Creating a Composite Temperature Record for Hokitika

NIWA has previously posted its NZ 'seven-station' temperature series data for download here: https://www.niwa.co.nz/our-science/climate/news/all/nz-temperature-rise-clear/seven-station-series-temperature-data. And here (xxx) is a link to documentation of the various sites changes that have occurred for the seven key locations of: Auckland, Masterton, Wellington, Nelson, Hokitika, Christchurch and Dunedin.

In order to estimate long-term trends in temperature at a particular location, it is necessary to create a homogeneous time series by merging data from the various local sites. The data from different sites should not simply be appended without adjustment, since significant biases can be introduced when measurement sites are moved. This particular document describes the necessary adjustments for the Hokitika location.

The Hokitika temperature record comprises measurements made at three different sites, as shown in Table 1 below. Thus, there are two site changes, and the temperature record must be closely examined before and after the change-dates, in order to identify potential biases. In addition, an early period of the record has been flagged in the station history notes as being erroneous.

Table 1: Information on Hokitika climate observations: (1st column) the actual sites; (2nd column) period of record for which the site contributes to the composite time series used by NIWA; (3rd column) "agent number" used by NIWA Climate Database (CliDB) to identify the station; (4th column) altitude of site in metres; (5th column) additional remarks about site changes, or the temperature record.

Location/Site	Period	Agent	Height	Remarks
Hokitika South (actually in Township) **Site 1**	1867-1880 1894-1943	3907	4	No data 1881-1893. Data error 1894-1912. Township site closed Dec-1945.
Hokitika South (old Aerodrome) **Site 2**	1943-1963	3907	4	New site opened without name change Aug-1943. Overlap data 1943-45 not currently available in CliDB, but Southside site 0.7°C colder than township during overlap period.
Hokitika Aero **Site 3**	1964-	3909	39	14-month overlap (Nov-1963 to Dec-1964) with agent 3907

Adjustment for Site Change in 1963/64

It is standard practice to adjust all the historical measurements to be consistent with the current open site. Thus, we will work backwards in time from the current Hokitika Aero data (agent number 3909, labelled as Site 3 in Table 1). This current site was opened in November 1963, and replaced the previous site at the old Hokitika Aerodrome south of the town and river (Site 2). However, there is an overlap period of 14 months (Nov 1963 to Dec 1964) during which both sites operated. This is the ideal situation, and allows a straightforward calculation of the temperature difference between the two sites.

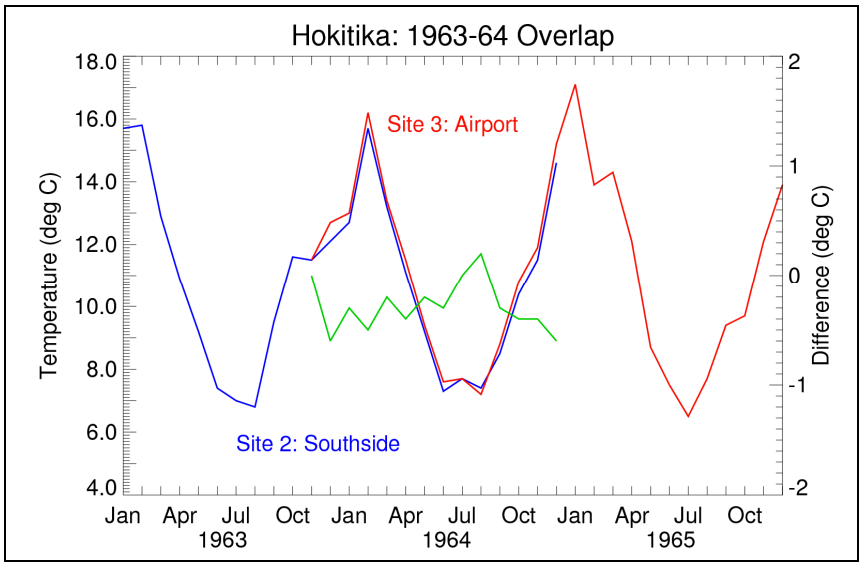

Figure 1: Monthly mean temperatures for Hokitika Southside (Site 2, agent 3907, blue line), Jan-1963 to Dec-1964, and Hokitika Aero (Site 3, agent 3909, red line), Nov-1963 to Dec-1965. The difference, Site 2 minus Site 3, is plotted in green, with the right-hand ordinate scale.

Figure 1 shows a plot for Hokitika Site 2 and Site 3 across the 1963/64 overlap period. The difference between the two sites varies somewhat from month to month, with an average difference of -0.3°C[1]: that is, the old site is colder than the replacement one. This means that, when merging the temperature data from the two sites, the earlier Site 2 temperatures must be *increased* by 0.3°C to be consistent with the current open site (Site 3).

Adjustment for Site Change in 1943

In August 1943, the climate measurements were moved from the Township (Site 1) to the Aerodrome (Site 2) south of the Hokitika River. Again, there was a period of overlap during which both sites were operated: in this case, the overlap is 29 months (Aug-1943 to Dec-1945). 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 therefore only one set of data was transferred to the computerized archive. In the NIWA Climate Database, the

[1] Over the 14-month overlap, the average difference is -0.29°C to two decimal places.

"Hokitika" temperatures refer to Site 1 (Township) up to Jul-1943, and then change to Site 2 (Aerodrome) from Aug-1943 onwards[2]. Of course, all original measurements from both Site 1 and Site 2 are still held in paper form in the NIWA climate archives[3].

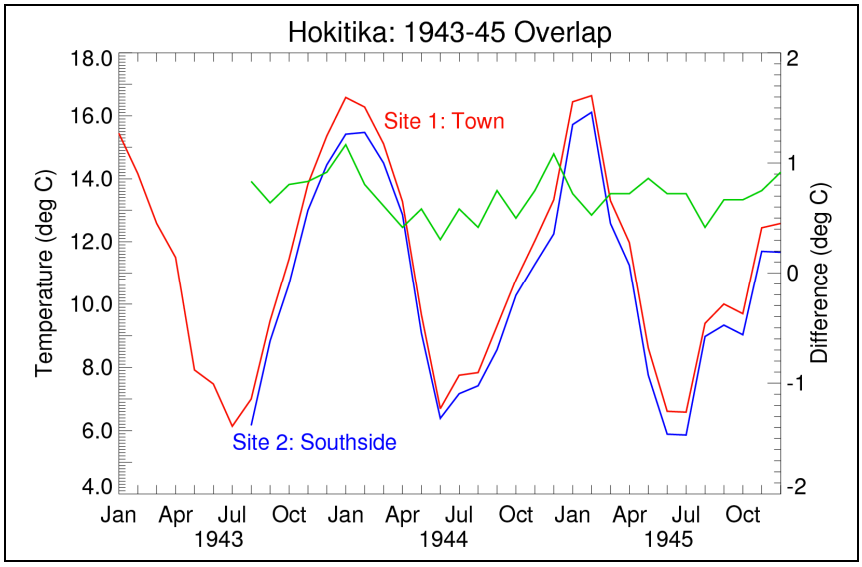

Figure 2: Monthly mean temperatures for Hokitika Township (Site 1, agent 3907, red line), Jan-1943 to Dec-1945, and Hokitika Southside (Site 2, agent 3907, blue line), Aug-1943 to Dec-1945. The difference, Site 1 minus Site 2, is plotted in green, with the right-hand ordinate scale.

Figure 2 shows a plot for Hokitika Site 1 and Site 2 across the 1943/45 overlap period (data are given in Appendix 1). The average difference between the two sites is +0.7°C[4]: that is, the old site (Site 1, the Township) is warmer than the replacement one. This means that, when merging the temperature data from the two sites, the earlier Site 1 temperatures must be *decreased* by 0.7°C to be consistent with the Site 2. Note that there is good evidence of an annual cycle in the mean temperature difference between Sites 1 and 2, so the adjustment should vary by month of the year with a larger adjustment in summer months than in winter[5].

For the annual mean temperature series, the final adjustment of Site 1 to the current open site (Site 3) will therefore be: -0.7 +0.3 = -0.4°C.

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[2] Actually, in the process of checking the 7-station records, an error was discovered in the CliDB Hokitika (agent number 3907) temperatures for 1945. The actual sequence of temperatures in the database is 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 Hokitika component of the 7-station series does not suffer from this problem – the sequencing of site data is correct.

[3] This database oversight will be corrected shortly. All Site 1 data for the overlap period will need to be digitised (ie, the underlying daily observations too, not just the monthly means used here), then a new agent number created, and the Site 2 data for Aug-1943 to Dec-1964 transferred from agent number 3907 to the new agent number.

[4] To two decimal places, the difference is +0.70°C over Aug-1943 to Dec-1945, or +0.68°C over Jan-1944 to Dec-1945. This estimate was made using the original monthly averages to the nearest 0.1°F, and only rounding to the nearest 0.1°C at the end of the calculation. If the daily temperatures are converted to °C and rounded to the nearest tenth first, then the final result could be 0.1°C different.

[5] An annual cycle in temperature differences between nearby sites is sometimes seen in temperature records, although it is the exception rather than the rule.

Correction for Instrument Error in early 1900s

It is noted in the Hokitika station history file (see Appendix 2) that the maximum temperatures were believed to be about 3°F too high through the period 1894 to August 1912. No comment was provided on the minimum temperatures. If the minima were correct, and the maxima exactly 3.0°F too high, then this would imply that the daily mean temperatures (the average of daily maximum and minimum) would be 0.8°C too high.

There are no other known temperature data recorded at Hokitika during this period (i.e., no overlap with another local site), but we can compare the Hokitika record with those from more distant locations. 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 the 1894-1911 Hokitika temperatures were too warm by: +1.7°C for the maximum (which agrees with the +3°F estimate in the station history file), +0.5°C for the minimum, and thus by +1.1°C for the mean temperature.

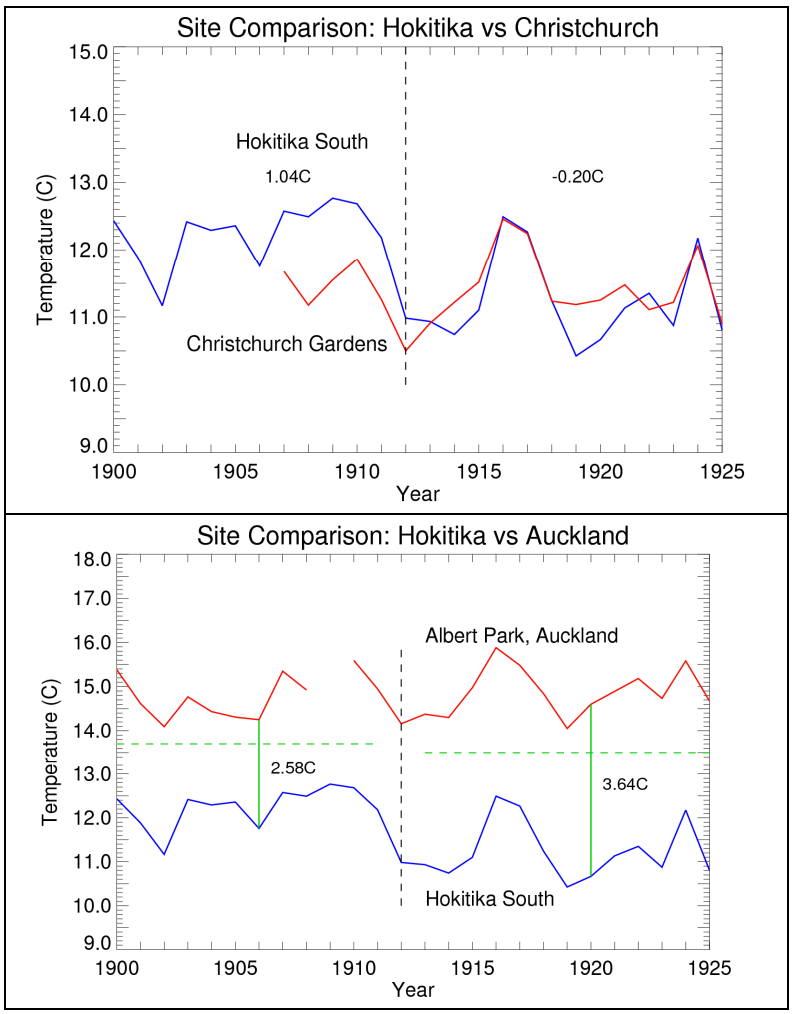

Figure 3: Annual mean temperature series for 1900-1925: (top panel) Hokitika Township (agent 3907) versus Christchurch Gardens (agent 4858); (bottom panel) Hokitika Township. versus Albert Park, Auckland (agent 1427). Inset values show the average station differences as discussed in text.

Figure 3 shows an independent comparison of the Hokitika annual mean temperatures with those measured at Christchurch Gardens (upper panel) and at Auckland (lower panel) over the period 1900-1925. Data are plotted only for those years with no missing months. The average differences 1900-1911 and 1913-1925 (i.e., with the year 1912 excluded since the climate enclosure was changed between August and September 1912) are also marked on the figure. In the upper panel, Hokitika is warmer than Christchurch Gardens by 1.04°C over 1907-1911, but colder by 0.20°C over 1913-1925. In the lower panel, Auckland is warmer than Hokitika by 2.58°C over 1900-1911 (excluding the missing 1909), but warmer by 3.64°C over 1913-1925.

Thus, the differences pre-1912 versus post-1912 are +1.24°C (with respect to Christchurch) and +1.06°C (Auckland), which are consistent with Salinger's 1981 estimate of +1.1°C. Thus, the final adjustment of the annual 1894-1912 data to the current open site (Site 3) should be: -1.1 -0.7 +0.3 = -1.5°C.

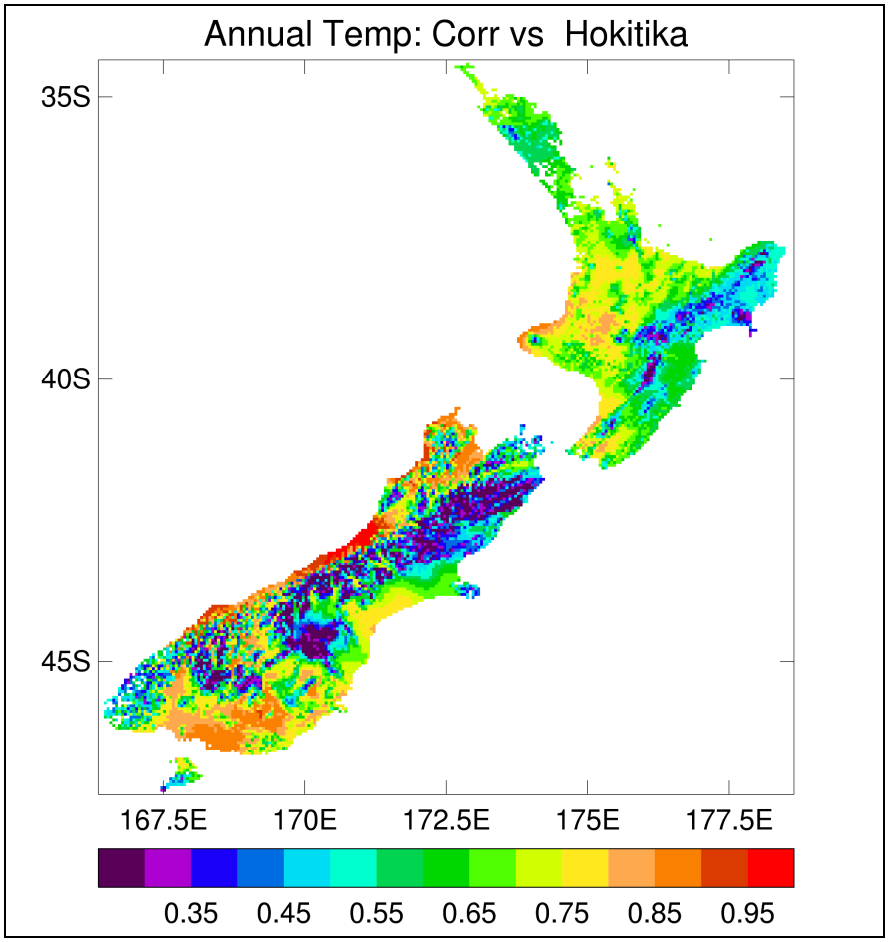

Figure 4: Map of correlation between annual temperatures at the Hokitika grid-point, 1972-2008, and all other grid-points in the NIWA 0.05° gridded "Virtual Climate Station" data set.

The reader might well query the use of Auckland as a comparison site to Hokitika, although Figure 3 speaks for itself: the interannual variations in temperature match extremely well between these two sites. Figure 4 is provided as further justification for the use of Auckland as a comparison site, at least for annual-average temperatures.

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-Jan-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).

Figure 4 maps the correlation of annual mean temperatures over the 1972-2008 period between Hokitika (the grid-point rather than the actual station point data) and all other locations on the VCS grid. Variations in annual mean temperature at Hokitika are well correlated to most western parts of New Zealand, and also to much of Southland. Focussing on just the 7 grid-points co-located with the 7-station series, Hokitika has the highest correlation with Nelson (+0.76 over 1972-2008), but has a correlation with Auckland (+0.70) that is not much worse[6].

Adjustment of Data in Period 1866-1880

For completeness in regard to the Hokitika record, it should be noted that Salinger (1981) also made a small adjustment to the earliest Hokitika temperature data prior to the gap in the record over 1881-1893. By comparing the 1866-1880 period with the 1913-1945 period between Hokitika and three other early sites (Nelson, Christchurch, and Dunedin), he estimated the 1866-1880 Hokitika mean temperature was 0.2°C too high relative to post-1912.

Putting all the Adjustments together

The various adjustments and corrections described above can be applied successively to the Hokitika temperature record. The resulting final time series from 1900 is shown in Figure 5, along with the unadjusted data from the two earlier sites (Site 1 and Site 2). Note that the original temperatures from Site 2 have been adjusted upward, and the Site 1 temperatures adjusted downward, along with the larger downward correction prior to 1912. A best-fit linear trend over the 1900-2009 period of the plot for the composite temperature record is +1.3°C.

Even though all the individual adjustments to the Hokitika data make sense by themselves, it would be reasonable to ask how the overall composite time series compares with records elsewhere in New Zealand. NIWA has also posted a web comment on temperature trends from a separate set of 11 stations with no significant site changes since the 1930s (https://www.niwa.co.nz/our-science/climate/news/all/nz-temperature-rise-clear/temperature-trends-from-raw-data). Two of these sites (Tauranga and Ruakura) have temperature records prior to

[6] The VCS annual correlation of Hokitika with Christchurch (+0.68) is similar to that with Auckland. As is evident from Figure 3 (upper panel), the year to year variations in Christchurch temperatures do not always match those at Hokitika, even though Hokitika is much closer to Christchurch than to Auckland: Christchurch is relatively warmer in years with stronger westerlies, but this is not the case at Hokitika. We would also expect all these correlations to be substantially weaker on the monthly timescale.

1930 with little missing data, and can provide a test of the composite Hokitika series in the early decades of the 19th century.

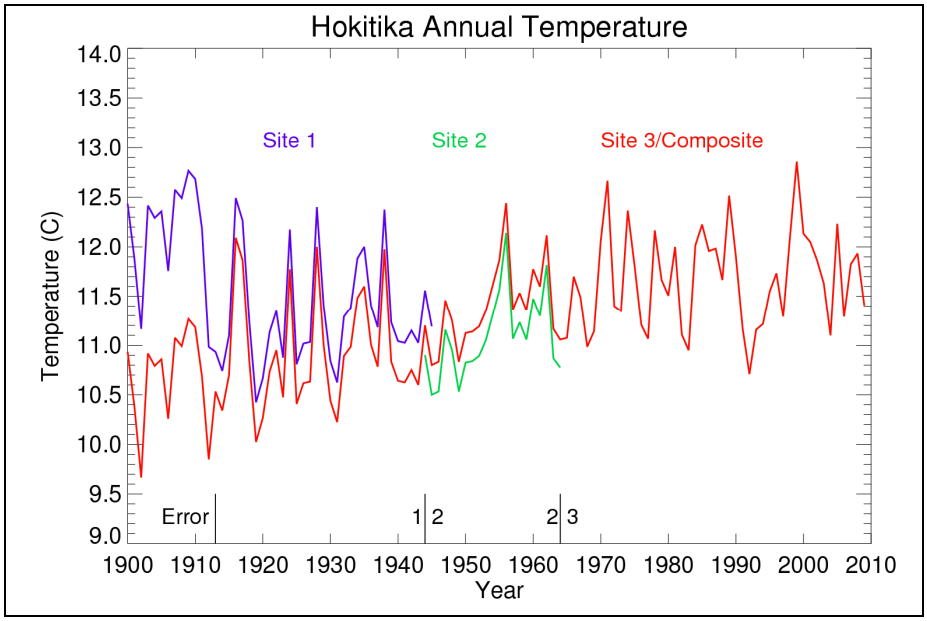

Figure 5: Annual mean temperature series for Hokitika: Site 1 (1900-1945, blue line), Site 2 (1944-1964, green), and Site 3 (1964-present, red). The Site 3 time series is extended back in time as the composite Hokitika series by applying the successive adjustments described in the text. The short vertical bars at the bottom of the plot mark the years of the site changes and the end of the period of instrumental error.

Figure 6 shows the result of this inter-comparison, where the composite Hokitika temperature curve is reproduced from Figure 5, and data from these two 'pristine' sites superimposed. Of course, Tauranga and Ruakura are substantially warmer than Hokitika (by 2.9°C and 2.0°C, respectively, over the 1971-2000 climatological period), and to make it easier for the eye to compare the long-term trends in the three series, these climatological offsets have been removed from the Tauranga and Ruakura data. No other changes have been made to these two records: eg, a constant of 2.9°C has been subtracted throughout the 1913-2009 period of the Tauranga data[7].

[7] Technical note on treatment of missing data: There are missing months in the records of Tauranga and Ruakura (as with almost all sites). Annual values could be calculated and plotted for *only* those years with no missing months, but this would throw away a lot of information. Thus, in Figure 6 the annual averages are estimated allowing up to 3 missing months in a given year. This can not be done by naively averaging the temperatures from the non-missing months (e.g., the annual value would be biased low if a summer month was missing, or biased high if a winter month was missing). The correct procedure is to: first, determine the monthly anomalies by subtracting the 1971-2000 climatology for that month; then, average the monthly anomalies to obtain the annual anomaly, ignoring missing months; and, finally, add back in the annual climatology. At Tauranga, for example, there are 12 years out of 97 that have one or more missing months of data, but this approach results in only a single break in years 1989 and 1990 in the Tauranga annual time series.

Figure 6 shows there is excellent agreement in the long-term trends at these three sites, and in most years also excellent agreement in the year to year fluctuations[8]. This gives us considerable confidence in the Hokitika adjustments. Obviously, with sites so far apart there are occasional climatic influences that affect the two northern sites differently from the Hokitika region. On the other hand, appending the raw data from the Hokitika records without correcting for known site change and instrumental effects would result in a long-term trend completely at variance with that from these two comparison sites.

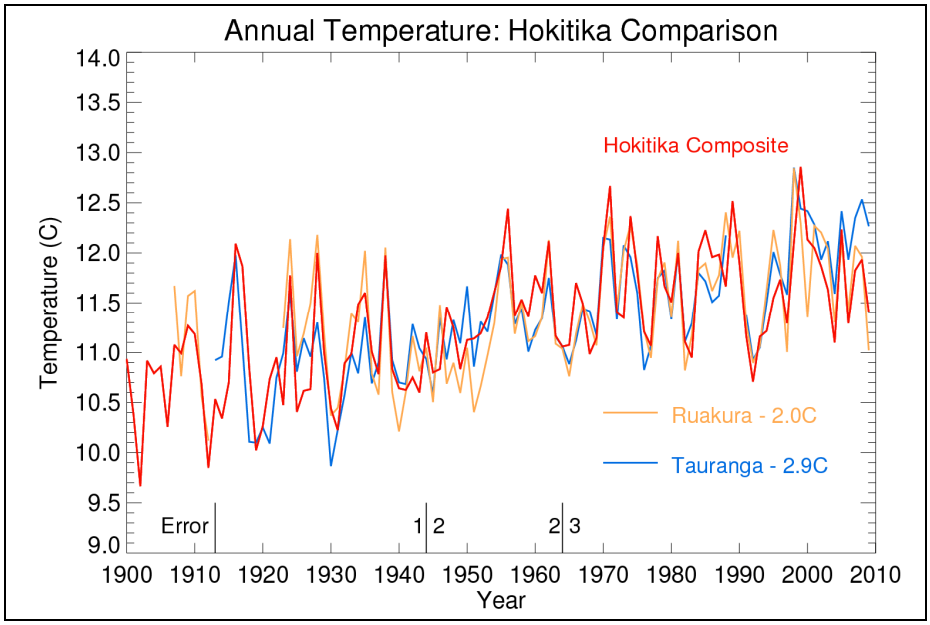

Figure 6: Annual mean temperature series: composite Hokitika record (1900-2009, red line), compared with data from Tauranga (1913-2009, blue) and Ruakura (1907-2009, orange). The Tauranga and Ruakura temperatures have been offset by their climatological differences with respect to Hokitika (2.9°C and 2.0°C, respectively) for ease of comparison.

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).

Author: Document created by Dr Brett Mullan, NIWA Principal Scientist (Climate), 03-Feb-2010.

[8] We have also received questions about how representative the 7-station series is of New Zealand temperatures generally. Given the striking agreement in interannual fluctuations and long-term trends in Figure 6, this question would seem to be satisfactorily answered, apart from some issues at high altitude locations (Figure 4).

References:

Peterson, T.C., et al., 1998 : Homogeneity adjustments of *in situ* atmospheric climate data: a review. *International Journal of Climatology*, **18**, 1493 – 1517.

Rhoades, D.A., and Salinger, M.J., 1993: Adjustment of temperature and rainfall measurements for site changes. *International Journal of Climatology*, **13**, 899 – 913.

Salinger, M.J., 1981. Site Assessments on Climatological Stations. Appendix C in: *New Zealand Climate: The instrumental record*. Thesis submitted for the degree of Doctor of Philosophy at the Victoria University of Wellington, January 1981.

Tait, A.B., 2008: Future projections of growing degree days and frost in New Zealand and some implications for grape growing. *Weather and Climate*, **28**, 17-36.

Appendix 1:

Table: Monthly mean temperatures at Hokitika Site 1 (Township) and Site 2 (Southside) over the period 1943-45, converted from °F and rounded to the nearest tenth °C. Site 1 closed at the end of December 1945. Italicised values are not available as yet (as of January 2010) in the NIWA climate database.

Site 1: Hokitika Township

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1943	15.4	14.2	12.6	11.5	7.9	7.5	6.1	*7.0*	*9.5*	*11.4*	*13.8*	*15.4*
1944	*16.6*	*16.3*	*15.1*	*13.3*	*9.7*	*6.7*	*7.8*	*7.8*	*9.3*	*10.8*	*12.0*	*13.3*
1945	16.4	16.6	13.3	12.0	8.6	6.6	6.6	9.4	10.0	9.7	12.5	12.6

Site 2: Hokitika Southside

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1943	-	-	-	-	-	-	-	6.1	8.8	10.7	13.0	14.5
1944	15.4	15.5	14.5	12.8	9.1	6.4	7.2	7.4	8.6	10.3	11.3	12.3
1945	*15.7*	*16.1*	*12.6*	*11.3*	*7.8*	*5.9*	*5.9*	*9.0*	*9.3*	*9.0*	*11.7*	*11.7*

Appendix 2:

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.