Creating a Composite Temperature Series for Hokitika

December 2010

Figure 1: Looking south towards the Hokitika Aero climate station (agent number 3909) in 1982.

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.

The present document revisits and describes in greater detail the process by which a composite temperature series has been developed for Hokitika. 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 temperature[1]. 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 Hokitika 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) additional remarks about the site location, and (in parentheses) the full period of available temperature 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, taken from the February 2010 'Schedule of Adjustments' in 'The NIWA "Seven-Station" Temperature Series';
(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 Hokitika Aero, Site 3), as discussed in the text.

Site Label	Site Name (Agent Number)	Location (Full Period of Record)	Height (m a.s.l.)	Previous Period	Prev. Temp. Adjust. (°C)	Revised Period	Revised Temp Adjust.[2] (°C)
Site 1	Hokitika Town (3907)	Fitzherbert Street, Hokitika (Jan 1866 to Dec 1880, Jan 1894 to Jan 1946)	2	Jan 1894 to Aug 1912	−1.3	Jan 1900 to Aug 1912	−1.57
				Sep 1912 to Jul 1943	−0.3	Sep 1912 to Oct 1928	−0.36
						Nov 1928 to Dec 1944	−0.34
Site 2	Hokitika Southside (37939)[3]	Old Hokitika Airport (Aug 1943 to Dec 1964)	13	Aug 1943 to Dec 1964	+0.3	Jan 1945 to Dec 1963	+0.34
Site 3	Hokitika Aero (3909)	Hokitika Airport (Nov 1963 to present)	39	Jan 1965 to present	0	Jan 1964 to Oct 1967	+0.05
						Nov 1967 to present	**0.00**

Calculation of Adjustments

Table 1 summarises the information about the local sites used to develop the composite temperature series for the Hokitika location. A comparison is provided between the adjustments in use as at February 2010 (labelled 'Previous Temperature Adjustment'), and the new ones derived in this document (labelled 'Revised Temperature Adjustment'). The previous adjustments were calculated to one decimal

[2] Because of lower confidence in early temperature measurements the revised temperature series is not constructed prior to 1900. Air temperatures are recorded to the nearest 0.1 °C in CliDB, but each revised adjustment used in the composite temperature record has been calculated to two decimal places, in order to minimise the accumulation of round-off errors. This should not however be interpreted as an indication of the accuracy of the adjustment.

[3] Hokitika Southside (37939) data were originally stored in CliDB under agent number 3907, along with the data from the earlier Hokitika Town site. A separate agent number was assigned early in 2010, after the publication of earlier version of the present document.

place, whereas the revised adjustments are specified to two decimal places. Table 1 lists three different sites as contributing to the composite Hokitika temperature series and at the first site there was a discontinuity in the record in 1912. In addition, there were two minor site changes so in total there are five change points to be considered. The temperature record must be closely examined before and after the change-dates, in order to identify potential biases.

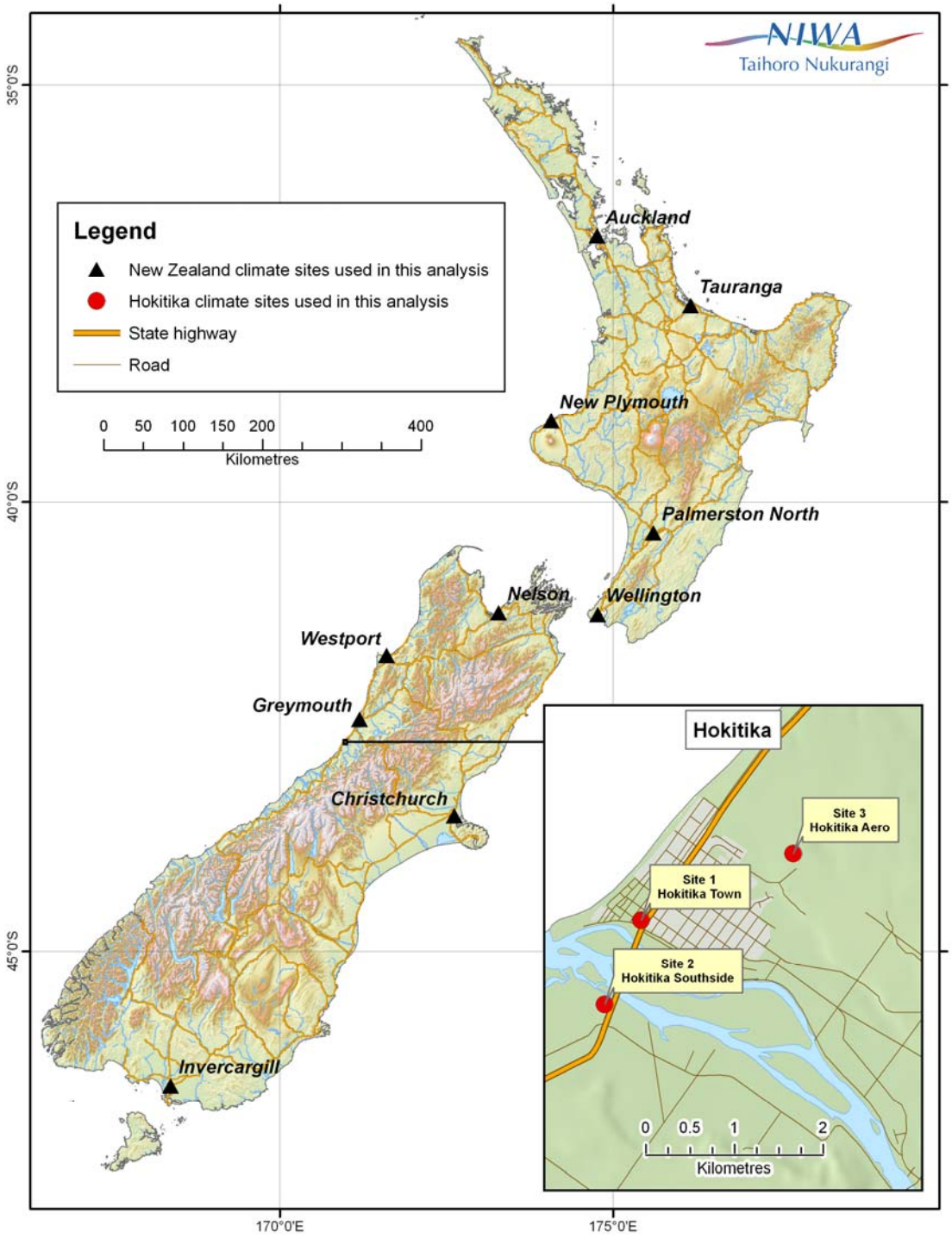

Figure 2: Map showing sites of temperature records referred to in this document. The inset map locates the Hokitika sites.

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. Furthermore, if there were site changes around 1910 for which an adjustment could not be estimated accurately, then the time series was truncated at that point. In the case of Hokitika, there was an instrumentation change in 1912, correcting temperatures that were previously too high. The adjustment required to account for this site change has been calculated by comparison with other climate stations (below) and is included in Table 1, but the value is uncertain because many of the comparison stations underwent changes at about the same time. Furthermore, although it is quite clear from the site documentation and the data themselves that there was a significant bias in the measurements before the change, the specific reason for the bias is not clear, and the possibility that it varied with time cannot be ruled out. So the revised Hokitika annual temperature time series is constructed from 1900, but the values before 1913 must be considered somewhat unreliable.

It is common practice to adjust all the historical measurements to be consistent with the current open site, which is then called the "reference site" (Aguilar *et al.*, 2003). This practice is followed for Hokitika, where the reference site is Hokitika Aero (Figure 1), labelled Site 3 in Table 1. Figure 2 provides a map locating the Hokitika sites of Table 1, and also the more distant sites discussed in the subsequent text.

The sites contributing to the Hokitika series generally have complete data during the relevant periods, with a few minor exceptions. The handling of suspect and missing data is described in Appendix 1.

Adjustment for Site Changes in 1964 and 1967

We will work backwards in time from the current open site: Hokitika Aero (Site 3). This instrument enclosure is some 200 m NW of the Hokitika Airport terminal area, surrounded by low scrub (Figure 1 and Figure 2). Hokitika Aero opened in November 1963, replacing the Hokitika Southside site at the old airport, south of Hokitika River (Site 2). There was an overlap period of 14 months (Nov 1963 to Dec 1964) during which both sites operated. However, there is the complication that the Hokitika Aero instruments were initially installed in a temporary enclosure west of the terminal area and were moved to the present location in October 1967. Below we shall use three different approaches to estimate the separate and combined effects of the move from Hokitika Southside to Hokitika Aero and the site change at Hokitika Aero.

The 14-month overlap period between Site 2 and the temporary enclosure at Site 3 allows a straightforward calculation of the temperature difference, although ideally one would like an overlap period of two years or more (Della-Marta *et al.*, 2004). The difference (Figure 3) is reasonably steady from month to month (standard deviation = 0.23 °C) and has a mean value of 0.29 °C (Site 3 temporary enclosure minus Site 2).

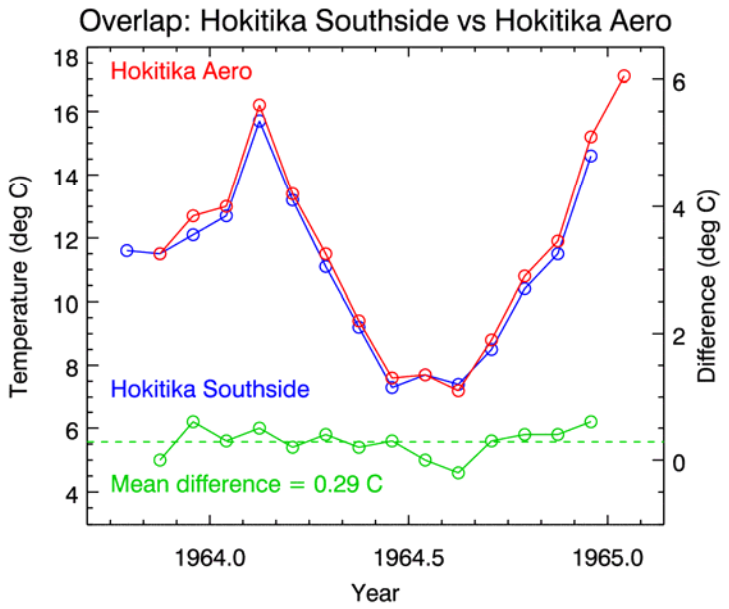

Figure 3: Monthly mean temperature series for Hokitika Southside (Site 2, blue line) and Hokitika Aero (Site 3, red line) during their overlap period. The monthly difference, Site 3 minus Site 2, is indicated by the solid green line, using the right-hand ordinate scale, and the mean monthly difference is indicated by the dashed green line.

The overlap period did not encompass the 1967 site change, therefore the only way to objectively estimate the effect of that change is by comparing the measurements with those at other climate stations. Comparison stations were chosen subjectively, based on a number of factors:

- availability of annual temperature data for a reasonable period—preferably 10 years—before and after the change;
- absence of any evidence of a site change or instrumentation change at the comparison station or (less ideally) a good estimate for the effect of that change;
- proximity, geographic similarity and climatic similarity to the candidate stations (i.e., the two stations between which the change is to be estimated);
- a high correlation between temperatures at the comparison station and temperatures at the candidate stations.

As background information for the selection of comparison stations, Figure 4 shows the correlation of mean temperature interannual differences at the Virtual Climate Station (VCS) grid cell containing Hokitika Aero (Site 3) with interannual differences at all other locations on the VCS grid from 1972 until 2008 (i.e., 1972-73 difference, 1973-74, … , 2007-08)[4]. This map gives a good indication of the locations at which

[4] 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 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).

temperatures are likely to be highly correlated with the sites comprising the Hokitika composite series.

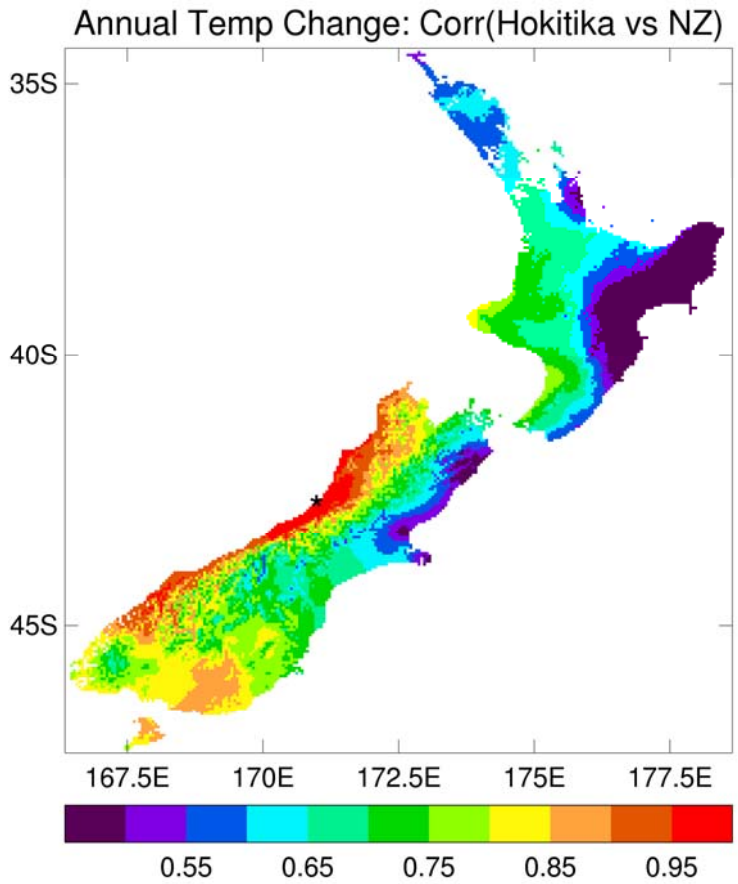

Figure 4: Map of correlation between interannual temperature changes at the Hokitika Aero grid-point (Site 5, location marked by asterisk), 1972-73 to 2007-08, and all other grid-points in the NIWA 0.05° gridded "Virtual Climate Station" data set.

Not surprisingly, interannual temperature variations at Hokitika correlate highly with those in the Westland region as a whole, the correlation coefficient typically being over 0.90. The correlation is above 0.80 in Southland and remains at or above 0.70 in a band extending through Nelson and on the west coast of the North Island. It is lower (~ 0.5) on the east coasts of both the North and South Island.

To isolate the effect of the 1967 change, we form a composite Hokitika temperature series, with Hokitika Southside data up to 1963 and Hokitika Aero data from 1964, the former adjusted by +0.29 °C to allow for the difference between the two stations, as estimated from the overlap (Figure 3). This series is then compared (Figure 5) with the temperature records at four stations: Invercargill Aero (5814)[5], Appleby (4239), Wellington Kelburn (3385) and Palmerston North (3238). They are all at least 200 km distant from Hokitika and the first-difference correlation coefficients shown in Figure 4 are ~ 0.7–0.8. The closer, more highly correlated stations of Greymouth Aero (3950) and Westport Aero (3810) were also considered, but in both cases there was evidence of an inhomogeneity affecting their data around 1965 (Appendix 3).

[5] A number in parentheses after a climate station name indicates the CliDB agent number.

The comparison period was 1957–1977, excluding the change year, 1967. The closeness of the match between each comparison station and the Hokitika series was quantified using the correlation coefficient of the first-difference series of annual temperatures over the comparison period, excluding any differences affected by the change (Aguilar *et al.*, 2003). For the four stations used here, the correlations were 0.63, 0.78, 0.70 and 0.80, respectively.

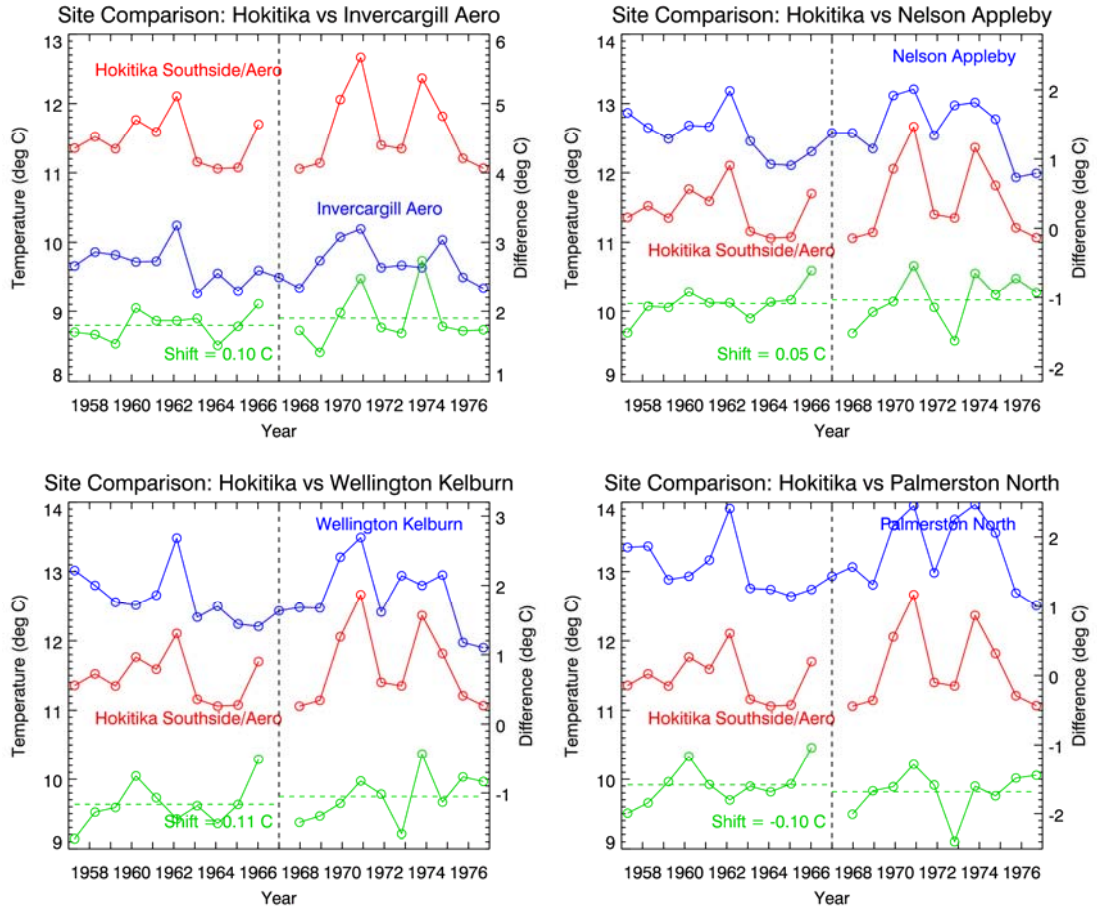

Figure 5: A composite annual-mean temperature series at Hokitika Southside/Aero before and after the site change in 1967, compared with Invercargill Aero, Appleby, Wellington Kelburn and Palmerston North. The procedure for compositing Hokitika Southside and Hokitika Aero data is described in the text. The solid blue line in each plot represents the temperature at the comparison station and the solid green line represents the difference (Hokitika minus comparison station) using the right-hand ordinate scale. The year of the site change, 1967, is indicated by a vertical dashed line. The mean differences for the periods before and after the change are indicated by dashed green lines.

The temperature change at 1967 is estimated relative to each comparison station in turn. Before the change, the Hokitika series was on average 1.80 °C warmer than Invercargill Aero. After the change, the Hokitika series was on average 1.90 °C warmer than Invercargill Aero. Therefore, the comparison with Invercargill Aero results in the estimate that Hokitika Aero temperatures warmed by 0.10 °C with the 1967 site change.

A similar procedure was followed for the other three comparison sites. The comparison with Appleby results in the estimate that Hokitika Aero was 0.05 °C

warmer after the site change than before. The comparison with Wellington Kelburn results in the estimate that Hokitika Aero was 0.11 °C cooler after the site change than before. The comparison with Palmerston North results in the estimate that Hokitika Aero was 0.10 °C cooler after the site change than before.

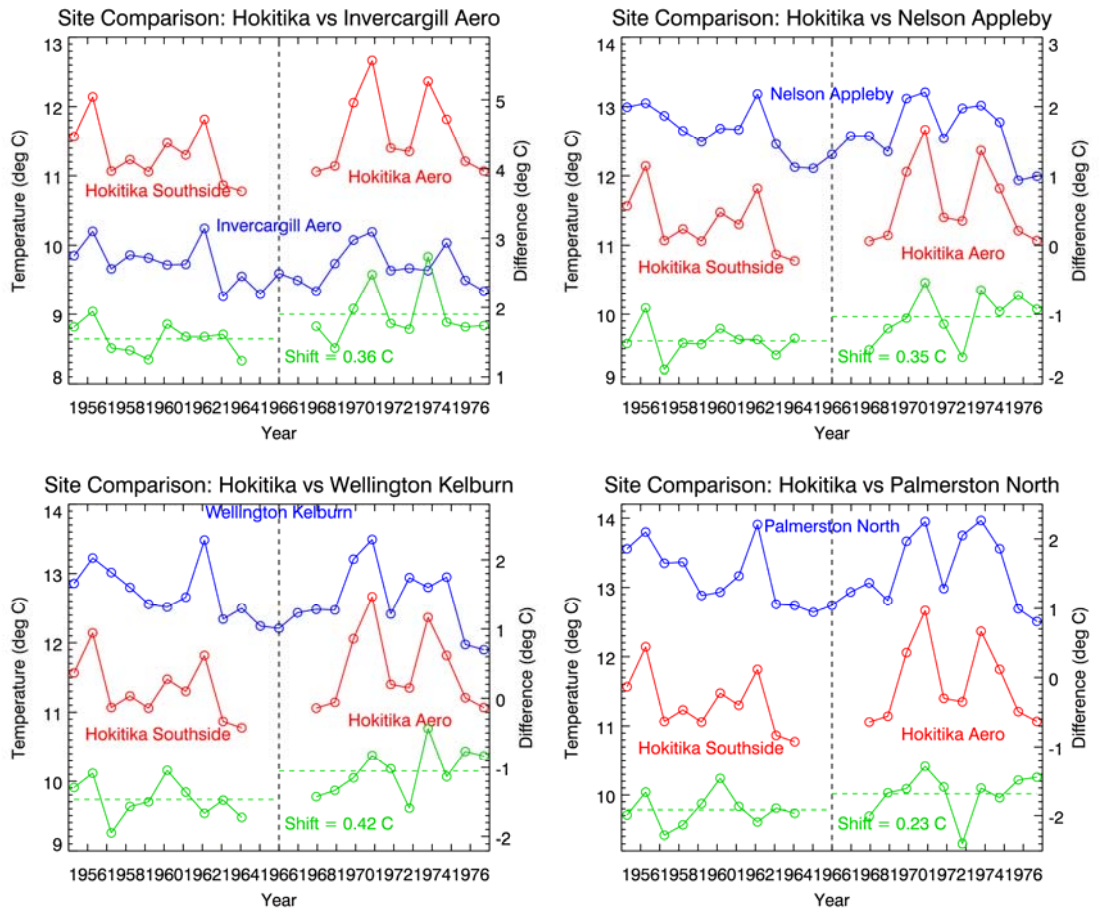

Figure 6: Annual-mean temperature series at Hokitika Southside and at Hokitika Aero after the site change in 1967, compared with Invercargill Aero, Appleby, Wellington Kelburn and Palmerston North. The solid blue line in each plot represents the temperature at the comparison station and the solid green line represents the difference (Hokitika minus comparison station) using the right-hand ordinate scale. The mean differences for the periods before and after the change are indicated by dashed green lines.

An average of the four differences (0.10 °C, 0.05 °C, 0.11 °C and −0.10 °C), gives the estimate that Hokitika Aero after the 1967 site change was 0.04 °C warmer than before the site change.

As an alternative approach, Figure 6 presents a set of comparisons with the same four stations to determine the difference between the Hokitika Aero permanent enclosure and Hokitika Southside, omitting the Hokitika Aero data from 1964 to 1967. The resulting estimates are 0.36 °C (Invercargill Aero), 0.35 °C (Appleby), 0.42 °C (Wellington Kelburn) and 0.23 °C (Palmerston North). The average of all four is 0.34 °C.

Synthesising these estimates, the move from Hokitika Southside to the Hokitika Aero temporary enclosure resulted in a warming of 0.29 °C, and there was a further

warming of 0.05 °C with the move to the present enclosure in October 1967. The latter change is very small and could be approximated as zero. However we retain it because it is associated with a documented site change. Thus, the adjustment required for Hokitika Aero temperatures before October 1967 to make them homogeneous with the reference period at Hokitika Aero is +0.05 °C and the adjustment required for temperatures at Hokitika Southside is + 0.05 + 0.29 = 0.34 °C. The latter is the same, to one decimal place, as the +0.3 °C applied to this station in the previous series.

Adjustment for Site Change in 1945

Hokitika Southside (Site 2) opened in August 1943 at what was then the airport on the south side of Hokitika River, approximately 1.1 km from the previous climate station on the edge of Hokitika town (Site 1). However, for some reason a new station number was not initiated at the time. Thus, when the climate data were digitised in the late 1960s, there was only the one station number and only one set of data was transferred to the computerized archive. This situation has recently been corrected and the Hokitika CliDB site has been split into two—Hokitika Town (3907) and Hokitika Southside (37939)—with data from an overlap period between August 1943 and January 1946 re-entered from paper and assigned to the correct station[6]. Of course, all original measurements from both sites are still held in paper form in the NIWA climate archives.

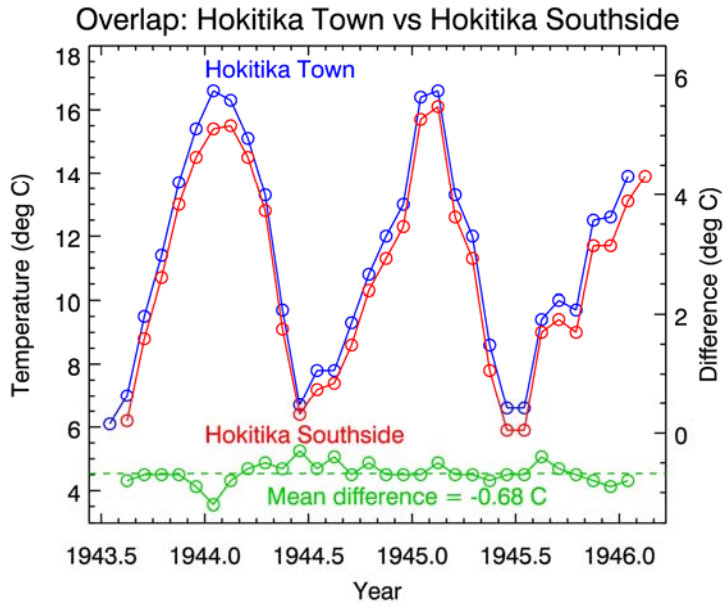

Figure 7: Monthly mean temperature series for Hokitika Town (Site 1, blue line) and Hokitika Southside (Site 2, red line) during their overlap period. The monthly difference, Site 2 minus Site 1, is indicated by the solid green line, using the right-hand ordinate scale, and the mean monthly difference is indicated by the dashed green line.

[6] In the process of checking the records, an error was discovered in the CliDB Hokitika (agent number 3907) temperatures for 1945. The actual sequence of temperatures in the database (now corrected) was as follows: Site 1 up to Jul-1943; Site 2 for Aug-1943 to Dec-1944; Site 1 for Jan-1945 to Dec-1945; Site 2 from Jan-1946. Note that the previous Hokitika composite temperature series does *not* suffer from this problem – the sequencing of the site data used in calculating that was correct.

The 30-month overlap period should allow an accurate estimate of the effect of the shift (Figure 7). The difference is reasonably steady from month to month (standard deviation = 0.17 °C) and has a mean value of −0.68 °C (Site 2 minus Site 1).

As a check, the effect of the site change has also been estimated by comparison with other stations (Figure 8). The stations were Westport Aero (3810), Appleby (4239), Wellington Kelburn (3385) and New Plymouth (2276). The comparison period was 1935–1954, with the change taken between 1944 and 1945, and the first-difference correlations were 0.97, 0.83, 0.80 and 0.84, respectively.

The estimates resulting from the comparison are −0.44 °C (Westport Aero), −0.54 °C (Appleby), −0.54 °C (Wellington Kelburn) and −0.55 °C (New Plymouth). The average of all four is −0.52 °C, which is smaller (less negative) than the overlap estimate by 0.16 °C.

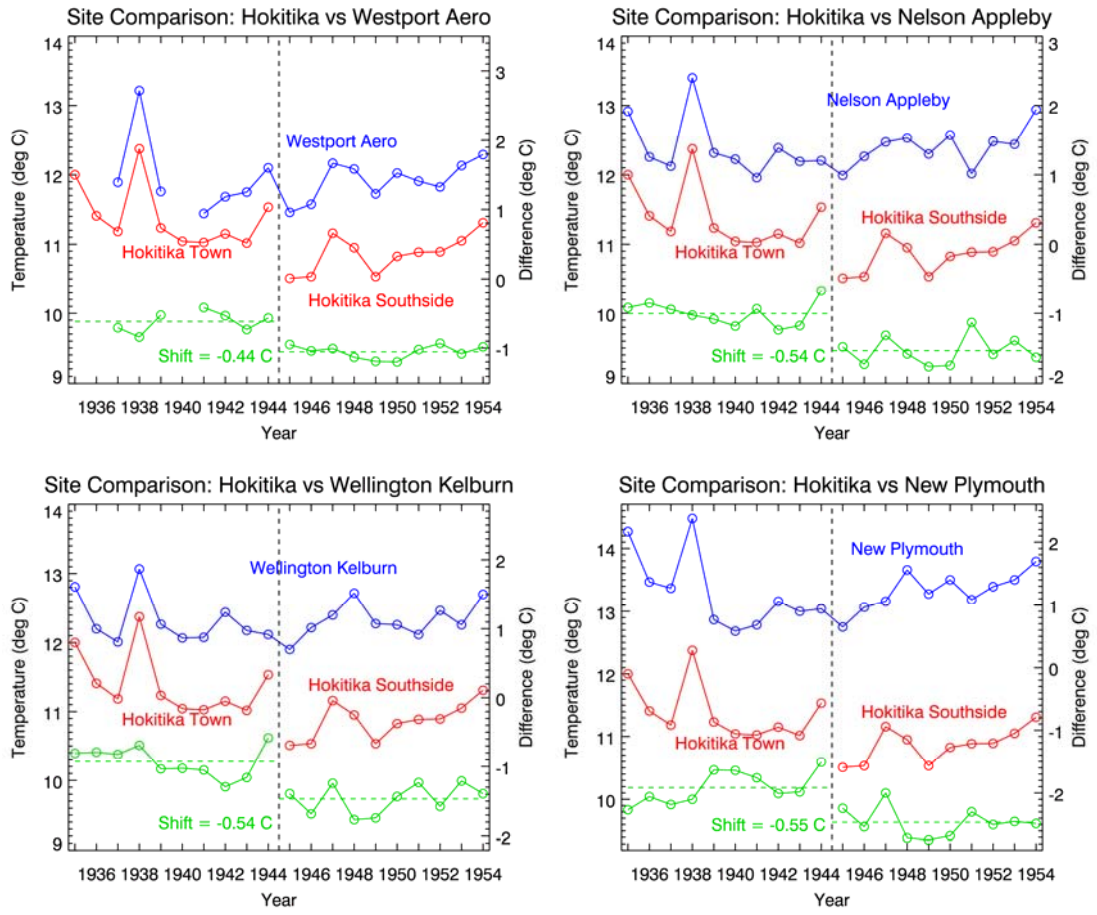

Figure 8: Annual-mean temperature series at Hokitika Town and at Hokitika Southside, compared with Westport Aero, Appleby, Wellington Kelburn and New Plymouth. The solid blue line in each plot represents the temperature at the comparison station and the solid green line represents the difference (Hokitika minus comparison station) using the right-hand ordinate scale. The mean differences for the periods before and after the site change are indicated by dashed green lines.

So the comparison method and the overlap method both indicate that Hokitika Southside is substantially cooler than Hokitika Town, but the former suggests a smaller difference than the latter, by ~ 0.2 °C. We have decided to adopt the estimate

from the overlap method, on the grounds that an overlap between two nearby stations should provide a more direct estimate of the difference between them than a comparison involving more distant stations.

The final adjustment of temperatures at Hokitika Town (Site 1) to make them homogeneous with Hokitika Aero (Site 3) is + 0.05 + 0.29 − 0.68 = −0.34 °C. This agrees to one decimal place with the −0.3 °C applied to this station in the previous series.

Adjustment for Site Change in 1928

It is noted in the Hokitika station history (Appendix 2; see also *Fouhy et al.*, 1992) that the original enclosure was only 2.1 × 2.7 m and was enlarged to 15 × 12 m in October 1928. Such a change to the physical surroundings of the thermometer screen has the potential to affect temperature readings. The effect on the mean temperature has been estimated by comparison with other climate stations.

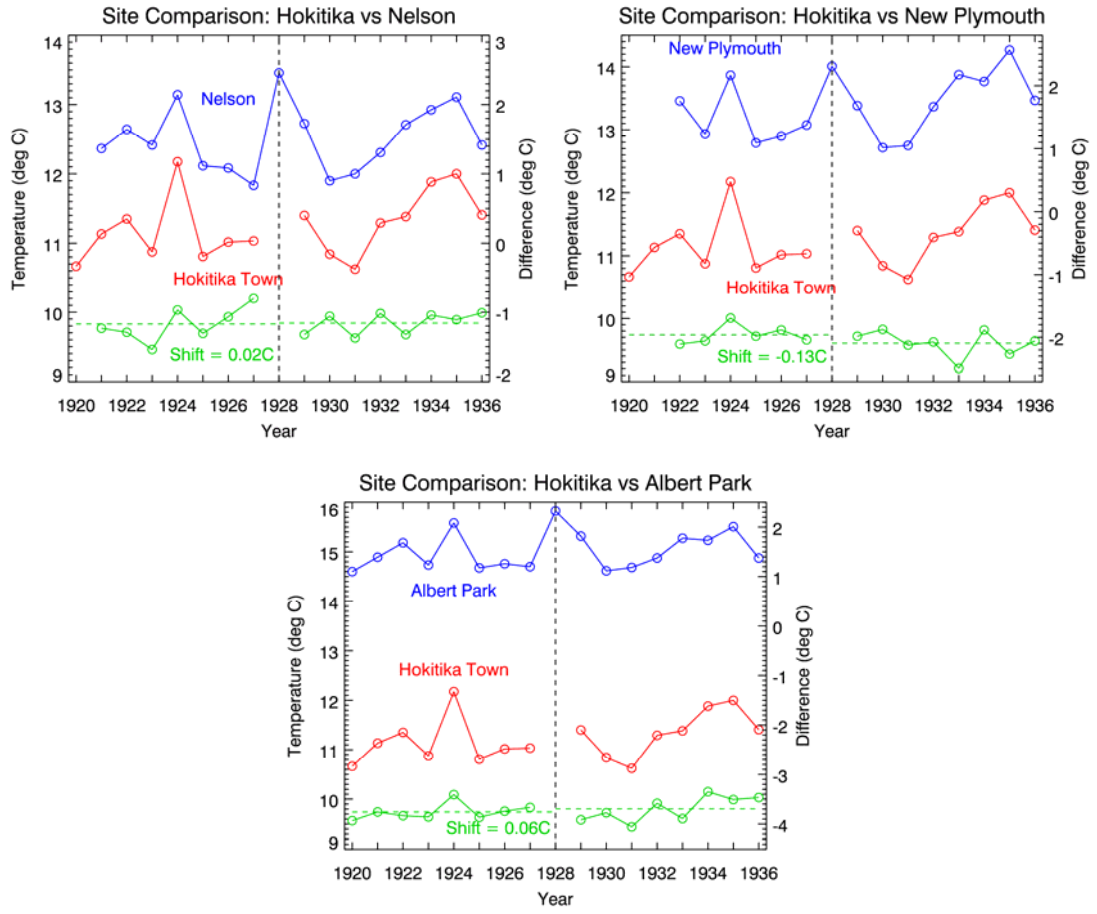

Figure 9: Annual-mean temperature series at Hokitika Town (Site 1) before and after the enclosure enlargement in 1928, compared with Nelson, New Plymouth and Albert Park. The solid blue line in each plot represents the temperature at the comparison station and the solid green line represents the difference (Hokitika Town minus comparison station) using the right-hand ordinate scale. The year of the change, 1928, is indicated by a vertical dashed line. The mean differences for the periods before and after the change are indicated by dashed green lines.

The stations selected for the 1928 comparison were Nelson (4244), New Plymouth (2276) and Albert Park, Auckland (1427). They are all (but particularly New Plymouth and Albert Park) distant from Hokitika and the first-difference correlation coefficients shown in Figure 4 are ~ 0.7–0.8. The comparison period was from 1920 to 1936, i.e., eight years before and after the change year of 1928. The Nelson data for 1920 was omitted because it was affected by a site change[7].

The comparison is shown in Figure 9. The estimates are 0.02 °C (Nelson), −0.13 °C (New Plymouth), and 0.06 °C (Albert Park) and the average is −0.02 °C. The final adjustment of Hokitika Town temperatures before the enclosure change to make them homogeneous with the reference period at Hokitika Aero (Site 3) is + 0.05 + 0.29 − 0.02 − 0.68 = −0.36 °C.

Adjustment for Site Change in 1912

The station history (Appendix 2) records that the maximum temperatures were believed to be about 3 °F too high before August 1912, at which time new thermometers and a new screen were installed. Again, there was no overlap between measurements with the different thermometer/screen combinations, but the effect of the change can be estimated by comparisons with other climate stations. Salinger (1981) compared the Hokitika data with four sites: Nelson, Christchurch, Lincoln, and Dunedin. The average inter-site differences between 1894–1911 and 1913–1945 were calculated, and Salinger concluded that Hokitika maximum temperatures cooled by 1.7 °C after 1912 (which agrees with the estimate that they were 3 °F too high beforehand) and that minimum temperatures cooled by 0.5 °C. Thus the mean temperatures cooled after 1912 by 1.1 °C.

Here we repeat the comparison, but with our own choice of comparison stations and for a shorter period, more in line with the other comparisons in this and other documents. The comparison period was from 1904 to 1920, i.e., eight years before and after the change year of 1912. For changes occurring as long ago as 1912, the selection of comparison stations is severely constrained by the lack of high-quality, homogeneous records. The stations selected were Christchurch Gardens (4858), Nelson (4244) and Albert Park, Auckland (1427)[8]. The first-difference correlations were 0.82, 0.95 and 0.87, respectively.

Figure 10 compares annual temperatures at Hokitika Town with those at the comparison stations. From the comparison with Christchurch Gardens, we estimate that the temperature difference associated with the change was −1.30 °C. From the comparisons with Nelson and Albert Park, we estimate differences of −1.17 °C and −1.15 °C, respectively. After averaging the three differences, we estimate that the difference in mean temperature associated with the change was −1.21 °C. The estimated differences in maximum and minimum temperatures are −1.97 °C and −0.42 °C, respectively. These are reasonably close to Salinger's (1981) estimates of −1.1 °C (mean), −1.7 °C (maximum) and −0.5 °C (minimum).

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[7] See "Creating a Composite Temperature Series for Nelson".

[8] The Albert Park measurement site was shifted in 1909 from the Auckland Museum to Albert Park. According to the Auckland document ("Creating a Composite Temperature Series for Auckland", Appendix 4) the new site was 0.09 °C cooler than the old site. Therefore, for the present work, temperatures before 1909 have been shifted by −0.09 °C to correct for the site change.

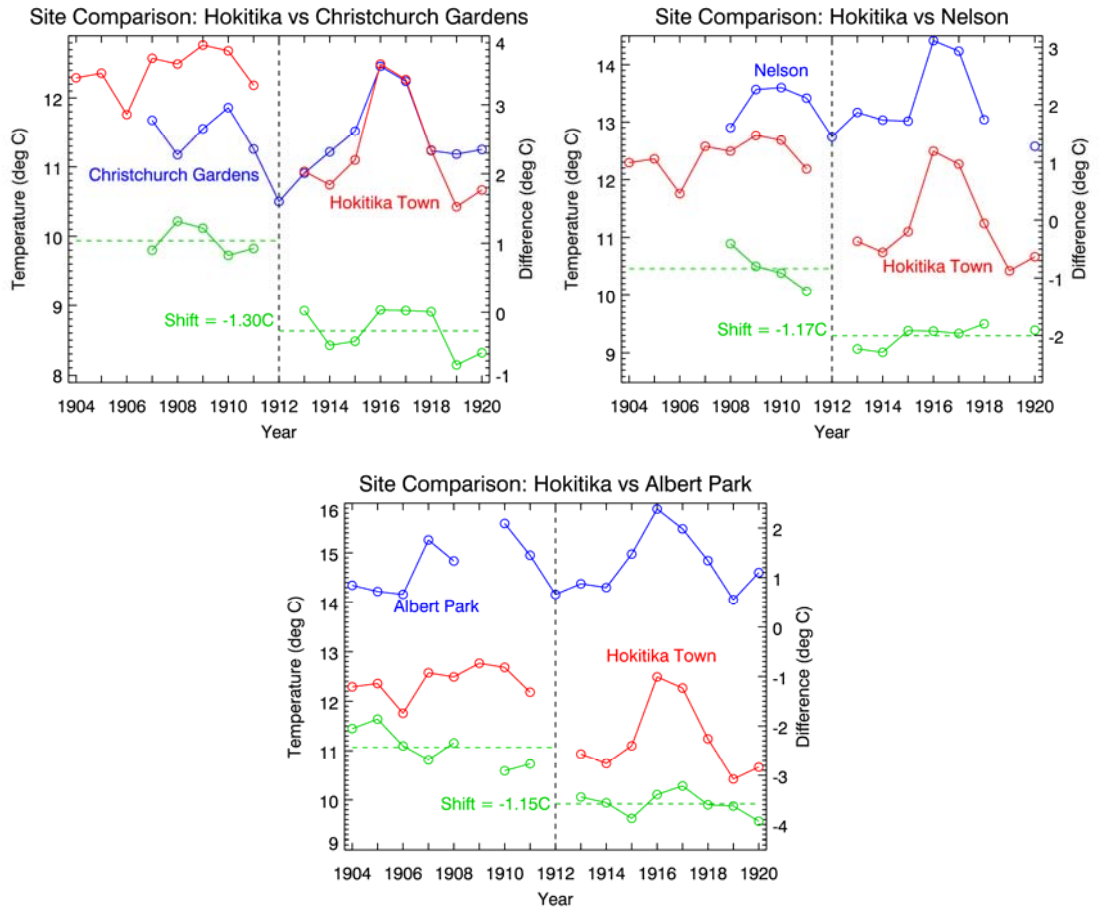

Figure 10: Annual-mean temperature series at Hokitika Town before and after the instrumentation change in 1912, compared with Christchurch Gardens, Nelson and Albert Park. See footnotes in the text for information about adjustments applied to Albert Park. The solid blue line in each plot represents the temperature at the comparison station and the solid green line represents the difference (Hokitika minus each comparison station) using the right-hand ordinate scale. The year of the site change, 1912, is indicated by a vertical dashed line. The mean differences for the periods before and after the site change are indicated by dashed green lines.

The final adjustment required to make observations at Site 1 before the 1912 instrumentation change consistent with the reference period at Hokitika Aero (Site 3) is therefore: + 0.05 + 0.29 − 0.68 − 0.02 − 1.21 = −1.57 °C.

Putting the Time Series Together

The various adjustments described above can be applied successively to the Hokitika temperature records. The resultant annual time series from 1900 to 2009 is shown in Figure 11, with a comparison to the previous Hokitika series. A linear trend has been fitted to each series over the period 1913–2009. Expressed in units of degrees per century, the linear trend in the revised series is 1.11 (±0.36) °C/century, as compared to 1.07 (±0.36) °C/century for the trend calculated from the seven-station time series published in February 2010.[9]

As discussed in the section on "Calculation of Adjustments", the series before 1913 is considered less reliable because of uncertainty in estimating the effect of the instrument problems before August 1912. However for completeness we have also calculated the trends for the period 1909–2009: the values are 1.14 (±0.35) °C/century for the revised series and 1.07 (±0.35) °C/century for the previous series.

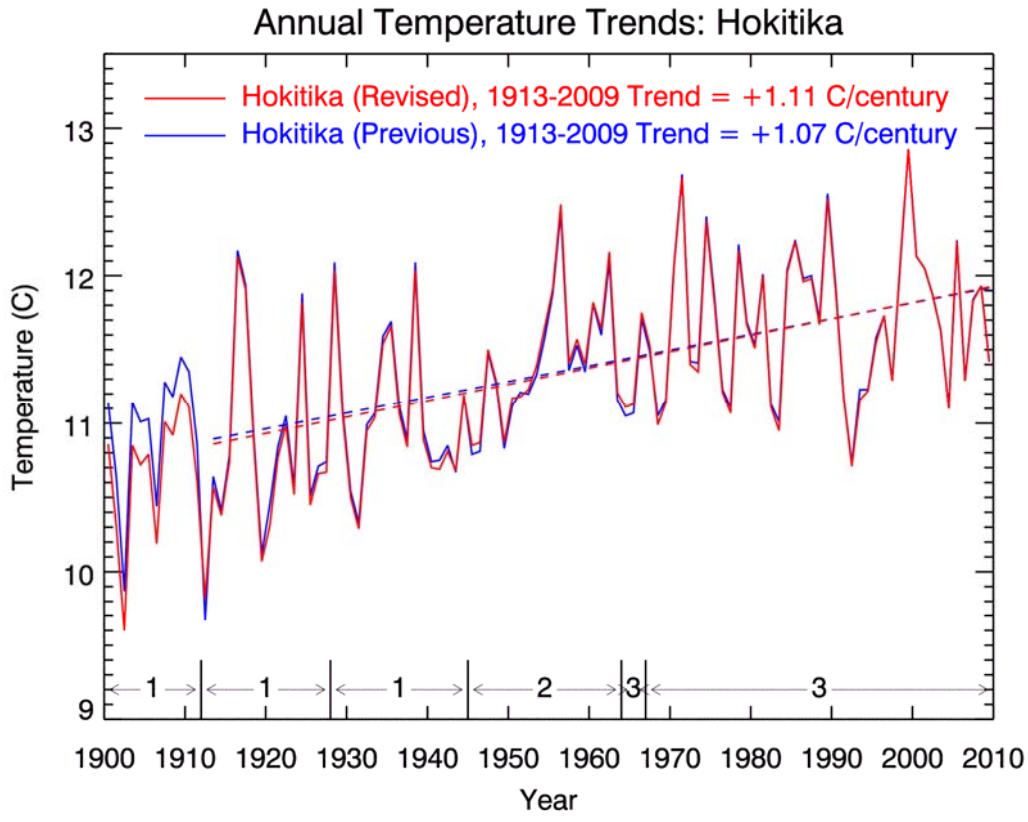

Figure 11: Comparison of the revised composite series of annual mean air temperatures for Hokitika (red line) with the previous NIWA Hokitika series (blue line) from 1900 to 2009. The dashed lines show the fitted linear trends from 1913 to 2009. Site labels from Table 1 are displayed at the bottom of the plot.

[9] The uncertainty here (±0.36 °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.

Once the temperatures from the Hokitika sites have been adjusted for consistency with Hokitika Aero (Site 3), and then combined, we have a series dating back to 1900. However, simply appending the raw data from the Hokitika records without correcting for known site changes would result in an inhomogeneous history of temperature, unsuitable for the analysis of long-term trends.

Figure 12 repeats the graph of the revised composite annual mean temperature series for Hokitika, and compares the composite with the unadjusted raw multi-site temperatures. For the period 1968–2009 the two series are identical, since this period is covered by the reference site for which no adjustment is applied. The cumulative adjustments relative to the reference site are also shown in Figure 12, and correspond to those in the final column of Table 1.

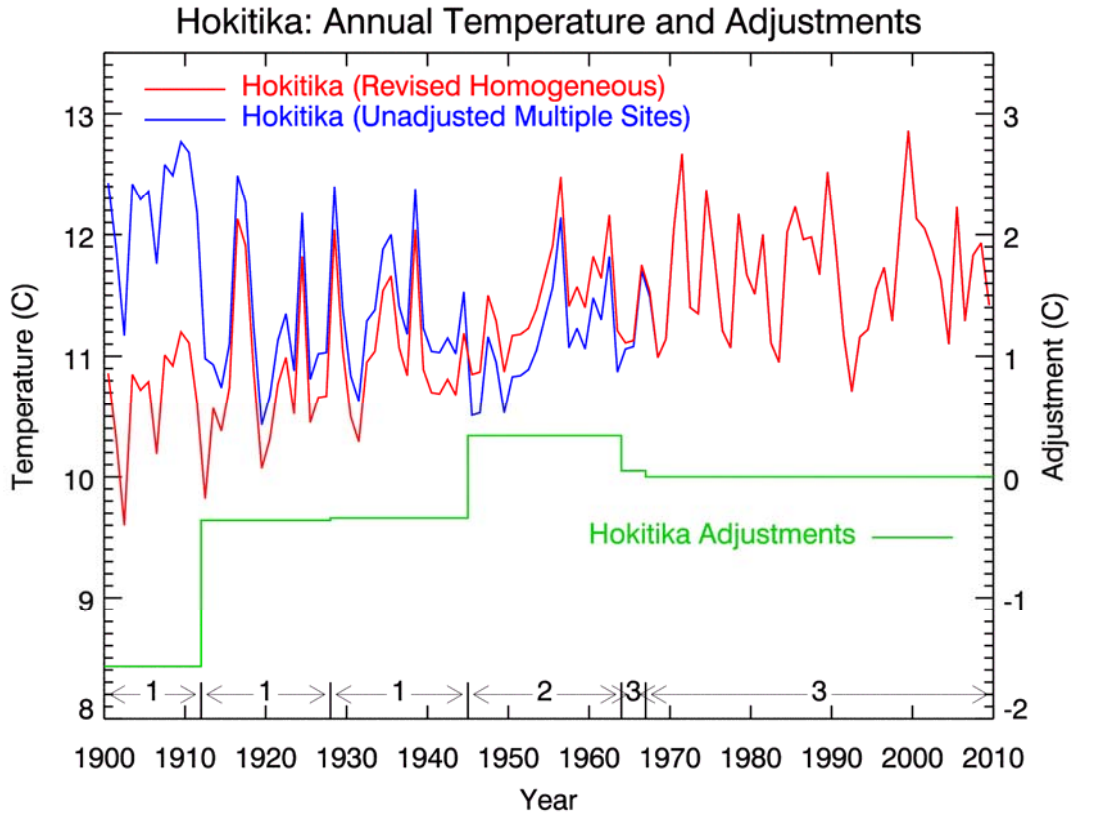

Figure 12: Comparison of the revised composite temperature series for Hokitika (red line), with an unadjusted composite series (blue line) from 1900 to 2009. Numbers near the bottom of the plot denote the site labels of Table 1, with vertical lines marking the time periods over which each site contributes to the composite series. The green line (using right-hand ordinate scale) indicates the adjustment for each period.

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; Wang *et al.*, 2007).

Date: A review of the Hokitika adjustments was posted on the NIWA website in February 2010. This current document, created 15 December 2010, updates that earlier version following the same methodology and formatting as for the other 6 station review documents.

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Appendix 1

Treatment of missing and suspect data

We could calculate annual-mean temperatures at each station only for those years with no missing monthly data, but this would discard potentially useful information. Instead, if monthly data are missing at a station for only a small number of months in a given year, we estimate the annual mean temperature in that year by a procedure that uses the temperatures from the remaining months. The procedure is described in Appendix 2 of "Creating a Composite Temperature Series for Masterton" and was applied to the data used in constructing the Hokitika series. The maximum number of missing months allowed in any year was three. In practice most applications of the procedure involved missing data for just a single month.

The procedure to account for missing monthly data requires a monthly climatology for the station in question. This was generally calculated from 30 years of data at that station, over a period spanning the year(s) to be filled. Note that the climatology is needed only to define the *variation* in temperature during a typical year, not the absolute value, so the procedure is not sensitive to the range of years over which the climatology is calculated.

The years for which an annual-mean temperature was calculated with missing monthly data were:

Hokitika composite series

Hokitika Southside, 1951 (July); Hokitika Aero, 1968 (May).

1945 site change, comparison stations

Wesport Aero (3810): 1937 (January, February).

Appleby (4239): 1942 (June); 1943 (June); 1944 (April); 1949 (August).

Appendix 2

Station History

Notes on the early Hokitika climate record from the station history file, as made by Dr Edward Kidson, Director of the New Zealand Meteorological Service 1927–1939.

Notes on the Climatological Station at Hokitika.

The station was established in February 1866 although there had been some observations of a less organized nature previously. Mr. Rochfort, the first Observer reported that,-

"The Observatory is 11 feet 3 inches above mean sea level. The rain gauge is 30 feet above the surface of the ground, or about 37 feet above mean sea level. There is a second rain gauge on the ground. Taking a north-east direction, the land gradually rises by steps till, at the distance of a mile from the station, it attains the height of about 100 feet. The station is 19 chains east of the sea, and 7 chains north of the Hokitika River. There are no hills near it with the exception of the terrace, 100 feet high, to the north-east."

The station appears to have been throughout in an open space behind the Government buildings but to have been moved to several different parts of this enclosure. There is, for instance, reference to a move in April 1869. In the beginning, the principal rain gauge appears to have been on the roof of a building. A square gauge was used. The rainfall record from from 1866 to 1880 is, therefore, probably subject to some error. Observations were made at 9 a.m. in February 1866, at 10 a.m. from March 1866 till December 1867, and thereafter at 9.30 a.m. until February 1907. Apparently the time was changed to 9 a.m. in March 1907 or possibly at the beginning of the year.

The mercury barometer was apparently housed in a small building near the meteorological station, and was for the most part of the time subject to extreme temperature changes. Observations were discontinued in 1880. When observations were recommenced in 1894 it was presumably with the same instruments and on the same site as in 1880. By this time the gauge would be circular in pattern and on the ground. The station was inspected in September 1912 and a new screen and thermometers were provided. It was then found that the enclosure was too small. From 1894 to this time, the maximum thermometer was apparently reading about 3°F. too high. The observations of wind direction are different from those at other periods, and apparently some method other than that of observing the local surface wind must have been adopted. The amount of cloud, also, was evidently recorded much too low during this period. The humidity values are too low, probably owing chiefly to the error in the maximum dry thermometer. From 1918 to 1920, also, the humidity data are unreliable, presumably due to errors in the wet-bulb thermometers.

In 1912 a new Fortin barometer was taken to the Harbour Board Office for the daily weather reports. The old barometer at the station was becoming worn out, and from April 1913 the barometer readings made at the Harbour Board (to hundredths of an inch only) were used. The height was assumed to be the same as that at the Meteorological station (12 feet.) In October 1920, the barometer was transferred from the Harbour Board Office to a building in the grounds near the Meteorological station (apparently the position of the old barometer.) Its altitude was 12 feet. It was subject to a similar range of temperature to what it would have experienced in the open air.

In August 1925, the barometer was removed to Mr. Chesney's Office, the altitude being 30 feet. Apparently it was affected in some way by the move since the readings have been high since then.

Although the enclosure for the instruments was presumably enlarged in 1912, it was found by Mr. Pemberton in January 1928 to be only 9 ft. x 7 ft. and surrounded by a fence 3 feet high. It was enlarged to 40 ft. x 50 ft. later on in that year.

In January 1928 ordinary wet and dry bulb thermometers were substituted for the maximum and minimum wet bulbs. and a new Kew Pattern Barometer in January 1931.

The observers have all been Government servants and, except in the case of Mr. Fleming (1917-1919) members, apparently, of the Lands and Survey Department.

Further details will be found on the sheet of mean pressure readings.

E.K.

23rd May, 1930.

Appendix 3

Hokitika versus Other Stations

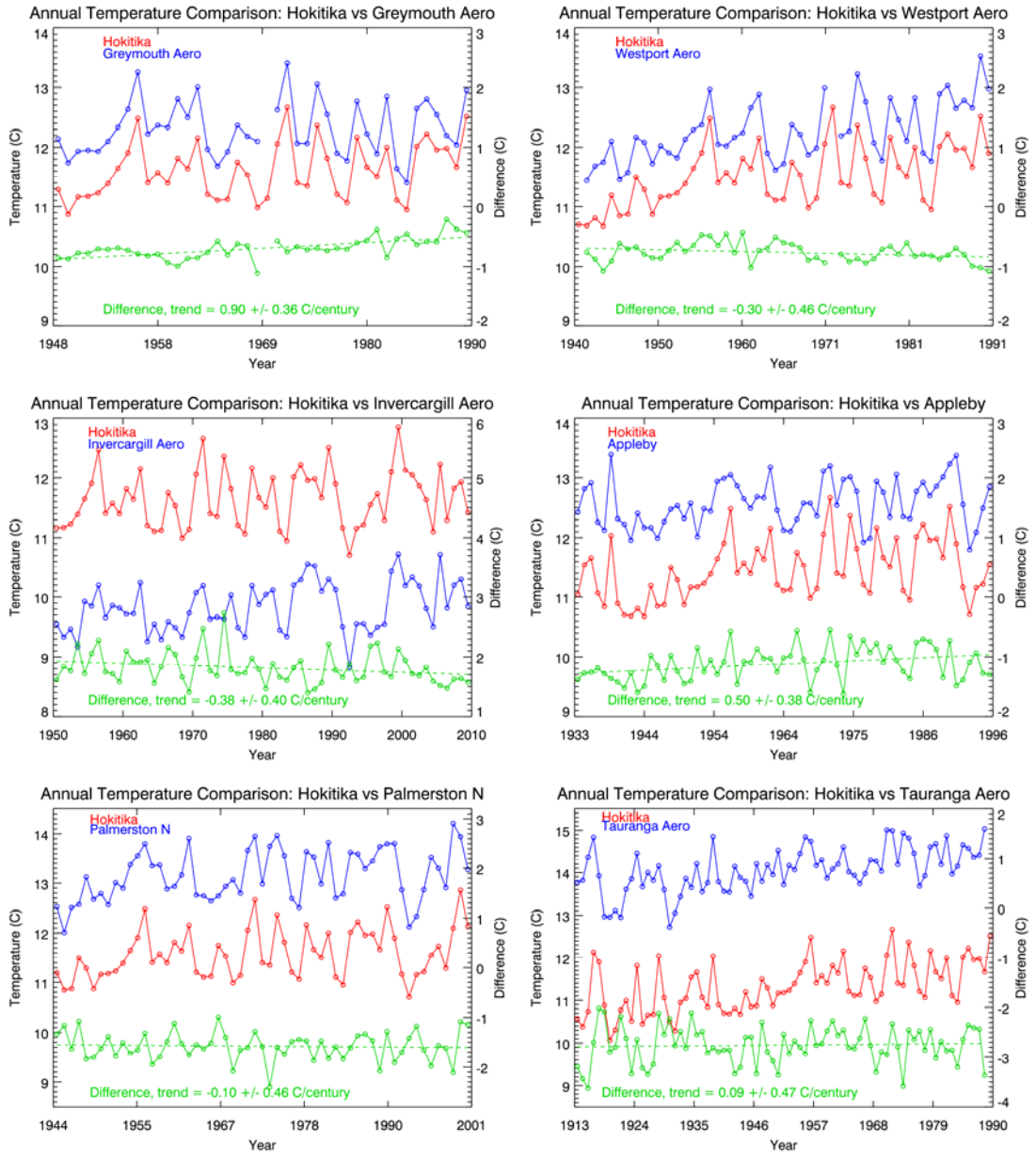

Figure A3.1: Comparison of the revised composite temperature series for Hokitika (red line), with time series of annual mean temperature (blue line) at other stations: Greymouth Aero, Westport Aero, Invercargill Aero, Appleby, Palmerston North and Tauranga Aero. The solid green line represents the difference (Hokitika minus the other station) using the right-hand ordinate scale. The dashed green line represents a linear trend fitted to the difference time series; the legend indicates the slope of the trend line and its associated uncertainty[10].

It is reasonable to ask whether other, comparable stations show a similar trend to Hokitika. Figure A3.1 shows the revised Hokitika composite temperature series

[10] The uncertainty here is twice the standard error of the slope in the least squares linear fit to the difference time series, with the effective sample size reduced to allow for the lag-one serial autocorrelation (Santer *et al.*, 2008, Equations 4–6).

compared with temperature series from several other climate stations in Westland and further afield. The stations have been chosen to have a long record (at least 40 years) with no evidence of significant inhomogeneities; no adjustments have been applied to the data from them.

The Greymouth Aero (3950) and Westport Aero (3810) stations are both situated on the Westland coastal plain (Figure 2). The name "Aero" indicates an airport station, but the Greymouth Aero station moved away from the airport in 1991, at which point the time series shown here is terminated. The difference time series (Hokitika minus Greymouth) shows a positive trend of +0.90 ± 0.36 °C/century, implying that Hokitika has warmed relative to Greymouth Aero over the period shown. However for Westport Aero there is a smaller, statistically insignificant negative trend in the difference, of −0.30 ± 0.46 °C/century. The large (~ 1 °C/century) range of trends encompassing Westport Aero, Hokitika and Greymouth Aero is surprising as all three locations appear to be similar climatically, and interannual fluctuations in temperature track each other very closely (Figure 4). The site history on CliDB for the Greymouth and Westport stations shows no entries for the first 30–40 years, but a search through the paper records revealed a site change at Greymouth Aero in December 1965. Comparisons of temperature difference with other stations suggest very little change in mean temperatures at Greymouth Aero as a result of that site change, but a warming of a few tenths of a degree at about the same time at Westport Aero. Clearly, a more careful examination of the metadata and data for these two stations is required before firm conclusions can be drawn about the trends relative to Hokitika.

Looking further afield, Hokitika warmed significantly relative to Appleby (4239, 0.50 ± 0.38 °C/century over 62 years), cooled relative to Invercargill Aero (5814, −0.38 ± 0.40 °C/century over 60 years), and had no significant change relative to Palmerston North (3238, −0.10 ± 0.46 °C/century over 55 years). The longest period comparison shown here is with Tauranga Aero (1615) over 76 years from 1913 to 1988; it shows a statistically insignificant difference in the trend (0.09 ± 0.47 °C/century). The differences in the trend amongst these stations probably involve various climatic differences, and possibly some non-climatic effects, such as changes in station exposure. However the trend in the Hokitika composite time series is within the range of variation observed at other New Zealand stations.