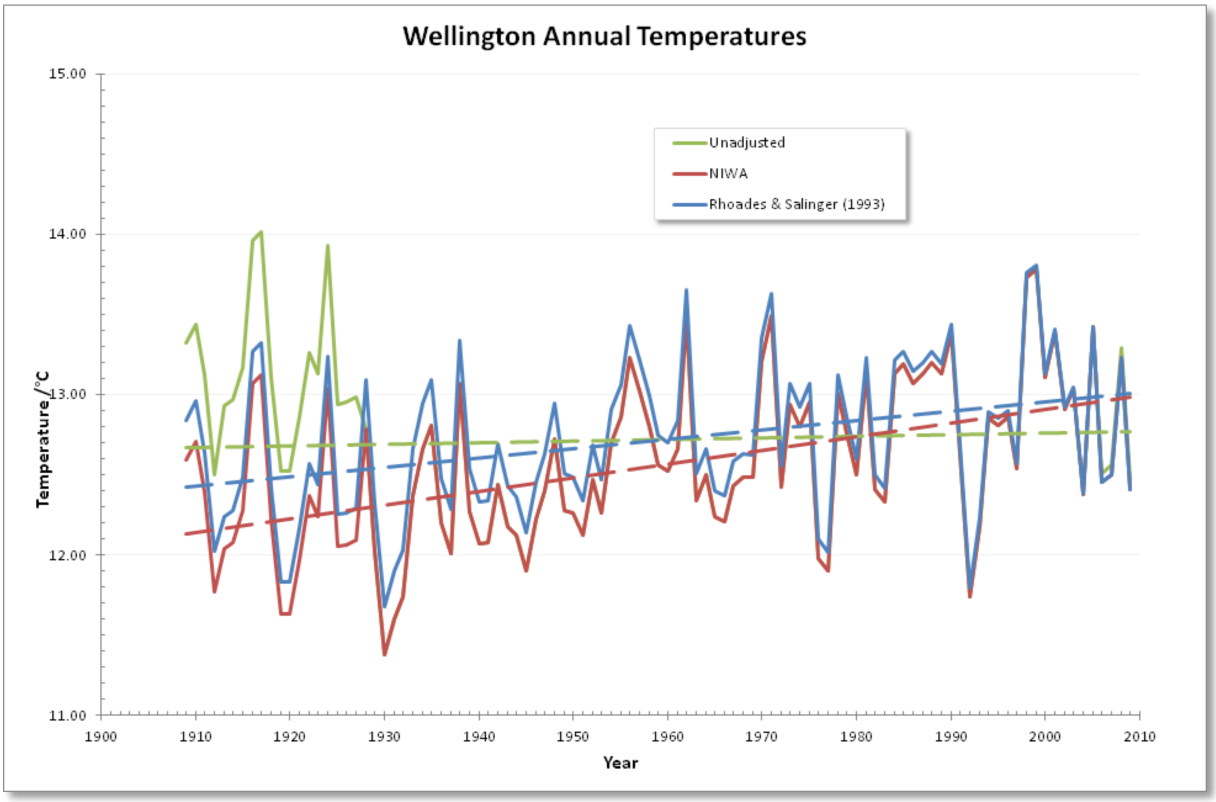

Figure 16: Annual Temperature Trends for Wellington

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%.

Nelson

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 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 15 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods respectively.

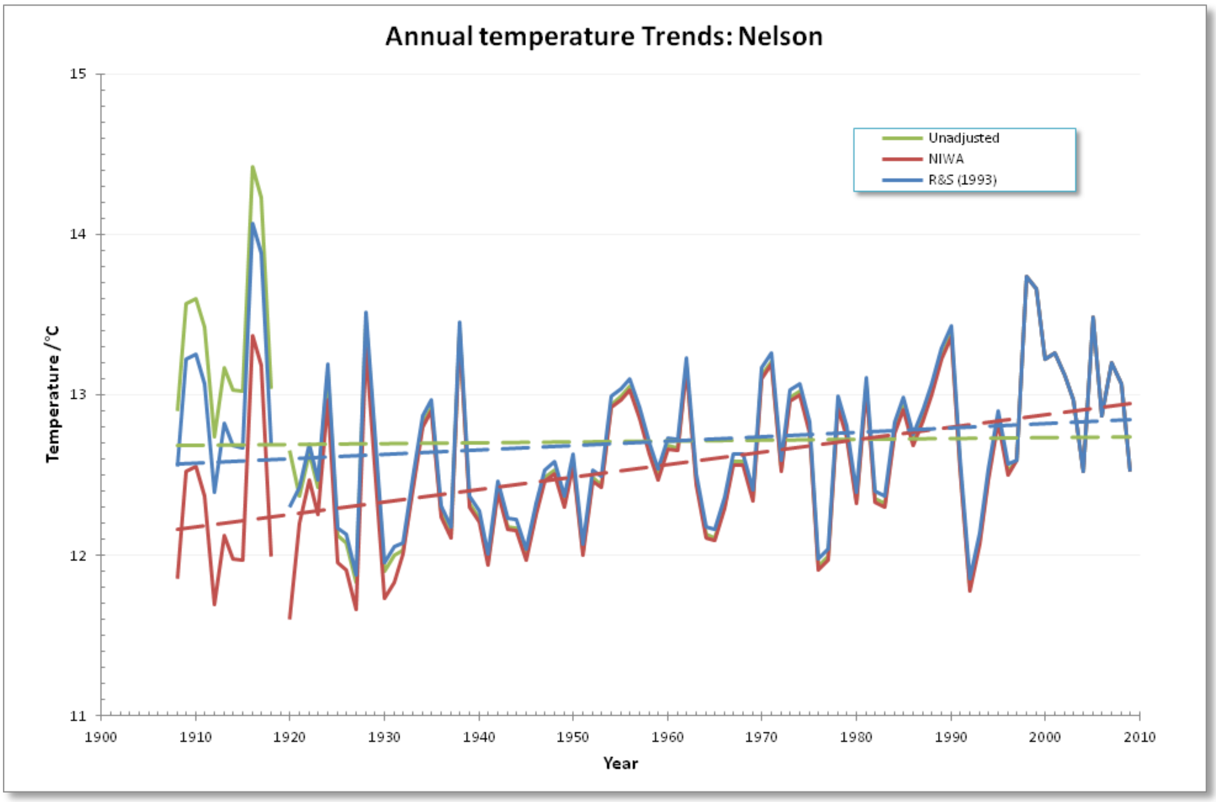

Figure 17: Annual Temperature Trends for Nelson

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%.

Hokitika

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 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 15 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods.

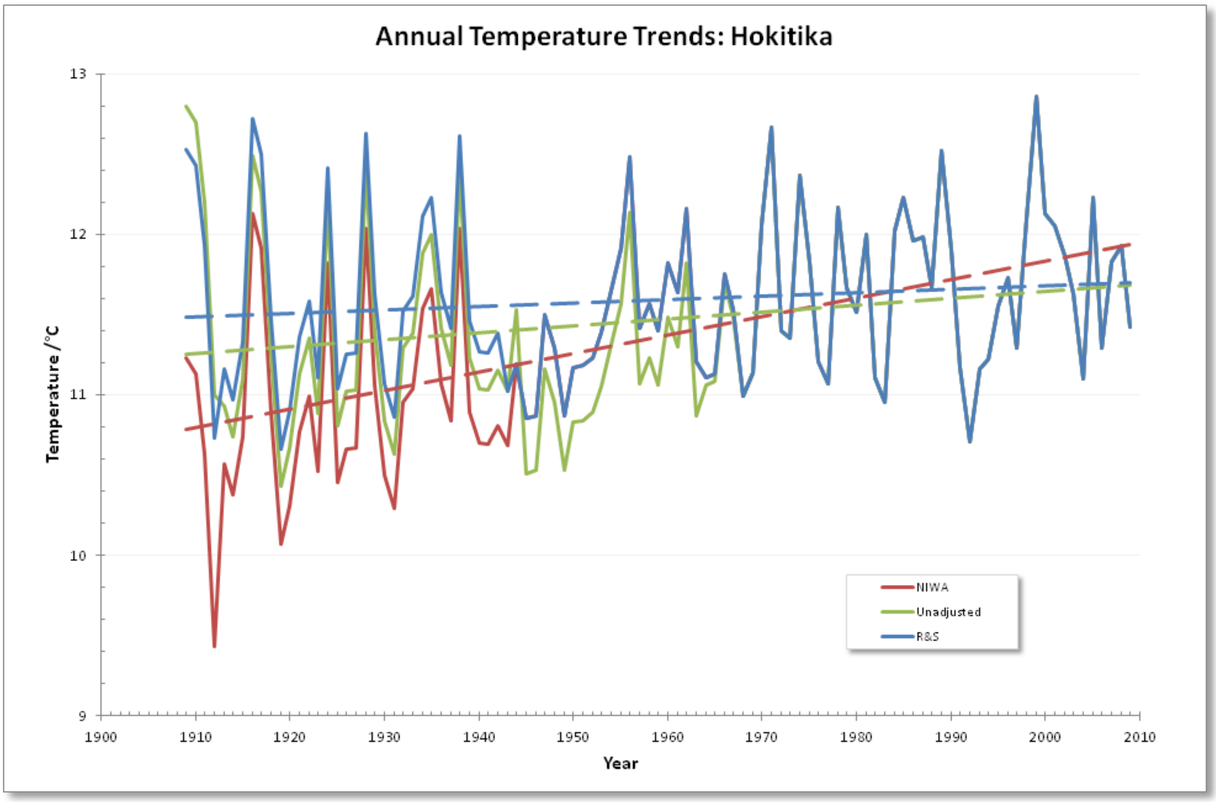

Figure 18: Annual Temperature Trends for Hokitika

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%.

Lincoln

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

Table 7: 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 19 below. The figure shows the unadjusted series, together with the two series adjusted using NIWA's and the Rhoades & Salinger methods.

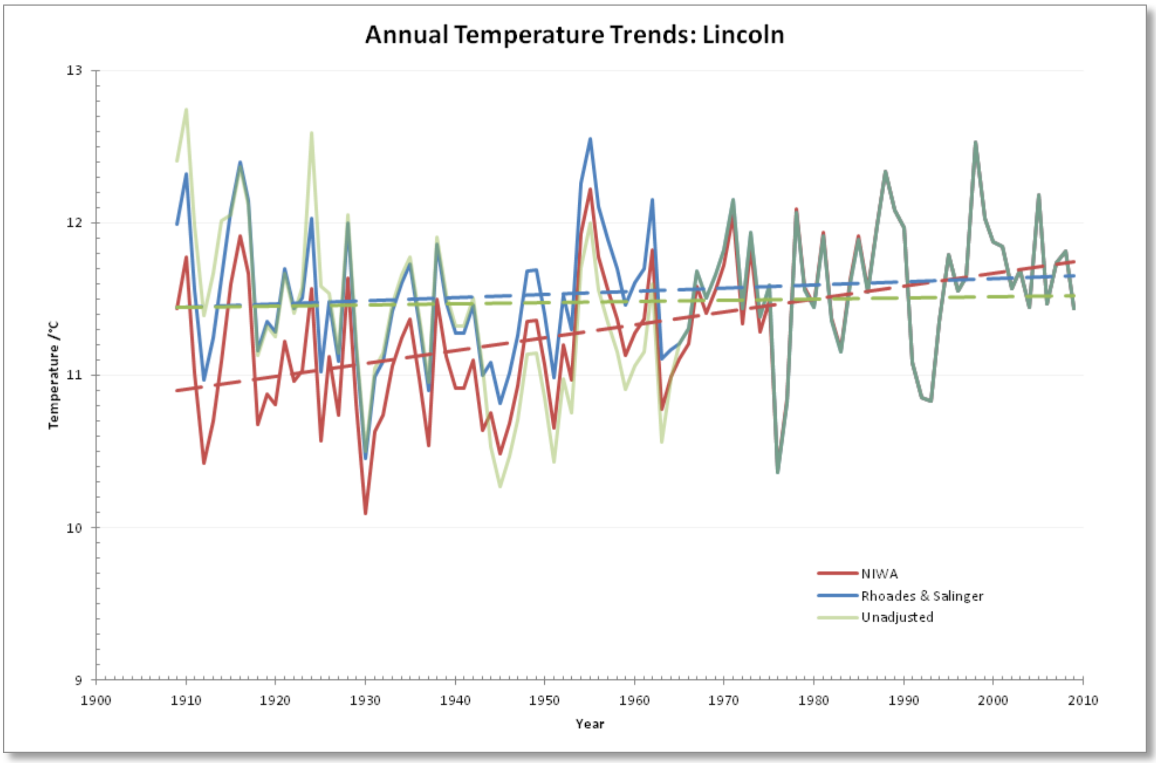

Figure 19: Annual Temperature Trends for Lincoln

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%.

Conclusions and Discussion

In conducting their review of the New Zealand 7-station temperature series, NIWA have stated repeatedly that Rhoades & Salinger (1993) was used as their adjustment method. We have found that this is not the case, and that the R&S method has not been used correctly in NIWA's analysis.

When the Rhoades & Salinger method is used correctly for adjustments to the New Zealand data, the trend is not the published **0.91**°C/century, but instead a much lower **0.34**°C/century.

This finding corroborates NIWA's own assertion that New Zealand is likely to warm less than the global average (about 0.6-0.7°C /century), due to the moderating influence of the Southern Oceans.

The table below summarises the trend differences between the stations when the NIWA and Rhoades & Salinger methods are used. It is interesting to note that both Wellington and Auckland show significantly higher trends than the others. Both these sites are known to suffer from urbanisation effects, according to the peer-reviewed scientific literature (Hessell, Fouhy).

Station	Unadjusted	NIWA Method	R&S Method
Dunedin	0.53	0.62	0.24
Lincoln	0.08	0.83	0.21
Hokitika	0.44	1.14	0.21
Nelson	0	0.76	0.27
Wellington	0.01	0.86	0.59
Masterton	0.36	0.88	0.36
Auckland	0.69	1.53	0.48
Total:	**0.23**	**0.91**	**0.34**

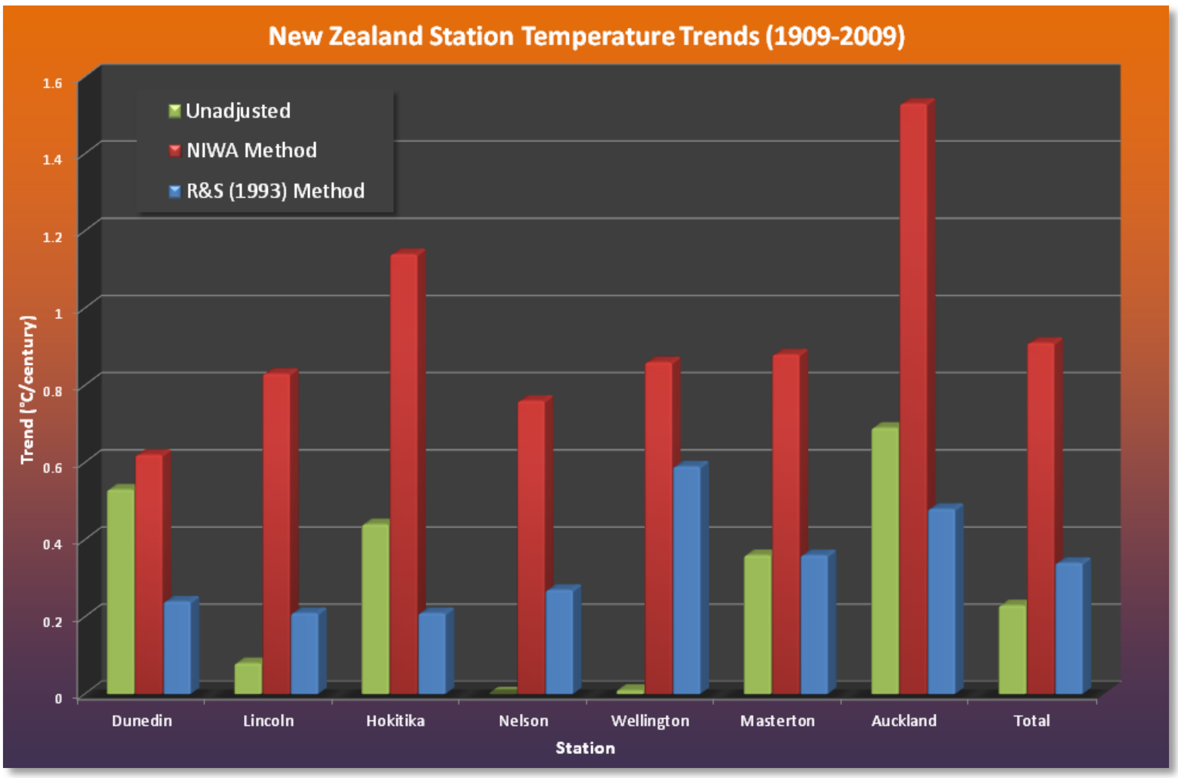

Figure 20: Summary of trends

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Appendix A

The Rhoades & Salinger (1993) Method

Description of the method

The correct R&S neighbouring stations comparison approach is to use monthly data, and cover just two years pre and post. This essentially uses the differences between 12- and 24-months of data respectively, which is an adequate set of values for the purpose at hand. If there is a genuine shift in temperatures due to a station change, the shift should be obvious in the monthly data when comparing one or two years before and after.

Each of the *n* stations is denoted using the convention $i = 0,1,2,\ldots,n$ where $i=0$ is the station with the site change. Thus the general monthly temperature series for station *i* is $x_t^{(i)}$ $where\ t = 1,2,\ldots$

Assume a station site change occurred at time τ. First, the difference series $y^{(i)}$ are calculated, for 12-month ($k=1$) and 24-month ($k=2$) cases.
I.e.:

$$y_t^{(i)} = x_{\tau+t}^{(i)} - x_{\tau+t-12k}^{(i)}\ where\ t = 1,2,\ldots,12k$$

This involves subtracting the previous year's monthly temperature from each post-shift month. In other words, if the station change occurred at the end of December 1975, y_1 for any station (when $k=1$) is made up of the January 1976 temperature minus the January 1975 temperature. y_2 is February 1976 minus February 1975, and so on.
For $k=2$, y_1 is January 1976 minus January 1974, y_2 is February 1976 minus February 1974, etc.

Once all the $y^{(i)}$ series have been assembled, the correlations ρ_i are calculated (using $k=1$) between each differenced series $y^{(i)}$ ($i=1,2,\ldots,n$) and $y^{(0)}$ as follows:

$$\rho_i\left(y_t^{(0)}, y_t^{(i)}\right) = \frac{\sum(y_t^{(0)} - \overline{y_t^{(0)}})(y_t^{(i)} - \overline{y_t^{(i)}})}{\sqrt{\sum(y_t^{(0)} - \overline{y_t^{(0)}})^2 \sum(y_t^{(i)} - \overline{y_t^{(i)}})^2}}$$

Then, following the R&S example, the weights are computed using the 4th power of the correlations

$$w_i = \rho_i^4 \Big/ \sum_{j=1}^{n} \rho_j^4$$

All that remains is to calculate the weighted differences between the $y^{(i)}$ series and the base series $y^{(0)}$ as follows:

$$z = \sum_{i=1}^{n} w_i\, y_t^{(i)} - y_t^{(0)}$$

And finally the mean of the differences is calculated:

$$\bar{z} = \sum_{t=1}^{12k} \frac{z_t}{12k}$$

The standard error of the mean is given by:

$$s = \sqrt{\frac{\sum_{t=1}^{12k}(z_t - \bar{z})^2}{12k(12k-1)}}$$

and the 95% confidence level is calculated as follows:

$$\bar{z} \pm t_{12k-1;\alpha/2} \times s$$

where α is 0.05 in this case (5%).

The above calculations are performed for both cases *k=1* and *k=2*.

If the 95% confidence interval does not contain zero, the adjustment is valid. The adjustment is made by subtracting the mean of the z_t from the base $x_t^{(0)}$ series for all values pre-change (ie: replace $x_t^{(0)}$ by $x_t^{(0)} - \bar{z}$ for $t < \tau$). In the cases analysed here, the convention has been to use the mean of all the significant results, for *k=1* and *k=2*, when making an adjustment.

If on the other hand the 95% confidence interval contains zero (i.e. the 95% confidence limit is greater than the shift itself), no adjustment is made.

In some cases, where there are conflicting results between *k=1* and *2*, *k=3* has been used to break the deadlock. These cases are rare, and have been handled on a case-by-case basis. In general, R&S advocates taking a conservative approach: adjustments should not be made unless there is clear and unambiguous evidence of a genuine shift in temperatures as the result of a site change.

For consistency with the signs used by NIWA, the adjustments are shown in this document using the variable $\delta = -\bar{z}$.

Appendix B

Comments on NIWA's method

Weightings

NIWA do not weight the individual neighbour station shifts at all. The correct R&S method for weighting is described fully in section 2.3 on page 905 of R&S:

> The weights $\{w_i, i = 1, \ldots, n\}$ are based on correlations between the target station and neighbouring stations. It is better to use correlations between the differenced series $\{y^{(i)}\}$ (with k = 1) than between the raw series $\{x^{(i)}\}$

The only time NIWA uses correlations at all is when comparing annual values between neighbouring stations, and then only to justify the use of each station. The correlation period (1972 onwards) also doesn't coincide with the times of most of the station changes.

Error Analysis

The most significant error in the NIWA method is the failure to base each adjustment on the clearly-defined confidence levels as specified on page 904 of R&S (emphasis added):

> A $100(1-\alpha)$ per cent confidence interval for the site change is $\bar{z} \pm t_{12k-1:\alpha/2} \times s$. Following what seems to be the standard convention, **we adjust for the site change only if the change is significant at the 5 per cent level**, i.e. if the 95 per cent confidence interval does not contain zero.

In other words, one can *only* adjust a station record up or down if one has first demonstrated that the comparative difference in monthly values is significant at the 95% confidence level.

NIWA have shown no indication that they have even performed error analyses on these adjustments to date, and they appear not to have used any technique whatsoever in determining whether an adjustment should or shouldn't be made. **This means the NIWA method appears to be 100% open to Type I (false positive) errors, since no attempt has been made to prevent them.**

Why is this important? In the 7-station series, the 'noisiness' of temperature values can cause apparent shifts at times when no site change occurred.

To illustrate the point, we performed an R&S shift analysis for a period when we knew no site change occurred: Hokitika Aero on 1 June 1970 (chosen at random). We used the same neighbouring stations as the 1967 shift check.

The result obtained for *k=1* was 0.21 ± 0.50 °C, and for *k=2* the result was 0.28 ± 0.35 °C. According to R&S, this result is **not significant** at the 95% confidence level, and so (correctly) **no adjustment should be made**.

NIWA, on the other hand, **would in this case have made the adjustment of (0.21 + 0.28)/2 = 0.25°C to all pre- June 1970 temperatures** simply because they didn't calculate the correct monthly comparison confidence limits, or use them to determine the validity of their adjustments. This of course would greatly influence the trend of the whole series.