

Creating a Composite Temperature Series for Nelson

December 2010



Figure 1: Climate station G13222, Nelson Aero, looking north (2007, NIWA). Note that this site, although still called Nelson Aero, is situated beside Whakatu Drive (State Highway 6); it was moved off the airport grounds in mid-1997.

NIWA has previously analysed temperature trends from data at seven locations which are geographically representative of the country: Auckland, Wellington, Masterton, Nelson, Hokitika, Lincoln (near Christchurch) and Dunedin (see <http://www.niwa.co.nz/our-science/climate/nz-temp-record/review/changes/seven-stations-series>). The calculation of climate trends ideally requires very long records of temperature measured with comparable instruments at the same site unaffected by changes in the local environment. Since such undisturbed and very long records do not exist in New Zealand, it is necessary to combine records from different nearby sites, and adjust for the effect of any changes unrelated to the broad-scale climate, such as site moves or instrument changes.

In February 2010, NIWA documented the adjustments in use at that time (see web link above). 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). Subsequent to 1992, the time series have been updated regularly, taking account of further site changes as circumstances required.

This present document revisits and describes in greater detail the process by which a composite station series has been developed for Nelson. The primary purpose is to demonstrate in an intuitive way how to estimate adjustments to temperature records when combining data from different sites, or when there are changes in exposure or instrumentation at a given site. The focus in this document is on annual mean temperature¹. The data from different sites should not simply be appended without adjustment, since significant biases can be introduced when measurement sites are moved.

¹ Mean temperature is defined as the average of the daily-maximum and daily-minimum temperature. Further research will determine adjustments to monthly temperatures, including maximum and minimum temperatures separately, and apply statistical methods (e.g., RHtests, Wang *et al.*, 2007) to identify other change-points in the data.

Table 1: Information about Nelson climate observations:

(Column 1) the site label used in the text;
 (Column 2) the site name, and (in parentheses) the 'agent number' used by the NIWA Climate Database (CliDB) to identify the station;
 (Column 3) additional remarks about the site location, and (in parentheses) the full period of available record;
 (Column 4) altitude of site in metres above sea level;
 (Column 5) previous period of record (as of February 2010) for which the site contributed to the composite time series used by NIWA;
 (Column 6) previous temperature adjustment (with respect to Appleby, Site 4), taken from the February 2010 'Schedule of Adjustments', and further discussed in the appendices;
 (Column 7) new period of record for which the site contributes to the composite time series; and
 (Column 8) revised temperature adjustment to be applied (with respect to Nelson Aero, Site 7), as discussed in the text.

Site Label	Site Name (Agent Number)	Location (Full Period of Record)	Height (m a.s.l.)	Previous Period	Previous Temp. Adjust. (°C)	Revised Period	Revised Temp. Adjust. (°C)
Site 1	Nelson (4244)	Nelson City (Jul 1862 to Dec 1880)	6	Jul 1862 to Dec 1880	-0.6	Not Used	-0.42 ²
Site 2	Nelson (4244)	Nile St East, Nelson City (Oct 1907 to Nov 1920)	10	Oct 1907 to Nov 1920	-0.9	Oct 1907 to Nov 1920	-1.05
Site 3	Nelson (4244)	Cawthron Institute, Nelson City (Dec 1920 to Dec 1951)	7	Dec 1920 to Dec 1931	-0.1	Dec 1920 to Dec 1931	-0.17
Site 4	Appleby (4239)	Appleby, DSIR station west of Nelson (Jan 1932 to Nov 1996)	17	Jan 1932 to Nov 1996	0.0	Jan 1932 to Nov 1996	-0.02
Site 5	Appleby EWS (12755)	Appleby, HortResearch station, about 10 km west of Nelson airport (Oct 1996 to May 2000)	17	Dec 1996 to May 2000	+0.2	Not Used	N/A
Site 6	Nelson Aero (4241)	Nelson airport (Apr 1943 to May 1997)	2	Not Used	N/A	Dec 1996 to May 1997	+0.31
Site 7	Nelson Aero (4241)	Whakatu Drive (SH6), about 2 km east of Nelson airport (Jun 1997 to present)	2	Jun 2000 to Mar 2001	+0.2	Jun 1997 to present	0.00 ³
Site 8	Appleby 2 EWS (21937)	Appleby, Seifried Estate (Apr 2001 to present)	18	Apr 2001 to present	+1.0	Not Used	N/A

² We have included the estimated adjustment of Site 1 in this Table for ease of comparison with previous estimates (column 6). The correction is derived in the Appendix. We do not, however, have high confidence in the adjustments estimated for very early temperature data, and so have "not used" (column 7) these early adjusted temperatures in the revised NIWA temperature series for Nelson.

³ The zero adjustments in bold in columns 6 and 8 mark the reference stations to which temperatures from all other stations are adjusted. The previous Nelson composite series was adjusted relative to Appleby (Site 4), whereas the revised Nelson composite series is referenced to Nelson Aero (Site 7).

Calculation of Adjustments

Table 1 summarises the information about the local sites used to develop the composite temperature series for the Nelson location. The adjustments in use as at February 2010 (labelled ‘Previous Temperature Adjustment’) are based on Sites 1-5, then Sites 7 and 8. The new adjustments derived in this document (labelled ‘Revised Temperature Adjustment’) are based on Sites 2-4, and then Sites 6 and 7. The previous adjustments were calculated to one decimal place, whereas the revised adjustments are specified to two decimal places.⁴

In the process of documenting the revised adjustments for all the ‘seven-station’ series, it was recognised that there was lower confidence in New Zealand’s early temperature measurements, and there were fewer comparison sites from which to derive adjustments for non-overlapping temperature series. Thus, a decision was made not to include temperatures prior to 1900. In the case of Nelson, the natural starting point for the revised series is October 1907, given the break in the Nelson observations over the period January 1881 to September 1907.

Table 1 lists eight different sites, although one of these (listed as Site 5) involves automation of the observations and is not a change in the physical location. The ‘previous’ NIWA temperature series for Nelson (i.e., corresponding to the adjustments published in February 2010) was based on Sites 1 to 5 plus Sites 7 and 8. As seen in Table 1, short periods of record from three different sites were used after the closure of the long-running Appleby manual station (Site 4) in November 1996. This is not the optimal approach, but was simply how the series evolved operationally with the closing of sites outside of NIWA’s control.

The ‘revised’ Nelson temperature series uses Sites 2 to 4, and then Sites 6 and 7. Both Sites 6 and 7 are identified as Nelson Aero (agent 4241) in the NIWA Climate Database, although the station was actually moved off the airport grounds in June 1997. Apart from the desire to have as few stations as possible contributing to the composite Nelson series, two other factors are relevant to the decision to replace the Appleby automatic sites in the revised temperature series:

- Appleby 2 EWS (Site 8) has a rather different climate to Appleby (Site 4) or Appleby EWS (Site 5), having a significantly lower minimum temperature (by about 2 °C on average). Furthermore, Site 8 showed clearly anomalous rapid warming between 2007 and 2009, making the site unsuitable for long-term monitoring;⁵
- Nelson Aero temperature observations had been missing from the Climate Database over the period July 1994 to May 1997, but were located during the process of this revision exercise.

⁴ Calculation to two decimal places has been done to minimise the accumulation of round-off errors. This should not be interpreted as an indication of the accuracy of the adjustment. Air temperatures are recorded to the nearest 0.1 °C on the NIWA Climate Database.

⁵ Site photographs suggest that Appleby 2 EWS is in a ‘frost hollow’. NIWA climate scientists update the ‘seven-station’ series monthly, and had noticed the unusual behaviour at Appleby 2 EWS after 2007 – the Nelson location often had a very different monthly anomaly to the other six locations. An estimated anomaly from Nelson Aero was being used from late-2009 in place of the suspect data from Appleby.

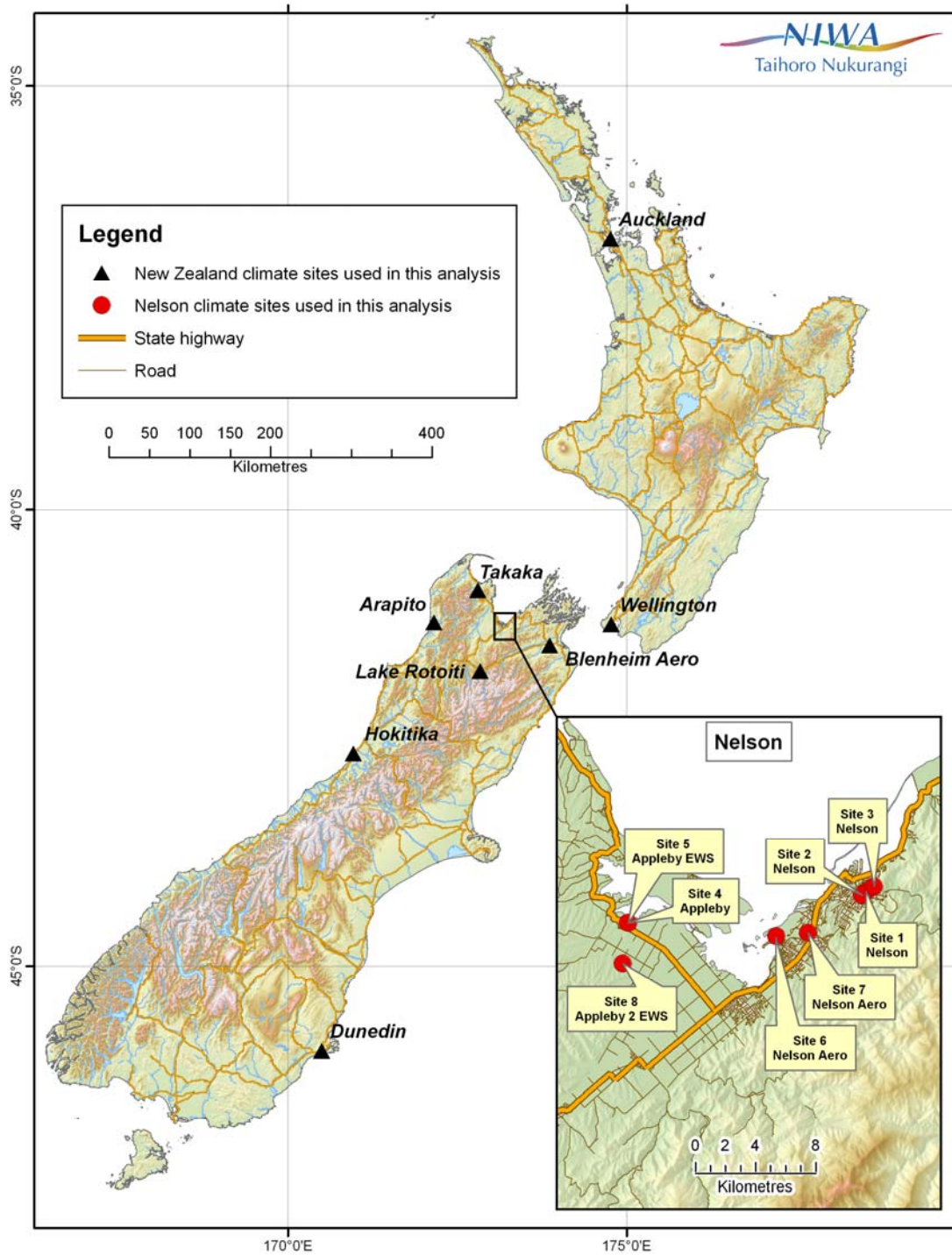


Figure 2: Map showing sites of temperature records referred to elsewhere within this document. The inset map locates the local Nelson sites.

The first factor was a strong argument in favour of not using Appleby 2 EWS data; the second allowed Nelson Aero data to be used continuously from December 1996 onwards, albeit with a site change in mid-1997.

These changes to the Nelson sites make it rather complicated to describe and explain the adjustments in both the ‘previous’ and ‘revised’ temperature series. The approach adopted here is to derive the adjustments to the new (revised) series in the main text, and describe the previous adjustments in the appendices.

It is common practice to adjust all the historical measurements to be consistent with the current open site (Aguilar *et al.*, 2003). For the revised temperature series, the current site of Nelson Aero is used as the ‘reference’ station, and all earlier sites adjusted relative to it. For the ‘previous’ temperature series, the adjustments shown in Table 1 are given relative to the manual Appleby station (Site 4) for consistency with what was done in practice.

Adjustment for Site Change in 1997

The temperature data from the Nelson Aero currently open site (Site 7, Figures 1 and 2) are adopted without change into the Nelson series. The first adjustment to consider is therefore that at June 1997 when the Nelson Aero station (Site 6) was moved about 2 km away from the airport to nearby Whakatu Drive (Site 7, the current open site). This station is not rural but has a fairly open exposure, and is situated in a small greenbelt set back from a highway.

Nelson Aero is generally an excellent site with a record extending back to April 1943. At the time of the Site 4 closure though, Nelson Aero had also closed temporarily, with the Climate Database record for the Nelson Aero site ending June 1994. This station was re-opened in June 1997 outside the airport grounds on Whakatu Drive (State Highway 6) opposite a Mitre 10 carpark (and along from the World of Wearable Art Museum in Quarantine Road). Although Nelson Aero was officially closed during July 1994 to May 1997, the observer on site had nevertheless continued to record the daily temperatures and provide them to the Nelson newspaper⁶.

There is no overlap in the temperature observations between the Nelson Aero Sites 6 and 7. It is therefore necessary to make comparisons, before and after the 1997 site change, with other climate sites that respond similarly to climatic variations as do the Nelson Aero sites.

Figure 3 shows the correlation of mean temperature interannual differences at the Virtual Climate Station (VCS) grid point containing Nelson (Site 6) with interannual differences at all other locations on the VCS grid from 1972 until 2008 (i.e., 1972-73 difference, 1973-74, ... , 2007-08).⁷ Interannual temperature variations at Nelson

⁶ The observer was also servicing the MetService Nelson AWS (agent 4271) at the time. Nelson Aero (agent 4241) temperatures for July 1994 to May 1997 were quality controlled and added to the NIWA National Climate Database tables in August 2010. These Nelson Aero measurements were not available to the Database at the time Appleby (Site 4) closed.

⁷ Over the past few years, NIWA research scientists have developed gridded data sets of daily climate parameters, on a 0.05° latitude by 0.05° longitude grid covering the whole country (a total of

Aero correlate strongly with those in the Motueka River valley and western Marlborough, the correlation typically being over +0.95.⁸ Temperature variations at Appleby also correlate well with those in Auckland (+0.91), Wellington (+0.93), Masterton (+0.93), Lincoln (+0.92), and even Dunedin (+0.83). So if necessary, these more distant sites could be used.

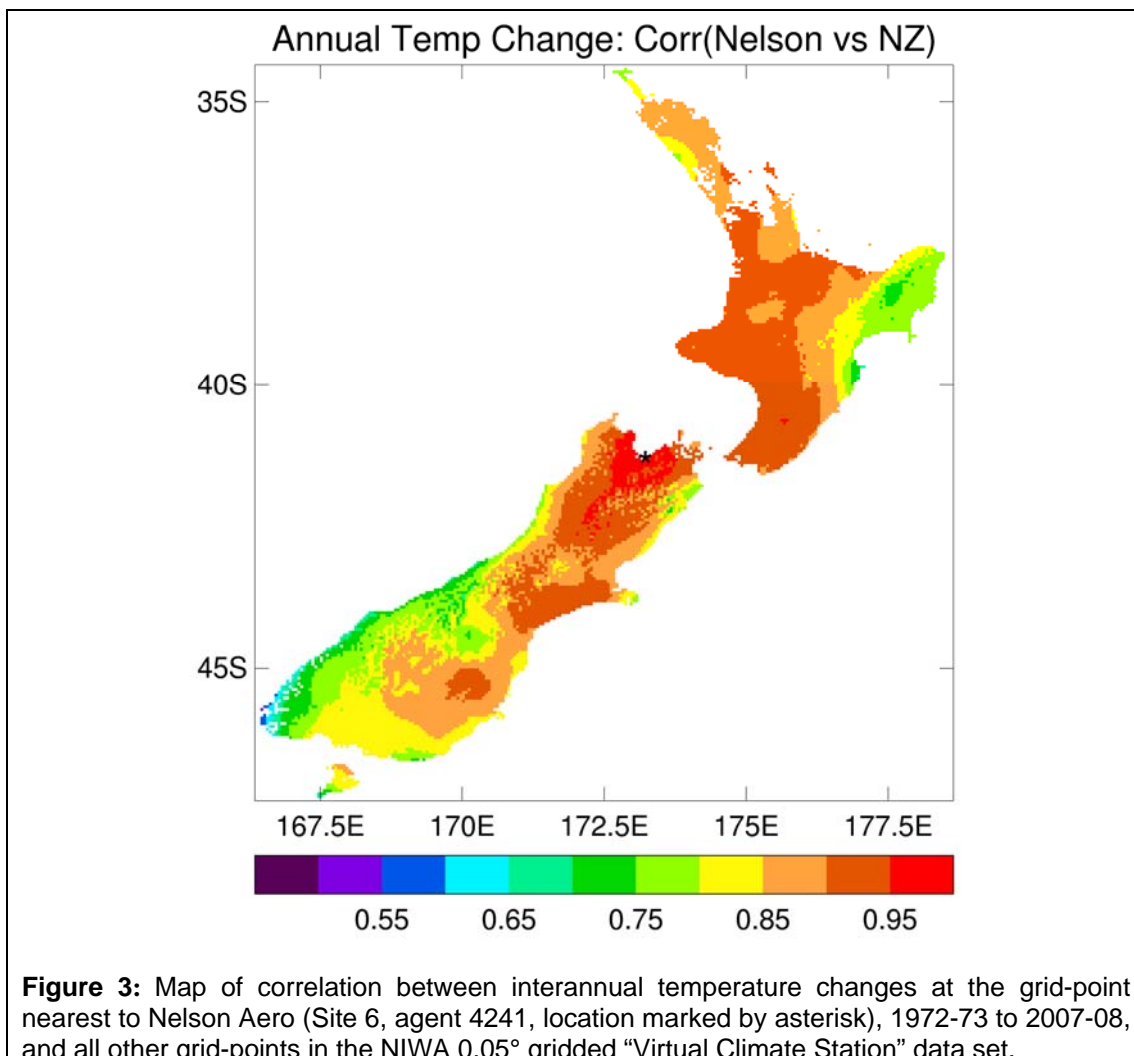


Figure 3: Map of correlation between interannual temperature changes at the grid-point nearest to Nelson Aero (Site 6, agent 4241, location marked by asterisk), 1972-73 to 2007-08, and all other grid-points in the NIWA 0.05° gridded “Virtual Climate Station” data set.

Figure 3 is a good guide to where we might find other climate sites that have a similar temperature response to that at Nelson. In practice, these ‘comparison’ sites are selected on a number of criteria:

- The comparison site obviously has to be operating for a reasonable period both before and after the site change that is being examined, and must not have a site change itself within this period;
- Inspection of the site history should not raise any concerns about the quality of the site observations;

approximately 11,500 grid-points). The “Virtual Climate Station” (VCS) data set for daily maximum and minimum temperatures begins on 1 January 1972, and interpolates data from between 150 and 200 climate stations using a sophisticated interpolation technique developed at the Australian National University in Canberra (Tait 2008).

⁸ A correlation of +1.0 indicates perfect agreement; i.e., that the interannual temperature variations at two sites match perfectly (except for a constant offset and multiplicative factor).

- Interannual correlations⁹ are calculated between the reference site (e.g., Nelson Aero) and a selected comparison site (e.g., Blenheim Aero, see Figure 2) for up to 10 years before and after the reference site change. This is done for maximum and minimum temperatures as well as for mean temperatures. We select comparison stations with the highest correlations;
- Adjustments for the site change are calculated with respect to each comparison station, and we look for consistency across the set of comparison sites eventually selected.

The intention in these analyses is therefore to compare temperatures over 10 years before and after the site change. This is not always possible since the record at the comparison site may not cover the full 21 year period, or there may be site history information that points to other potential inhomogeneities in the comparison site record.

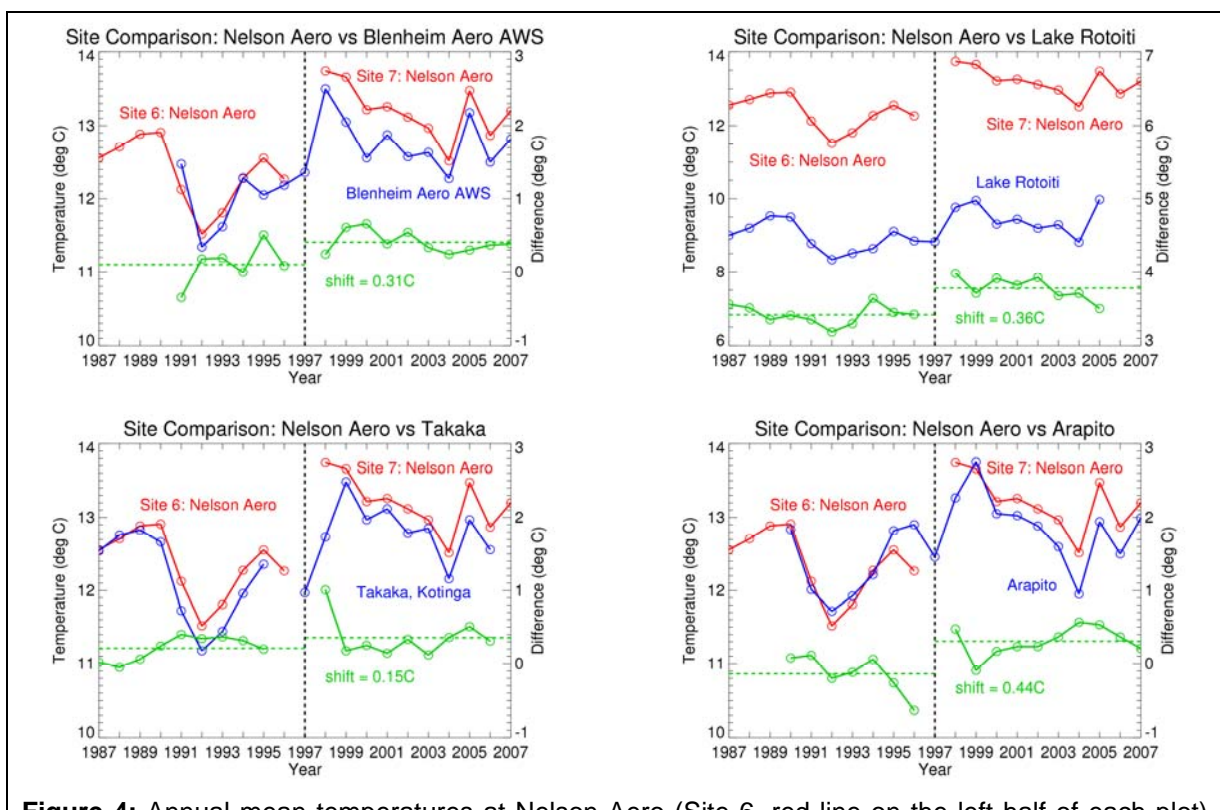


Figure 4: Annual mean temperatures at Nelson Aero (Site 6, red line on the left half of each plot) and the re-located Nelson Aero (Site 7, red line on the right half of each plot), compared with temperatures at four other stations that overlap the Nelson Aero site move: Blenheim Aero AWS (agent 4326), Lake Rotoiti (agent 3892), Takaka Kotinga 2 (agent 3789) and Arapito (agent 3846). The solid blue line shows the temperatures at these comparison stations. The solid green line represents the difference (Site 6/7 minus the comparison station) using the right-hand ordinate scale. The horizontal dashed green line is the average difference before and after the site change. The year of the site change, 1997, is indicated by the vertical dashed line.

Figure 4 shows annual temperatures before and after the Site 6/Site 7 change-over, comparing the Nelson Aero sites with four comparison stations (refer to Figure 2):

⁹ Correlations are used to assess how well the year to year variations at a comparison site match those at the Nelson sites in question (and therefore if it is a ‘good’ comparison site). Correlations are calculated using the first-difference series of annual temperatures, excluding the year of the site change itself. This method prevents any discontinuity at the site-change year from influencing the correlations (Aguilar *et al.*, 2003).

Blenheim Aero AWS (agent 4326)¹⁰, Lake Rotoiti (agent 3892), Takaka (agent 3789) and Arapito (agent 3846). These stations are between 60 and 90 km from Nelson, and share the characteristic with Nelson Aero that they are somewhat sheltered from south-westerly winds but are exposed to northerlies.

Before the 1997 site change, Nelson Aero (Site 6) was 0.10 °C warmer than Blenheim Aero, but after the site change the new Nelson Aero site (Site 7) was 0.41 °C warmer than Blenheim Aero. Thus, the new Nelson Aero Site 7 was 0.31 °C warmer than the earlier Nelson Aero Site 6, according to the comparison with Blenheim Aero. Examining each comparison site in turn, the Site 6 to Site 7 move caused measured temperatures to be higher by 0.36 °C (with respect to Lake Rotoiti), 0.15 °C (Takaka) and 0.44 °C (Arapito).

Thus, we have four estimates of the difference between Nelson Aero Site 6 and Nelson Aero Site 7: +0.31 °C, +0.36 °C, +0.15 °C, and +0.44 °C. The average is +0.31 °C, with Nelson Aero Site 7 being warmer than Nelson Aero Site 6. Thus, an adjustment of +0.31 °C needs to be made to the Nelson Aero Site 6 temperatures to bring them into line with the current open site (Site 7). This adjustment has been inserted into Table 1 (final column) against Site 6. The value is positive, meaning that the raw Site 6 temperatures must be *increased* by this amount to make them homogeneous with the current open site.

Adjustment for Site Change in 1996

We continue to work back in time from the current open site, and now need to consider the effect of the change from Site 4 (Appleby) to Site 6 (Nelson Aero). Appleby is located 13 km west of Nelson city and about 10 km west of the airport (Figure 2). The surrounding land is undulating, rising to the Moutere Hills to the south. The climate station was at the DSIR (later HortResearch) Fruit and Trees Research Station, with the instruments sited on a grassed knoll.

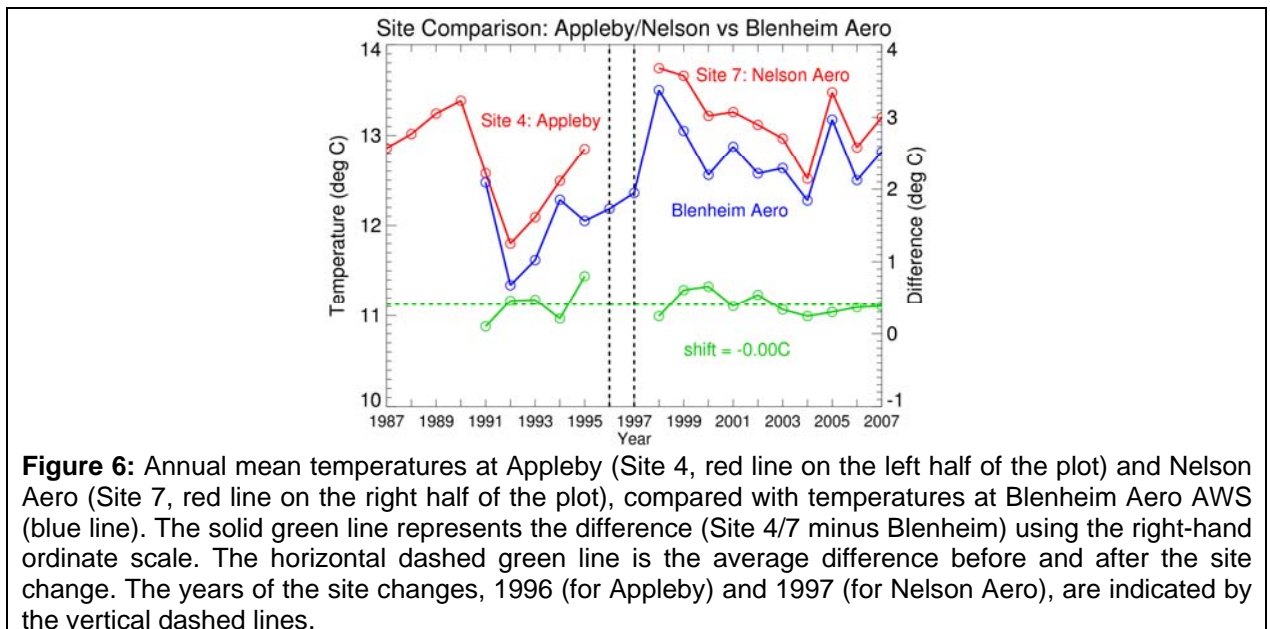
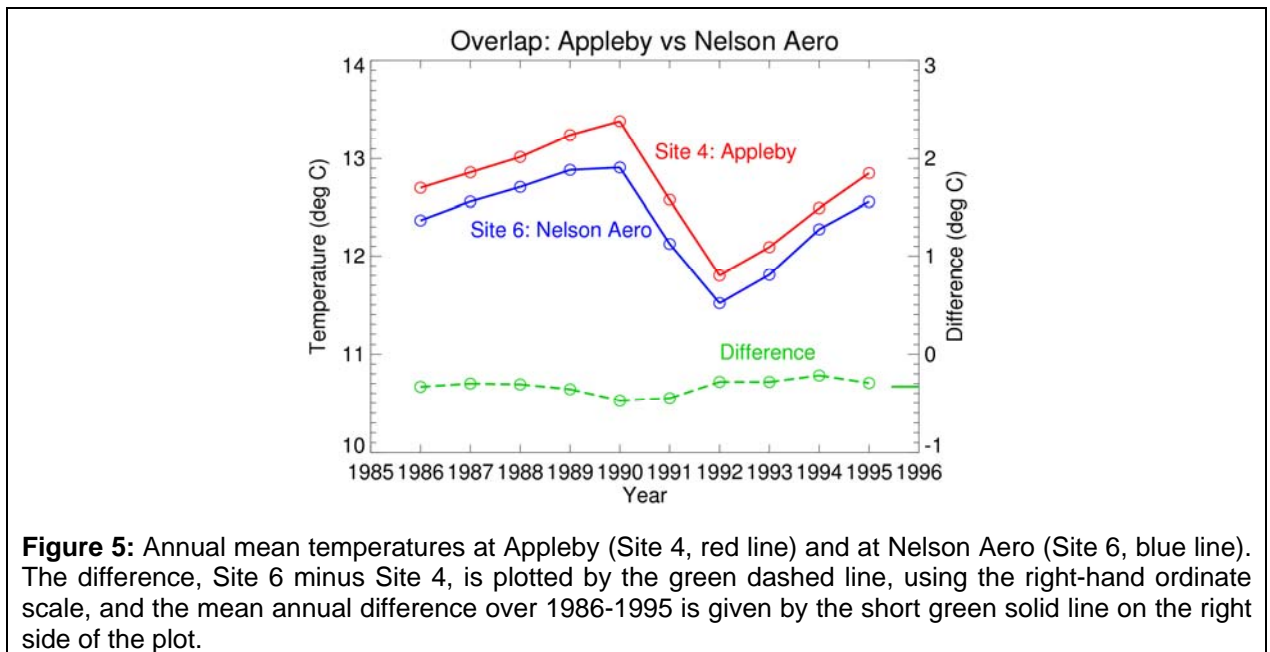
Nelson Aero (Site 6) is used in Table 1 to fill a 6-month gap, December 1996 to May 1997, between Site 4 and Site 8. There is however a long overlap between Nelson Aero (Site 6) and Appleby (Site 4), 1943-1996, which we can use to estimate the site correction. Figure 5 is a plot of just the 10 years 1986-1995 immediately prior to the closure of Appleby; there is a fairly constant difference between the two sites, with Nelson Aero being 0.33 °C cooler than Appleby.

Therefore, relative to Nelson Aero (Site 6), the Appleby temperatures should be reduced by 0.33 °C. The cumulative adjustment for Appleby (Site 4) relative to the current open site (Nelson Aero, Site 7) is thus: $-0.33 + 0.31 = -0.02$ °C. So it turns out that Appleby (Site 4) and the current Nelson Aero site (Site 7) have virtually no difference, on average, in their annual mean temperatures. This makes the adjustments in Table 1 easier to follow, since it doesn't make any significant difference whether

¹⁰ In the NIWA Climate Database, the two acronyms AWS (Automatic Weather Station) and EWS (Electronic Weather Station) are both used when referring to automated measurement sites. AWS refers to a MetService site, and EWS to a NIWA site. The data loggers are quite different in the two networks, and the sensors are often different also.

we adjust the other Nelson sites with respect to Appleby (Site 4) or the current Nelson Aero (Site 7).

Figure 6 provides further support for the equivalence of annual mean temperatures Appleby and the current Nelson Aero (Site 7). The plot shows that the annual mean temperature difference between Blenheim Aero and Appleby over 1991-1995 is essentially the same as between Blenheim Aero and Nelson Aero (Site 7) over 1998-2007.¹¹

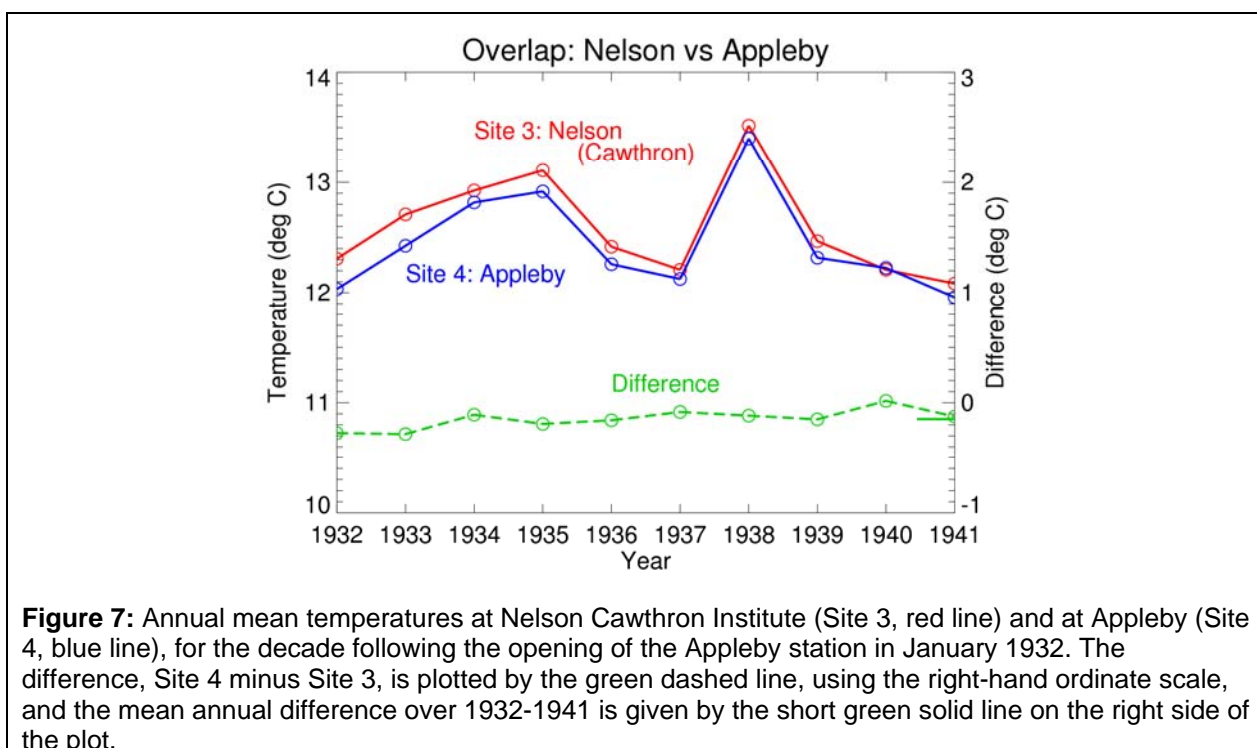


¹¹ The small difference between the two calculations (i.e., $-0.02\text{ }^{\circ}\text{C}$ and $0.00\text{ }^{\circ}\text{C}$) arises because different periods of data are used.

Adjustment for Site Change in 1932

The Appleby station (Site 4 in Table 1, and described earlier) was opened in December 1931. Prior to 1932, the composite temperature series uses the Nelson City measurements from Cawthron Institute (agent 4244, Site 3). The Cawthron Institute was situated in northwest Nelson city, partly on a hill and partly on the flat. The meteorological station was in an open enclosure on the flat with a wire netting fence. The elevation was 7 m with a good exposure. The station (Nelson Site 3) operated between December 1920 and December 1951. There is thus a 20-year overlap with Appleby (Site 4).

Figure 7 shows the first 10 years of overlapping records at Appleby and Cawthron, following the opening of the Appleby site. Over this period, the two sites were in close agreement, with Appleby averaging 0.15 °C cooler than Nelson Cawthron.



The difference line in Figure 7 has a small upward slope, suggesting that there might be some differential warming at Nelson City relative to Appleby. The Cawthron record continues for a further 10 years to 1951, and over the 1942-1951 period, the temperatures are clearly diverging. For 1932-1941 (as in Figure 7), Cawthron was 0.15 °C warmer than Appleby; over 1942-1946 it was 0.16 °C warmer (very similar), but over 1947-1951 Cawthron was 0.32°C warmer, suggesting the possibility of an urban influence affecting the City site in the late 1940s.

Owing to concerns that any non-climatic warming at Cawthron could affect the estimated site adjustment, we have also calculated site comparisons. Figure 8 shows annual temperatures before and after the Site 3/Site 4 change-over, comparing the Nelson sites with three comparison stations: Auckland, Albert Park (agent 1427),

Dunedin Botanical Gardens (agent 5375) and Hokitika Town (agent 3907). The comparison sites used previously (Figure 4) were not operating in 1932, so much more distant sites had to be considered instead.¹²

In this comparison, we ignore the Cawthron temperatures after 1931. Comparing the Cawthron and Appleby temperatures with the comparison site over 1921-1931 and 1932-1941, respectively, we find Appleby is consistently colder than Cawthron. The offsets are: $-0.11\text{ }^{\circ}\text{C}$ (with respect to Albert Park), $-0.12\text{ }^{\circ}\text{C}$ (Dunedin) and $-0.22\text{ }^{\circ}\text{C}$ (Hokitika). These average to $-0.15\text{ }^{\circ}\text{C}$, the same as found previously from the direct Appleby-Cawthron overlap in Figure 7.¹³

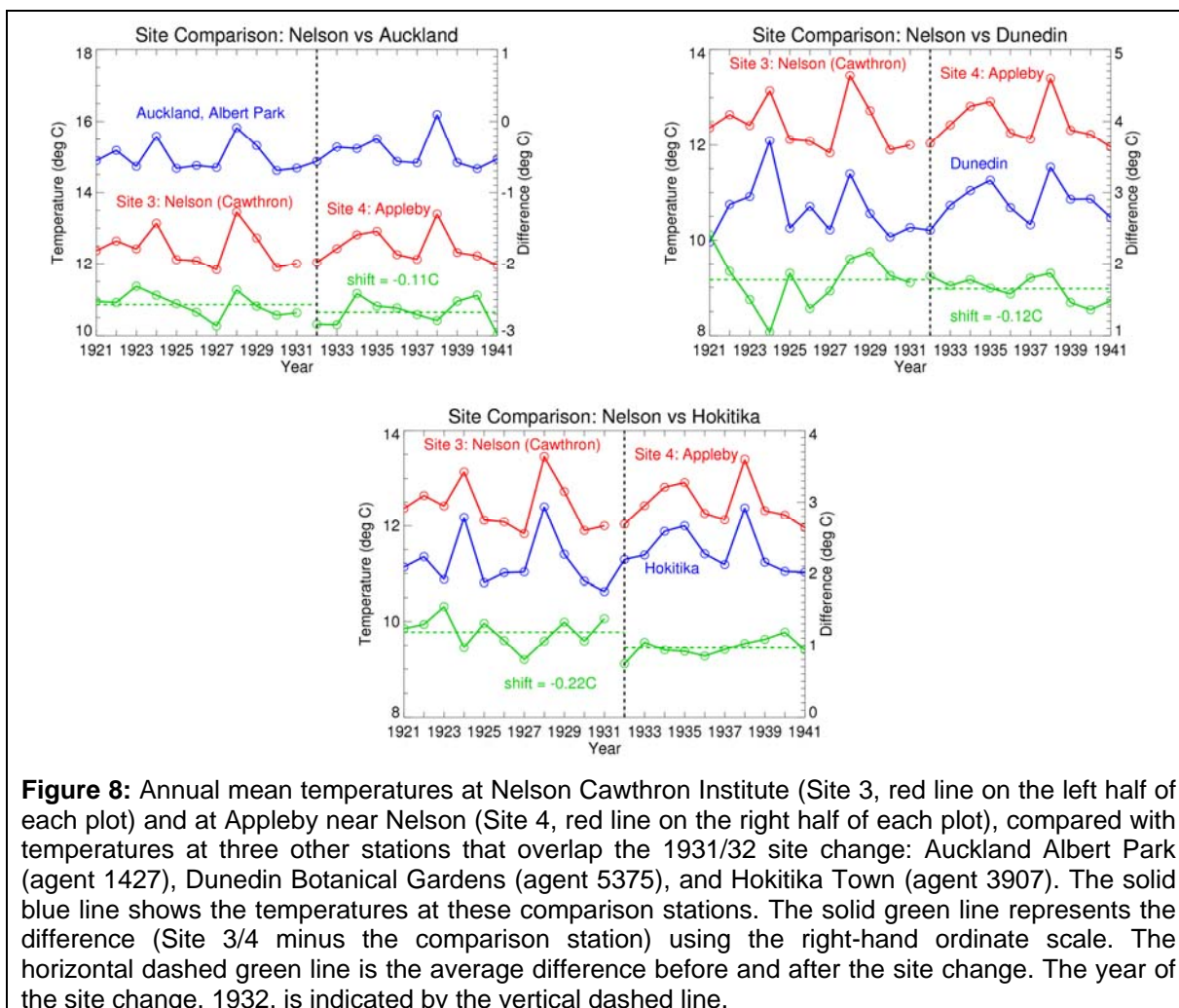


Figure 8: Annual mean temperatures at Nelson Cawthron Institute (Site 3, red line on the left half of each plot) and at Appleby near Nelson (Site 4, red line on the right half of each plot), compared with temperatures at three other stations that overlap the 1931/32 site change: Auckland Albert Park (agent 1427), Dunedin Botanical Gardens (agent 5375), and Hokitika Town (agent 3907). The solid blue line shows the temperatures at these comparison stations. The solid green line represents the difference (Site 3/4 minus the comparison station) using the right-hand ordinate scale. The horizontal dashed green line is the average difference before and after the site change. The year of the site change, 1932, is indicated by the vertical dashed line.

¹² We also considered Wellington Kelburn (agent 3385) and Waingawa Essex Street (agent 2473). However, Kelburn measurements began in 1928 so there are only 4 years for comparison with Cawthron; Waingawa had poorer interannual correlations (less than +0.8 for maximum and minimum temperatures) and the estimated adjustments for both mean and minimum temperatures were rather different to those of the other 4 sites. Thus, neither Wellington nor Waingawa (Masterton) were included in the final comparison.

¹³ The fact that the two calculations agree exactly to 2 decimal places is of course rather fortuitous. If a period of only 10 years prior to the site change was used (i.e., 1922-1931), then the average offset over the 3 comparison sites of Figure 8 changes to $-0.13\text{ }^{\circ}\text{C}$. If the additional two comparison sites mentioned in the footnote above (Wellington and Masterton) are included, the average offset is $-0.16\text{ }^{\circ}\text{C}$. The close agreement of all these figures gives us confidence in the robustness of the 1932 adjustment.

The cumulative adjustment of Cawthron relative to Nelson Aero Site 7 is thus: $+0.31 - 0.33 - 0.15 = -0.17$ °C. This adjustment has been inserted into Table 1 (final column) against Site 3. Note that the Cawthron data are not used after 1931, thereby avoiding the apparently anomalous 1940s temperature trend noted there.

Adjustment for Site Change in 1920

The meteorological station at Cawthron Institute (Nelson Site 3) operated between December 1920 and December 1951. There is no overlap with the earlier Nelson City site in Nile Street (Site 2)¹⁴, which closed in November 1920.

In 1920, there were a lot fewer climate stations operating than in recent history, and this limits the options for comparing the Site 2/3 temperature discontinuity. Figure 9 shows comparisons with four other long-term sites: Auckland Albert Park (agent 1427), Dunedin Botanical Gardens (agent 5375), Wellington Thorndon (agent 3391), and Hokitika Town (agent 3907). Three of these sites are common to the 1932 comparison (Figure 8), and they are all referred to elsewhere in the documents on the “seven-station” temperature series. The records from these comparison sites were truncated where necessary: for example, at Hokitika, data prior to 1913 were excluded because of the warm bias during the period 1894-1912.

Before the 1920 site change, comparisons were made over the six years 1913-1918 with Nelson Nile Street (Site 2). There are 5 months of missing data at Nile Street in the middle of 1919, which excludes this year from consideration. With respect to Auckland Albert Park, Nelson Nile Street was 1.54 °C colder, whereas Nelson Cawthron was 2.56 °C colder. With respect to Dunedin Botanical Gardens, Nelson Nile Street was 2.53 °C warmer, whereas Nelson Cawthron was 1.78 °C warmer. With respect to Wellington Thorndon, Nelson Nile Street was 0.13 °C warmer, whereas Nelson Cawthron was 0.78 °C colder. With respect to Hokitika, Nelson Nile Street was 2.02 °C warmer, whereas Nelson Cawthron was 1.16 °C warmer.

Thus, the comparisons show that the new Nelson site at Cawthron was consistently colder than the previous Nile Street site, by: -1.02 °C (Auckland), -0.75 °C (Dunedin), -0.91 °C (Wellington), and -0.86 °C (Hokitika). The average offset between Nile Street and Cawthron is -0.88 °C¹⁵. Therefore, just as Cawthron was warmer than Appleby (Site 4) by 0.15 °C, so Nile Street was warmer again than Cawthron by a further 0.88 °C. The cumulative adjustment of Nile Street relative to Nelson Aero Site 7 is thus: $+0.31 - 0.33 - 0.15 - 0.88 = -1.05$ °C. This adjustment has been inserted into Table 1 (final column) against Site 2.

¹⁴ According to 1932 historical notes by Dr Edward Kidson, then Director of the New Zealand Meteorological Service, the Nile Street location was “considered in Nelson to be a warm one, being sheltered from the southwest and sufficiently high not to be so subject to frost as places further north.”

¹⁵ The estimated offsets from different comparison sites could be combined in some other way than a simple average. Typical approaches in the literature are to weight by correlation or by distance, or both. In this instance, an alternative weighting would produce a very similar answer to a simple average. The two sites physically closest to Nelson are Wellington and Hokitika, whose individual offsets straddle the -0.88 °C average. These two sites also have the highest correlation on interannual differences in annual mean temperature (both +0.95), with lower correlations for the distant sites: +0.91 with Auckland, and +0.87 with Dunedin over the periods of record shown in Figure 8.

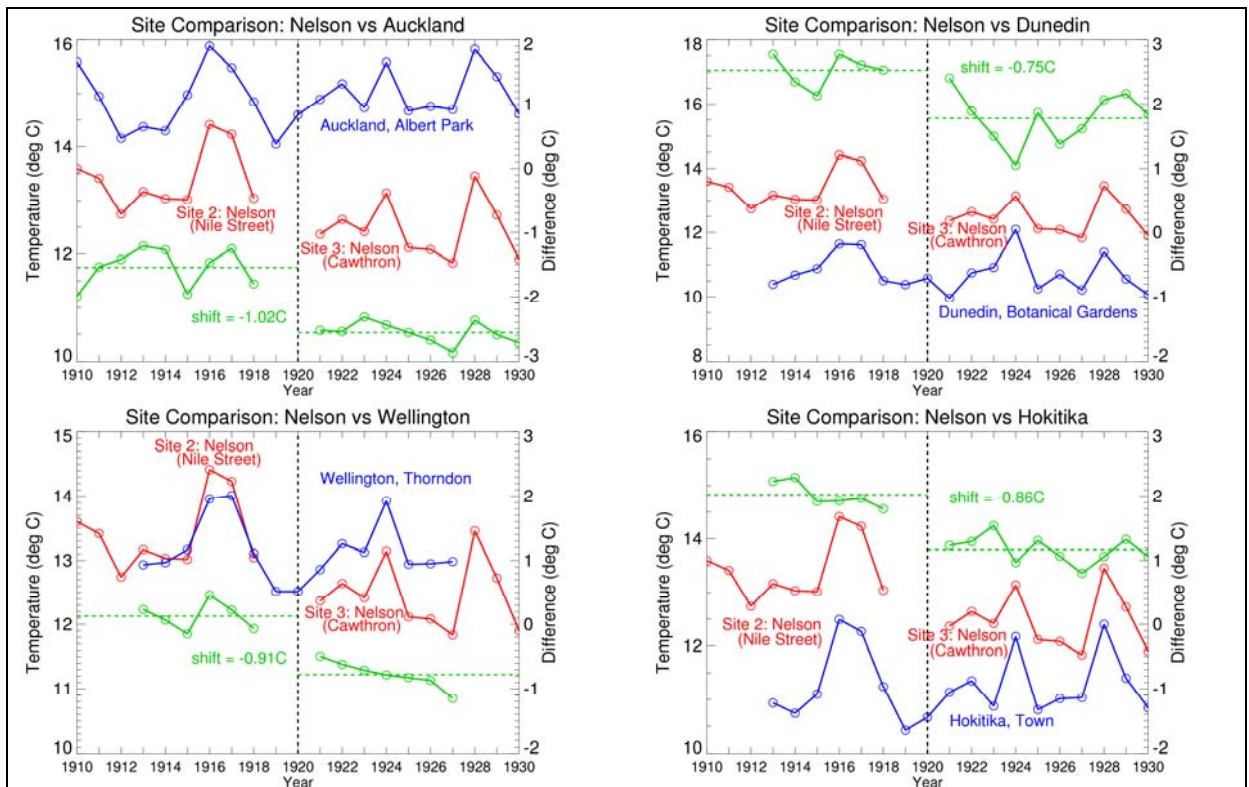


Figure 9: Annual mean temperatures at Nelson Nile Street (Site 2, red line on the left half of each plot) and Nelson Cawthron Institute (Site 3, red line on the right half of each plot) compared with temperatures at four other stations that overlap the Nelson site change: Auckland Albert Park (agent 1427), Dunedin Botanical Gardens (agent 5375), Wellington Thorndon (agent 3391), and Hokitika Town (agent 3907). The solid blue line shows the temperatures at these comparison stations. The solid green line represents the difference, Nelson minus the comparison station, using the right-hand ordinate scale. The horizontal dashed green line is the average difference before and after the site change. The year of the site change, 1920, is indicated by the vertical dashed line.

The adjustment for the Nile Street to Cawthron site change is the final one considered in the revised Nelson composite series. Adjustments for additional sites used in the previous Nelson composite series, but not used in this revised series, are re-derived in Appendix 1.

Putting the Time Series Together

The various adjustments described above can be applied successively to the Nelson temperature records. The resulting final time series from 1908 to 2009 is shown in Figure 10, including a comparison with the previous Nelson time series used by NIWA.¹⁶ A linear trend has been fitted to each series over the period 1909 to 2009. Expressed in units of degrees per century, the linear trend in the revised series is $0.76 (\pm 0.30) \text{ }^\circ\text{C / century}$, as compared with $0.81 (\pm 0.30) \text{ }^\circ\text{C / century}$ for the trend calculated from the previous Nelson time series published in February 2010.¹⁷

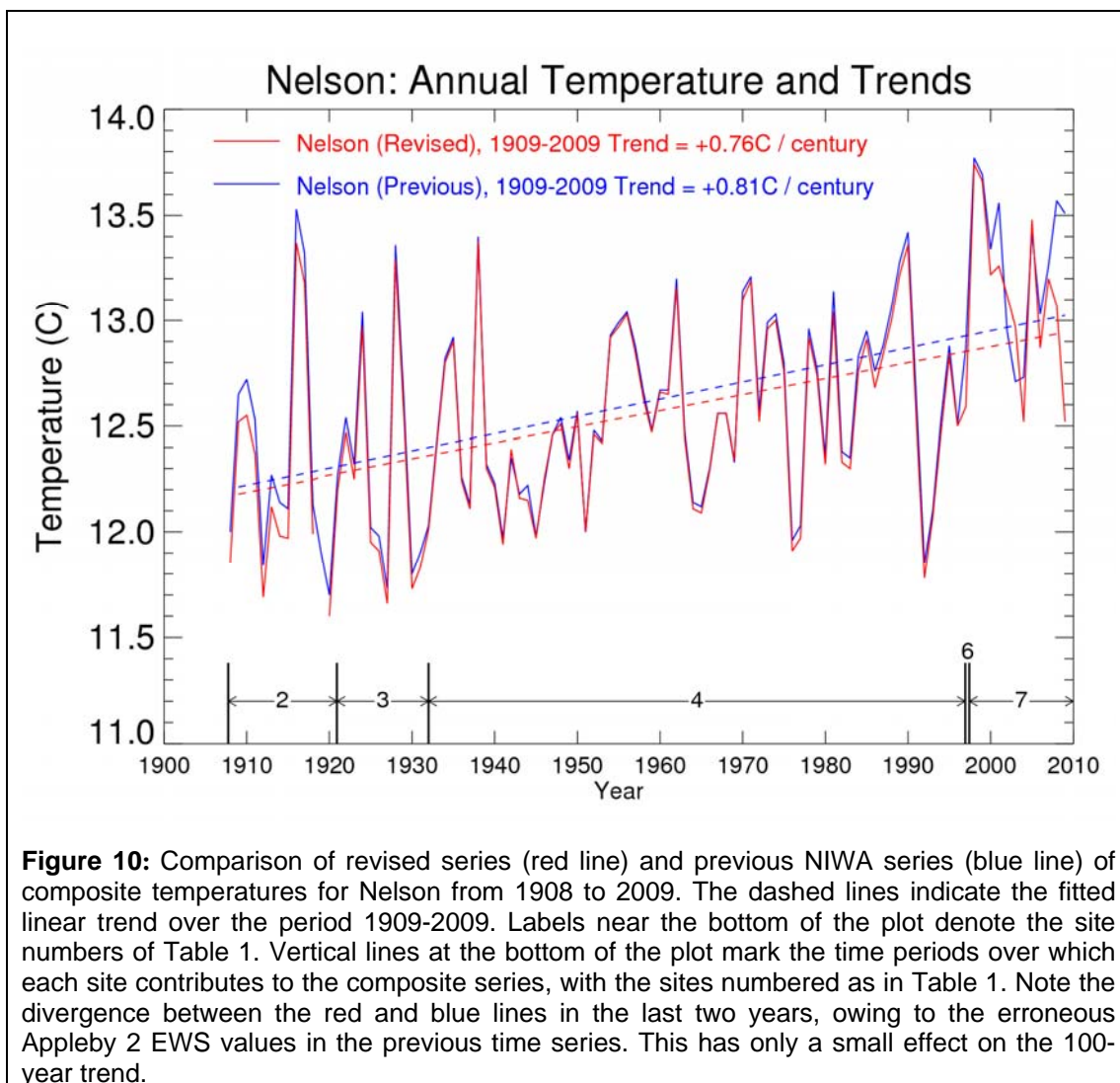


Figure 10: Comparison of revised series (red line) and previous NIWA series (blue line) of composite temperatures for Nelson from 1908 to 2009. The dashed lines indicate the fitted linear trend over the period 1909-2009. Labels near the bottom of the plot denote the site numbers of Table 1. Vertical lines at the bottom of the plot mark the time periods over which each site contributes to the composite series, with the sites numbered as in Table 1. Note the divergence between the red and blue lines in the last two years, owing to the erroneous Appleby 2 EWS values in the previous time series. This has only a small effect on the 100-year trend.

¹⁶ In the revised composite temperature series for Nelson shown in Figure 10, annual mean temperatures in years containing up to three missing months have been estimated from the composite 1971-2000 climatology for Nelson. The methodology for these estimates is described in Appendix 2 of the Masterton document.

¹⁷ The uncertainty here ($\pm 0.30 \text{ }^\circ\text{C}$) defines the standard 95% confidence interval on the linear trend fitted to the adjusted time series, and does not include any consideration of uncertainty about each adjustment. Further research is underway to quantify how the accumulating adjustments influence the trend estimates.

There is minimal change in the 100-year trend between the previous Nelson series (as posted on the NIWA website in February 2010) and the revised one using the adjustments derived in this document.

Figure 11 repeats the graph of the revised composite annual mean temperature series for Nelson, but now compares the composite with the unadjusted raw multi-site temperatures. The two series are identical from 1998 onwards, since this period is covered by the Nelson reference site (Nelson Aero, Site 7) for which no adjustment is applied. The estimated adjustments are also shown in Figure 11. The adjustments are cumulative relative to Nelson Aero Site 8, and correspond to those in the final column of Table 1.

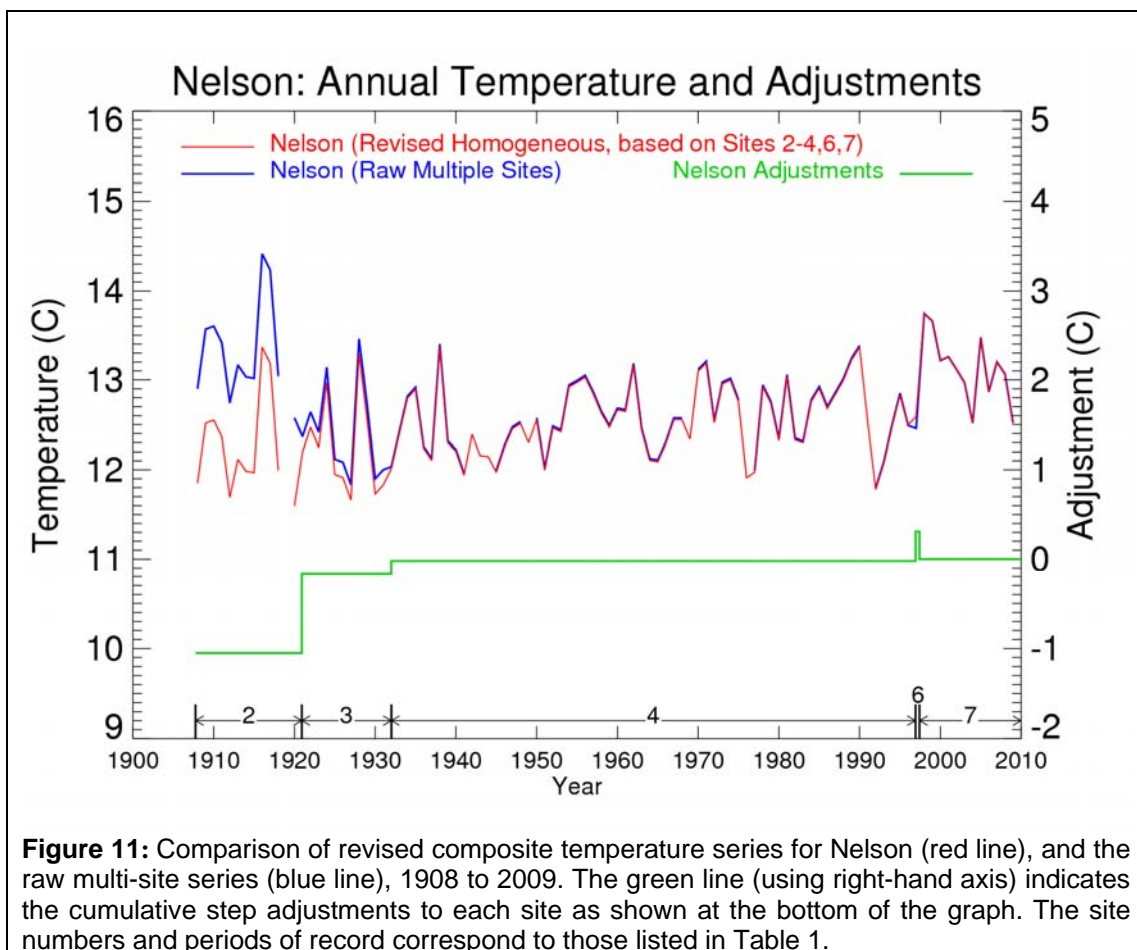


Figure 11: Comparison of revised composite temperature series for Nelson (red line), and the raw multi-site series (blue line), 1908 to 2009. The green line (using right-hand axis) indicates the cumulative step adjustments to each site as shown at the bottom of the graph. The site numbers and periods of record correspond to those listed in Table 1.

Further Information

Further technical information on different approaches to homogeneity adjustment of climate data can be found in the references below (Peterson *et al.*, 1998; Rhoades and Salinger, 1993).

Date: Document originally created 29 October 2010, and revised 13 December 2010 following review from the Australian Bureau of Meteorology.

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Appendix 1

Revisiting the 'Previous' Temperature Adjustments

Table A1.1 is an abbreviated version of Table 1, and summarises the adjustments based on the 'previous' set of Nelson stations, labelled Sites 1 through 5, then 7 and 8. A comparison is provided between the adjustments in use as at February 2010 (labelled 'Previous Temperature Adjustment'), and new ones derived in this document (labelled 'Revised Temperature Adjustment'). Some of the adjustments have already been discussed in the main text; the others will be described in this appendix.

Table A1.1: Information about Nelson climate observations:
 (Column 1) the site label used in the text;
 (Column 2) the site name, and (in parentheses) the 'agent number' used by NIWA Climate Database (CliDB) to identify the station;
 (Column 3) period of record for which the site contributed to the composite time series used by NIWA (as of February 2010) ;
 (Column 4) previous temperature adjustment, taken from the February 2010 'Schedule of Adjustments'; and
 (Column 5) revised temperature adjustment to be applied (with respect to Appleby, Site 4), as discussed in the appendix.

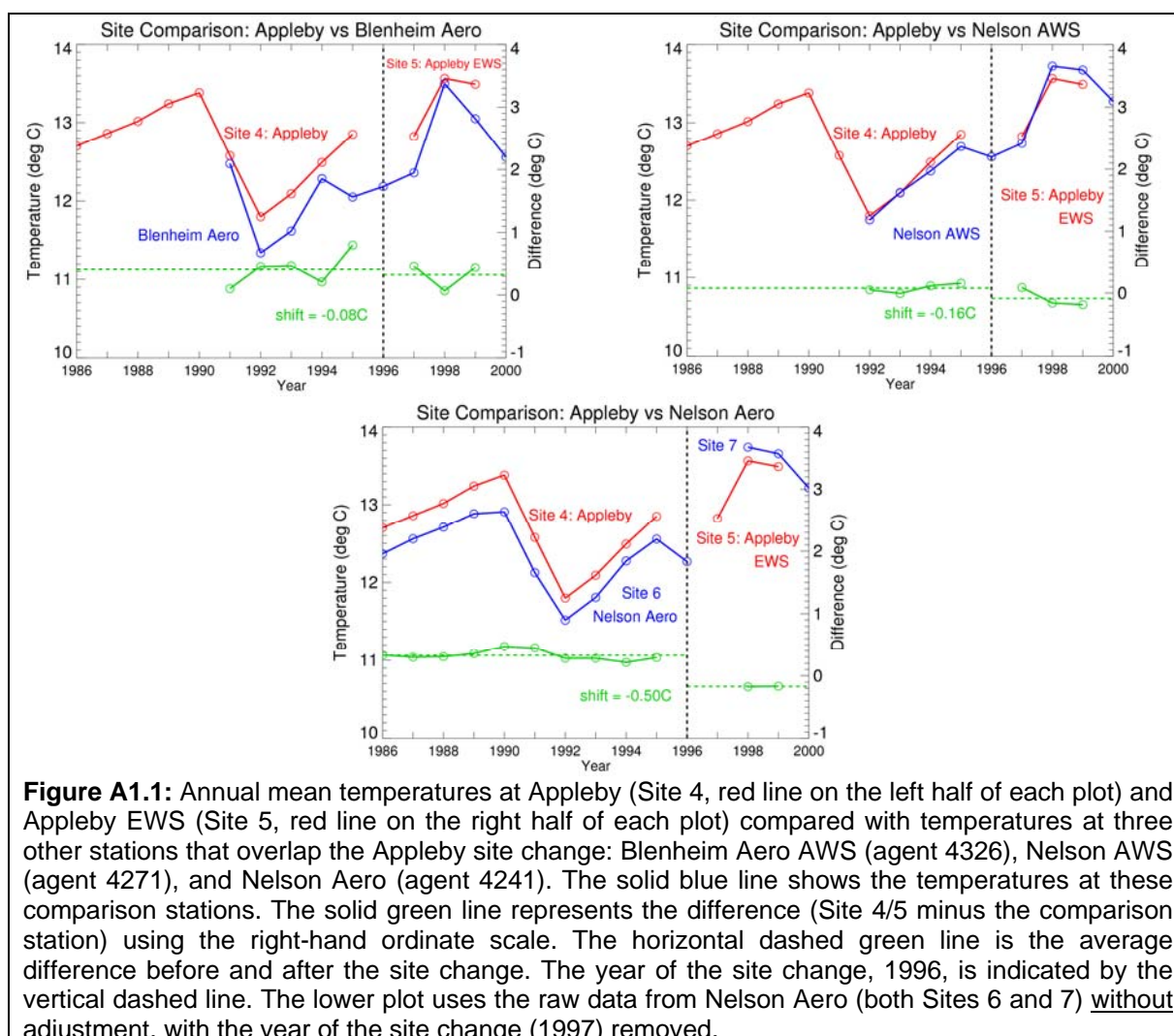
Site Label	Site Name (Agent Number)	Period of Record of Contributing Site Data	Previous Temperature Adjustment (°C)	Revised Temperature Adjustment (°C)
Site 1	Nelson City (4244)	Jul 1862 to Dec 1880	-0.6	-0.40
Site 2	Nelson City, Nile St East (4244)	Oct 1907 to Nov 1920	-0.9	-1.03
Site 3	Nelson City, Cawthron Institute (4244)	Dec 1920 to Dec 1931	-0.1	-0.15
Site 4	Appleby (4239)	Jan 1932 to Nov 1996	0.0	0.00
Site 5	Appleby EWS (12755)	Dec 1996 to May 2000	+0.2	+0.14
Site 7	Nelson Aero (Whakatu Drive) (4241)	Jun 2000 to Mar 2001	+0.2	+0.02
Site 8	Appleby 2 EWS (21937)	Apr 2001 to Dec 2007	+1.0	+1.03
		Jan 2008 to present	+1.0	?? ¹⁸

The previous adjustments were relative to Appleby (Site 4) as the reference site, so we will use the same convention here. The following sections go through each site change in turn, first working forward from Appleby's closure in 1996 to the present, and then working backwards prior to the start of Appleby in 1932. Table A1.1 uses the same site numbering as in Table 1. Note in particular that Site 6 (Nelson Aero, when it was actually at the airport) is not used in this series.

¹⁸ A spurious warming is evident in the observations after 2007. See discussion in text.

Adjustment for Site 4 to Site 5 Change in 1996

Two automated Appleby sites (Table A1.1) were previously used to build the Nelson temperature series. The manual observation station (Site 4) was closed 12 December 1996, and replaced by an automatic station on the same site (Appleby EWS, Site 5). Appleby EWS, which had a 2-month overlap (October-November 1996) with Site 4¹⁹, remained in operation until June 2000. Measurement of Appleby temperatures was taken over in April 2001 by a new station (Appleby 2 EWS, Site 8), situated 2.5 km south of the previous Site 5 within the Seifried Estate vineyard. There is thus a 10-month gap, June 2000 to March 2001, between Site 5 and Site 8 in Table A1.1, which is filled using a temperature record from Nelson Aero (Site 7). The Nelson Aero record extends back to April 1943. In June 1997, the station was moved off the airport grounds, as discussed in the main text.



¹⁹ Appleby EWS was colder than Appleby by 0.1 °C in October 1996, and warmer by 0.1 °C in November 1996.

Figure A1.1 shows annual temperatures before and after the Site 4/Site 5 changeover, comparing the Appleby sites with three comparison stations: Blenheim Aero AWS (agent 4326), Nelson AWS (agent 4271) and Nelson Aero (agent 4241). Unfortunately, Appleby EWS has only three complete years over which to make a comparison. Before the 1996 site change, Appleby (Site 4) was 0.40 °C warmer than Blenheim Aero and 0.08 °C warmer than Nelson AWS. After the site change, Appleby EWS (Site 5) was 0.32 °C warmer than Blenheim Aero and 0.08 °C cooler than Nelson AWS. Thus, the new Appleby EWS Site 5 was 0.08 °C cooler than Appleby Site 4 according to the comparison with Blenheim Aero and, 0.16 °C cooler according to the comparison with Nelson AWS.

The comparison of the Appleby sites with Nelson Aero is complicated by the fact that Nelson Aero had a site change itself in mid-1997. Thus, in Figure A1.1 (lower plot), the year 1997 has been removed from the Nelson Aero data. According to Figure A1.1, Appleby EWS is 0.50 °C cooler than Site 4. However, part of this difference is due to the re-location of the Nelson Aero station in mid-1997 Site 6 to Site 7. From analysis presented above, we know that the new Nelson Aero site from June 1997 was 0.31 °C warmer than the old one on the airport. Allowing for this difference implies that the new Appleby EWS site was only 0.19 °C cooler than the previous site.

Thus, we have three estimates of the difference between Appleby Site 4 and Appleby Site 5: -0.08 °C, -0.16 °C, and -0.19 °C. The average is -0.14 °C, with Appleby Site 5 being cooler than Appleby Site 4. Thus, an adjustment of +0.14 °C needs to be added to Appleby Site 5 to bring it into line with Site 4. This adjustment has been inserted into Table 2 (final column) against Site 5.

Following Figure 3, more distant comparison sites were also considered to help estimate the Site 4/5 change in mean annual temperature. Sites were selected according to how good their correlations were with Appleby, considering maximum and minimum temperature as well as mean temperature. In this instance, more distant sites had rather poorer correlations and so were not used²⁰.

Adjustment for Site 5 to Site 7 Change in 2000

Nelson Aero (Site 7) is used in Table A1.1 to fill a 10-month gap, June 2000 to March 2001, between Site 5 and Site 8. This adjustment has already been calculated in the main text. The adjustment of Nelson Aero back to the Appleby manual record is thus +0.02 °C, and this has been entered into Table 2 against Site 7. Note that there is a considerable discrepancy between the previous and revised adjustments for this site. We believe an error was made previously when updating the Salinger et al (1992) adjustments, probably due to overlooking the site move off the airport grounds.

²⁰ All the more distant sites examined had around +0.8 correlation or lower for at least one of Mean, Maximum and Minimum temperature correlations over the period in question (Figure 4). The indicated adjustments tended to be slightly positive with respect to the more distant sites: +0.02 °C (Tauranga Aero AWS, agent 1615), +0.05 °C (Wellington Kelburn, agent 3385), +0.07 °C (Auckland Aero, agent 1962). These were in conflict with the adjustments calculated from the nearby sites and were disregarded.

Adjustment for Site 7 to Site 8 Change in 2001

Appleby 2 EWS (Site 8) took over from Nelson Aero (Site 7) in April 2001 (Table A1.1). Nelson Aero continued in operation, so a direct temperature comparison can be made for the overlap from 2002 onwards (Figure A1.2). For the first 6 years of the overlap, 2002 to 2007, there is a relatively constant difference between the two sites: the new Appleby 2 EWS site is, on average, 1.01 °C colder than Nelson Aero, and therefore 1.03 °C colder than Appleby Site 4. This is consistent with the February 2010 ‘Schedule of Adjustments’. The large difference in mean temperature between Appleby 2 EWS and other Nelson region sites is due primarily to very low minimum temperatures recorded at Appleby 2 EWS. Over 2002-2007, its annual minimum averaged 2.37 °C colder than that of Nelson Aero. It could be said that Site 8 is in a ‘frost hollow’, and site photographs show there are banks at higher elevation on three sides of the meteorological enclosure.

Figure A1.2 (left-hand panel) shows a rapid warming trend in the most recent two years at Appleby 2 EWS, 2008-2009, possibly due to growth of trees or maturing of grape vines. The conclusion that it is Appleby 2 EWS and not Nelson Aero that has changed in the last two years is confirmed by a comparison of Nelson Aero with Blenheim Aero AWS (right-hand panel of Figure A1.2).

Thus, if the Appleby 2 EWS was to be used for 2008 and 2009, a different adjustment would need to be applied. This recent trend at Appleby 2 EWS does not give a lot of confidence in the last few years of the ‘previous’ Nelson composite record.

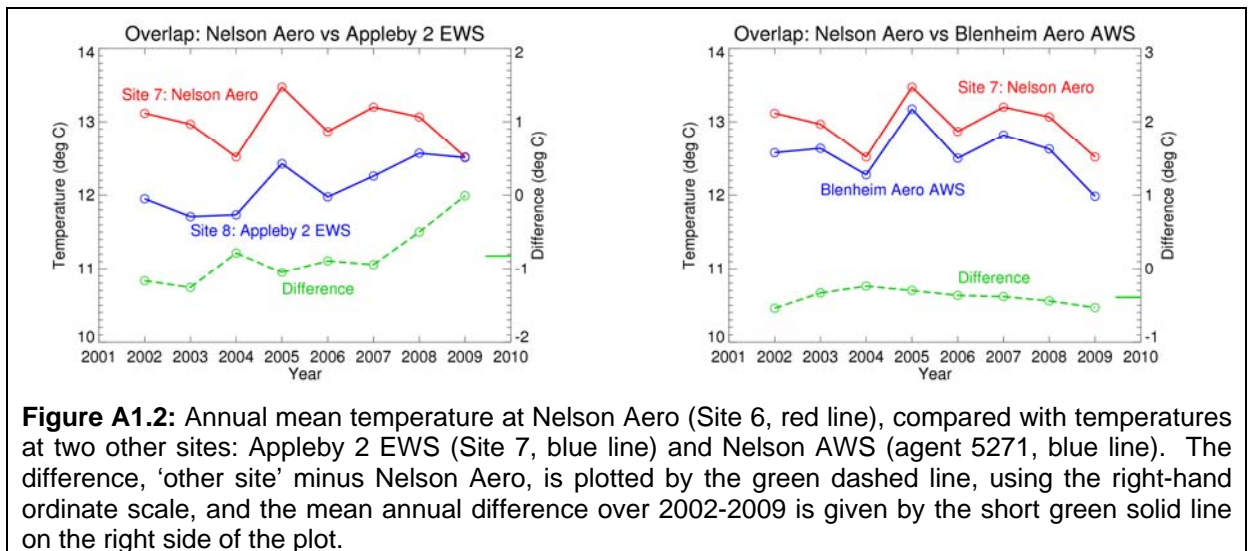


Figure A1.2: Annual mean temperature at Nelson Aero (Site 6, red line), compared with temperatures at two other sites: Appleby 2 EWS (Site 7, blue line) and Nelson AWS (agent 5271, blue line). The difference, ‘other site’ minus Nelson Aero, is plotted by the green dashed line, using the right-hand ordinate scale, and the mean annual difference over 2002-2009 is given by the short green solid line on the right side of the plot.

Adjustments for Site Changes 3 to 4 in 1932, and 2 to 3 in 1920

The adjustments for these site changes have been worked out in the main text: Site 3 (Cawthron) is 0.15°C warmer than Site 4 (Appleby), and Site 2 (Nile St) is a further 0.88°C warmer than Site 3 (Cawthron). These corrections have been accumulated relative to the reference site of Appleby (Site 4), and entered into Table A1.1.

Adjustment for Site 1 to Site 2 Change between 1880 and 1907

According to documented information on climate station histories (Fouhy et al., 1992), observations of air temperature at Nelson began as early as 1844. Sir James Hector, Director of the New Zealand Meteorological Service (and its forerunner²¹) 1867-1903, considered that there was a great improvement in the quality of the observations after 1863. In 1867, the observatory (station G13231) was situated in the centre of town at an elevation of 5.5m. The site was near the present Nelson Institute and the government buildings. NZ Meteorological Service staff notes on file say the temperatures would probably have been too high, as at most of the early stations, because of defects in the type of shelter used. The station was closed at the end of 1880, as happened to a number of other climatological stations at that time.

In 1905 daily observations recommenced at the Vicarage, Nile Street, but these were not considered sufficiently reliable until October 1907. The site elevation was 10 m and it was considered a “warm” site, being sheltered from the southwest and high enough to escape frosts. There were too many large trees for free exposure. In December 1920, the station was taken over by the Cawthron Institute.

In the NIWA Climate Database, there are records of Nelson temperature for the period 1864-1880, with a few months of observations in 1862 also. Then there is a large gap in observations until resumption in October 1907. In order to relate Nelson temperatures pre-1881 with those post-1907, there is only one feasible comparison site, Auckland Albert Park (agent 1427), there being too many site changes occurring in Wellington and Dunedin.

²¹ In 1879, there were two meteorological organizations in New Zealand: the Meteorological Department with its climatological stations under Sir James Hector, and the Weather Signal Department under Commander R.A. Edwin in the Marine Department (de Lisle, 1986). Hector proposed to the Colonial Secretary (Sydney) that cost savings could be achieved by combining the two organizations into one, and at the same time reducing the number of first-class climatological stations from 12 to just 3 (Auckland, Wellington, and Dunedin). This duly occurred at the end of 1880.

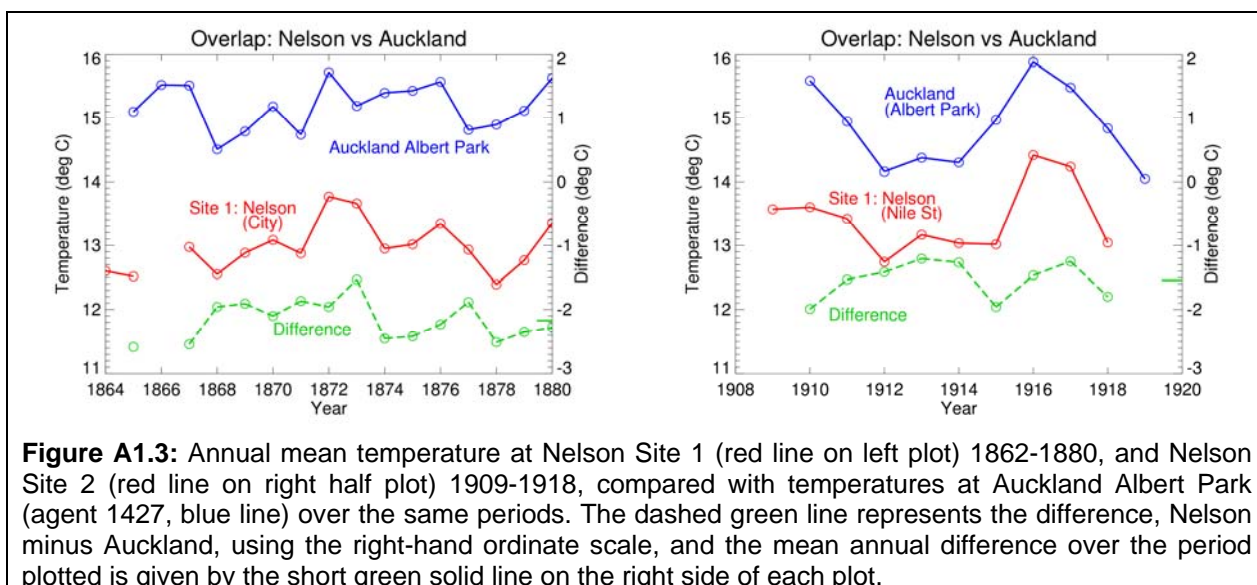


Figure A1.3 shows graphs of Nelson annual temperature up to 1880 (left panel) and following the move to Nile Street in 1907 (right panel).

In the earliest period of record, 1865-1880, Nelson City (agent 4244) averaged 2.17°C colder than Auckland. In the early 20th century, 1910-1918, Nelson was 1.54°C colder than Auckland. The location of the ‘Auckland’ site had itself changed twice in this period: from the Domain to the Museum in 1883, and from the Museum to Albert Park in 1909. However, the estimated temperature adjustments indicate no change in annual mean temperature between the pre-1880 site (Auckland Domain) and the post-1909 site (Auckland Albert Park).²²

These temperature comparisons imply that the pre-1881 Nelson City site was colder than Nile Street by 0.63 °C. Applying this change to Site 1, its adjustment relative to Appleby Site 4 would be: $-0.15 - 0.88 + 0.63 = -0.40$ °C. This means the early Nelson City site was 0.4 °C warmer than Appleby Site 4, and its temperature measurements would need to be adjusted downwards by this amount to match the micro-climate that Appleby would have been experiencing at that time.

Owing to the greater uncertainty in early temperature measurements, we have not included this period of record in the revised composite temperature series for Nelson. However, the adjustment has been included in Table 1 and Table A1.1 for ease of comparison with the Salinger *et al.* (1992) estimate. Note that the offset of +0.6 °C between Sites 1 and 2 (with Site 2 warmer) is rather different to the previous offset of +0.3 °C (Column 6 of Table 1, as determined by Salinger *et al.*, 1992), another indication of uncertainties in the early measurements.

²² The February 2010 Schedule of Adjustments, based on Salinger et al (1992), suggested a small change of 0.1 °C at September 1868 and thereafter no further adjustment until 1951. The revised adjustments (see Auckland document) suggest that the pre-1883 Auckland site in the Domain is equivalent to the post-1909 site in Albert Park. During 1883-1909, when there is no Nelson for comparison purposes, the intermediate Auckland Museum site was warmer by 0.1 °C.

Putting the Time Series Together using the 'Previous' Adjustments

The various adjustments described above can be applied successively to the Nelson temperature records. The resulting final time series from 1908 to 2007 is shown in Figure A1.4, including a comparison to the previous Nelson time series used by NIWA. Note that in this case we have truncated both series at 2007, so that the erroneous Appleby 2 EWS values in 2008 and 2009 do not influence the trend. This figure parallels Figure 10, but using our revised adjustments based on the earlier set of Nelson stations.

The revised 1909-2007 trend for the Nelson region is $+0.80\text{ }^{\circ}\text{C}/\text{century}$, which is similar to the $+0.75\text{ }^{\circ}\text{C}/\text{century}$ trend calculated from the seven-station time series published in February 2010. Note also the difference between the 'Previous' trend calculated here for the period 1909-2007, with that in Figure 10 for the 1909-2009 period. The difference is due to the erroneously high values in 2008 and 2009 at Appleby 2 EWS. The replacement of the Appleby automatic sites (Sites 5 and 8) by the Nelson Aero sites (Sites 6 and 7), as discussed in the main text, avoids this problem.

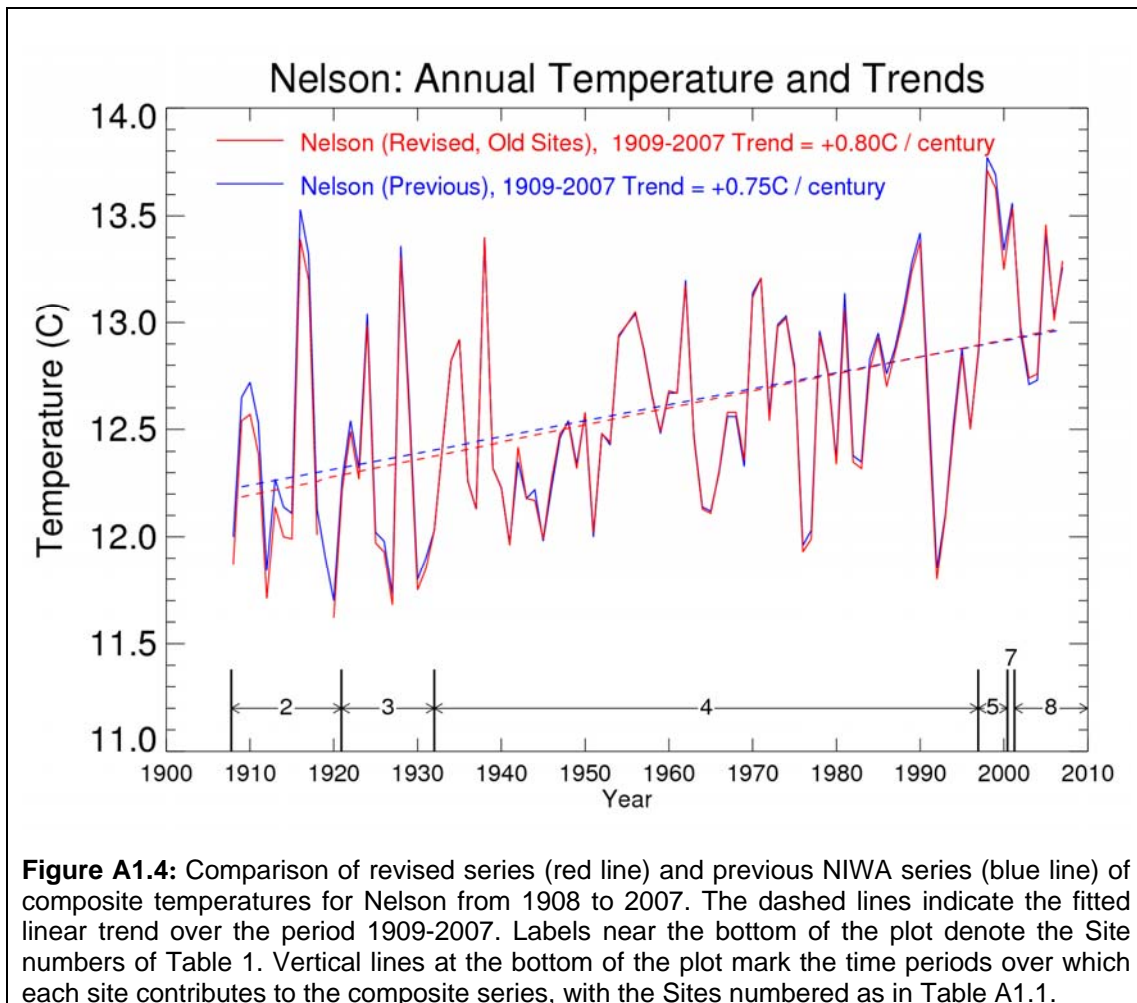


Figure A1.5 repeats the graph of the revised composite annual mean temperature series for Nelson, and compares the composite with the unadjusted raw multi-site temperatures. For the period 1932-1996 the two series are identical, since this period is covered by the Nelson reference site (Appleby, Site 4) for which no adjustment is applied. The estimated adjustments are also shown in Figure A1.5. The adjustments are cumulative relative to Appleby Site 4, and correspond to those in the final column of Table A1.1. Note that again the series have been truncated at the year 2007.

