Time series of relative humidity, wet-bulb temperature, and dewpoint temperature at Kelburn and Masterton over the last 90 years

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ABSTRACT

NIWA has recently digitised daily wet- and dry-bulb temperature records for both Kelburn, Wellington and Masterton, Wairarapa sites back to 1929 and undertaken an analysis of these records and comparison with reanalysis products. This article presents key results of the analysis in the context of climate change and also the steps taken to account for site moves, complications around a plethora of daylight savings changes, and observing methods.

Overall, there was a 0.7°C increase in dewpoint temperature (T_d) averaged over all seasons with the strongest trend being an increase in winter, amounting to +1.7°C over 90 years at Kelburn, and +1.8°C at Masterton for the same period. Autumn also saw increasing trends at both locations whereas summer and spring saw smaller increases.

Other points of interest were that January 2018 had the highest average T_d values of any month in both the Kelburn and Wairarapa records while February 1998 was ranked third in the Kelburn record. Both 1998 and 2018 are tied for third-warmest years on record for Aotearoa New Zealand (dry-bulb air temperature).

Despite the long-term upward trend, average T_d values for February 1938 and February 1935 were ranked second- and tenth-highest respectively in the Kelburn record. February 1935 is also ranked eighth-highest in the Wairarapa record.

Extreme high summer and autumn values of T_d occurred in the 1930s where there was considerable year-to-year variability.

Of the ten months with lowest average T_d values, seven occurred in the 1930s and 1940s for Wellington. At Masterton, six were in the 1930s and all ten had occurred by 1972.

1. INTRODUCTION

Wet-bulb temperature, dewpoint temperature and relative humidity are all important measures of the moisture content of air-mass characteristics. In terms of applied meteorological and climate applications these are perhaps most meaningful when combined with other parameters such as dry-bulb temperature to provide apparent temperature (heat indices), e.g., where high humidity and high temperatures are uncomfortable for humans or livestock as it limits the ability to regulate the cooling of the body. Physically, dewpoint temperature is, in the absence of a change of air-mass, often a useful indicator of what the overnight temperatures may drop to and when high in the summer is associated with sub-tropical air-masses and so can be used to assess climatic risk of spread of some potentially invasive insect pests from warmer climates, e.g., Red Imported Fire Ant (Turner et al., 2006). Extended periods of high relative humidity correlate well to leaf wetness and are used to assess the infection risk for plant diseases such as Myrtle Rust (Beresford et al., 2018). High duration humidity events are also associated with increased rates of corrosion (Schindelholz and Kelly, 2010). Low dewpoint temperatures near zero or below will also be associated with frost occurrence and extended periods of low-humidities in warmer months are associated with drought risk.

It is therefore of interest, especially in the light of the warming experienced under climate change, to investigate long-term trends in wet-bulb temperature, dewpoint temperatures and relative humidity in Aotearoa-New Zealand, where little if any work appears to have been done with surface records prior to 1972. Where most records are not available digitally, there also appears to be little done post-1972 with the moisture variables as well. In this paper, we present the results from an effort to reconstruct a 90-year record from two New Zealand climate stations; Kelburn, Wellington and Masterton, Wairarapa in the Greater Wellington Region of the lower North Island, see Figure 1.

2. DATA AND METHODS

2.1 Data

In New Zealand, historic climate records relating to moisture content of air masses (i.e., relative humidity (RH), dewpoint temperature (T_d), and wet-bulb Temperature (T_w)) are typically only available from daily 9am observations prior to 1972. Three hourly (or synop) records are commonly available from 1972 and hourly records of these variables are more commonplace from the early 1990s with the introduction of automated weather stations (AWS). Typically, only one of the three variables (RH, T_d, T_w) was reported. This is because when one of these is known along with the dry-bulb air temperature (T_a) (which is almost always reported), the other two variables can be reasonably determined. Abbot and Tabony (1985), Alduchov and Eskridge (1996), August (1828), Magnus (1844), and Stull (2011) provide background and various methods to do these calculations. Additionally, there are online calculators and resources which can be utilised to do these conversions. A listing of some of these sites is provided within the reference section, see Australian BOM, McNoldy, 2020 and Omni, 2020 websites.

A survey of NIWA station histories (Fouhy et al., 1992) and New Zealand's national climate database (CliDB) identified that for Wellington the Kelburn site could be used to derive moisture-related trends as 9am records there

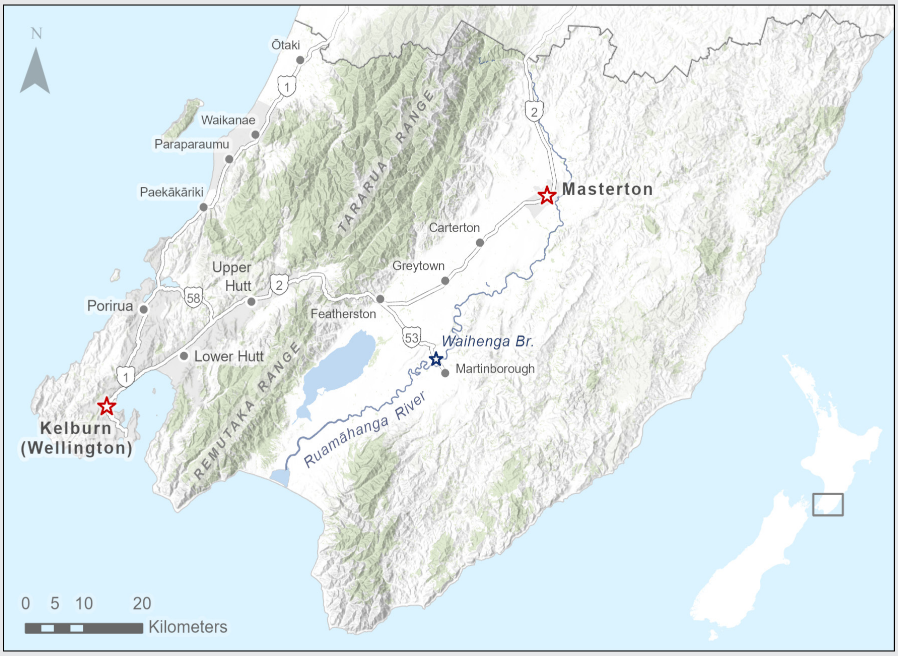

Figure 1: Map of the Wellington Region, Aotearoa-New Zealand, showing location (red stars) of Kelburn (in Wellington) and Masterton. The location of the Ruamāhanga River site at Waihenga Bridge (blue star) is also indicated.

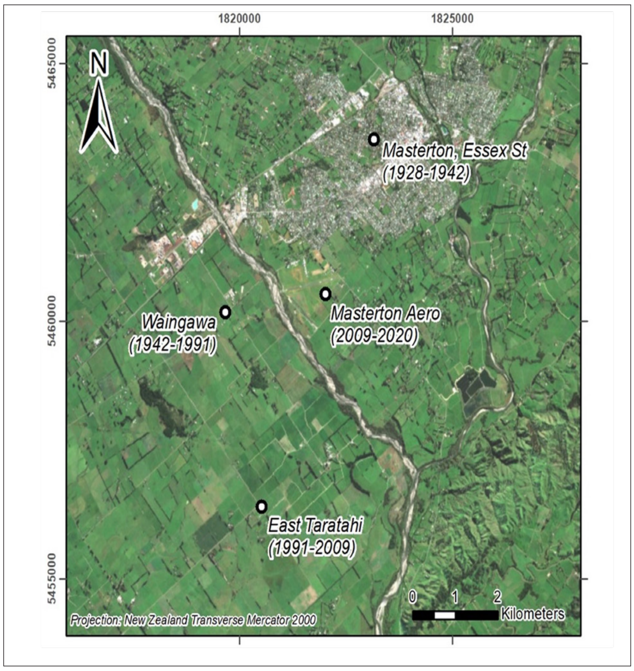

Figure 2: Map showing location of Masterton climate stations with records used in the dewpoint temperature analysis.

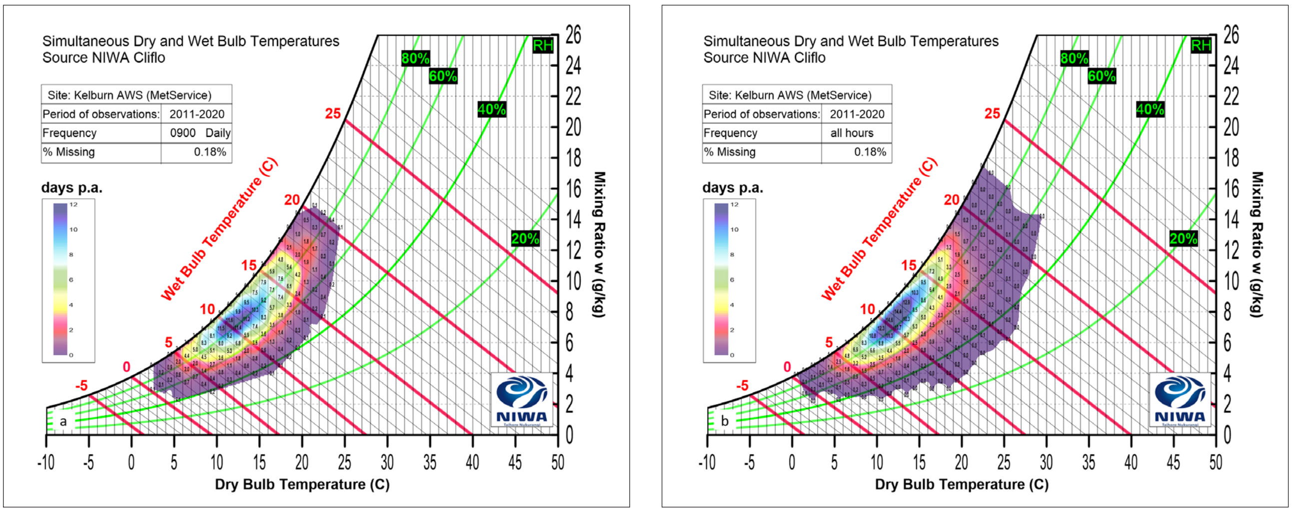

Figure 3: Distribution for period 2011-2020 at Kelburn for which various dry-bulb temperature and Mixing Ratio combinations for (left) 9am (expressed as days per year) and (right) for all hours.

go back to late-1928, and that a collection of sites could be used for Masterton (see Table 1 and Figure 2). The choice of 9am was primarily due to the fact that the longest available records are for this time. The 9am records still give a reasonable distribution of overall air-mass properties compared to distributions for all hours, see (Figure 3) which compares Kelburn "9am only" to "all-hours" psychrometric charts over the past decade. In terms of mixing ratios average diurnal variations, over the last decade, at Kelburn were within ±3% of the average (7.46g/kg) with the average 9am value being 7.53g/kg and were within ±9% of the average (6.79g/kg) at Masterton where the average 9am value was 7.09g/kg.

Digitisation, and quality control of records prior to 1972 was also required and done for this analysis. The data rescue process involved studying original meteorological forms which keep track of manually transcribed weather observations. These observations were manually typed into Excel documents, focusing on one column of data at a time. Each observation's column of data concluded with a 'Sums' and 'Means' option which have also been manually recorded. To ensure accuracy in digitizing the records, each column was added up using the excel 'Sum' feature to make sure the column's total matched that of the original document. This ensured the observations had been recorded accurately, despite the handwriting of some of the numbers making it difficult to read.

Some numbers that were particularly difficult to make out were determined by looking at the numbers recorded before and after them, which gave an indication of the figure likely recorded in the space.

Most of the original meteorological forms however were able to be read with ease (see Figure 4), and the sums calculated by the recorder were an added benefit for the digitization process. Quality control also consisted of visual inspection of records checking for obviously spurious values, unphysical values, e.g., when dewpoint or wet-bulb temperatures exceeded dry-bulb air temperatures, and also the conversion from Fahrenheit to Celsius when required. Prior to automated stations the observing method typically involved the observer recording the dry-bulb temperature and wet-bulb temperature then using psychrometric tables

Station Name	Begin Date (analysis)	End Date (analysis)	Comment
Wairarapa			
Masterton, Essex St	2-Sep-1928	30-Nov-1942	Digitized from paper records
Masterton Waingawa	2-Jan-1943	31-Dec-1971	Digitized from paper records
Masterton Waingawa	1-Jan-1972	31-Mar-1991	8am records in NZDT 1974 – 1991
East Taratahi[1,2]	28-Oct-1991	4-Nov-2009	8am records in NZDT 1991 - 1995
Masterton Aero AWS	5-Nov-2009	25-Mar-2020	
Wellington			
Kelburn[3]	1-Dec-1928	30-Jan-1961	Digitized from paper records
Kelburn[4,5]	1-Dec-1961	1-Sep-2005	8am records in NZDT 1989 – 2004
Kelburn AWS	2-Sep-2005	25-Mar-2020	

Table 1: Listing of climate stations where 9am (NZST) temperature and humidity records were obtained for this section.

[1] Dec 1996: Stevenson Screen Replaced
[2] May 2001: Humidity Probe replaced due to overheating
[3] Jul 1949: Exposure increased and improved.
[4] Apr 1970: Equipment replaced due to vandalism
[5] Dec 1989: Thermometer replaced

(also known as hygrogmetric tables as published by the Smithsonian Institute (1939)) or charts (similar to that of Figure 3) to determine relative humidity and dewpoint temperature. Either aspirated thermometers or at times a sling psychrometer were used to determine the wet-bulb temperature by a trained observer.

2.2 Methods

One complication in creating a "9am" record is that local time records were the only ones available, a complicated sequence of daylight savings periods and changes had to be accounted for. This meant that there were periods when 8 am New Zealand Standard Time (NZST) records were only available. To account for this, regression relationships between 8am and 9am NZST observations were developed from nearby stations where, or from a later period, when hourly observations were available, and adjustments made. Key details about the regression relationships and the periods for which these were applied in the adjustments are provided in Table 2.

Another aspect related to daylight savings that had to be accounted for was that the current NZST was adopted in 1941. In the period 1927-1941 New Zealand did have daylight savings in the summer months and in 1941 this daylight savings time was adopted all-year round and became the current NZST. The old standard time (NZMT)

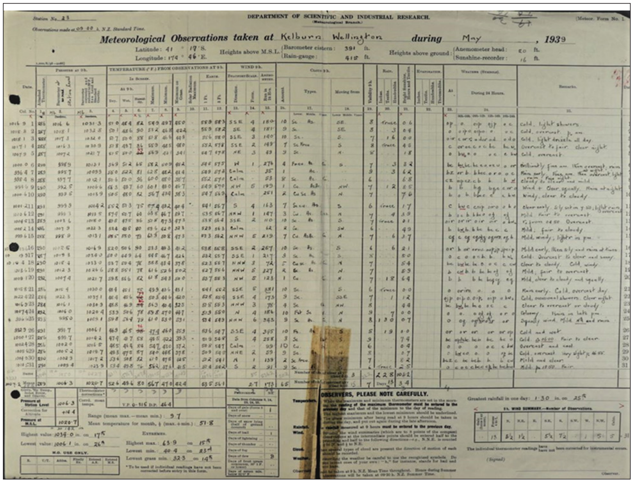

Figure 4: Capture of a typical observation chart with recordings taken at Kelburn, Wellington in May of 1939.

between 1927 and 1941 was 30 minutes behind our current NZST or +11:30 ahead of UTC. The period of daylight savings from 1928 to 1933 was from the 2nd Sunday in October to the 3rd Sunday in March and from 1933 to 1941 it was from the 1st Sunday in September until the last Sunday in April. Adjustments were thus also made to account for the half-hour shift during the period of NZMT. This adjustment resulted in a decrease of average summer dew-point temperatures in the 1930s of around 1°C at Masterton, but only a slight decrease of around 0.1°C at Kelburn. We suggest this difference could be due to maritime influences damping the diurnal cycle at Kelburn as it is much closer to the ocean.

Apart from the adjustments for time-of-observation, and applying corrections where there was some overlap of stations, little other effort was made to homogenise the data. No attempt was made to apply the methods of Rhoades and Salinger (1993) to account for site changes or detected breakpoint changes. This is because the Rhoades and Salinger method requires other coincident time-series of a parameter to be available at 'nearby' stations to check on consistency of trends when a site change occurs. The digitization of the Masterton and Kelburn records done here is to the author's knowledge the first to be done for New Zealand for dewpoint and wet-bulb temperatures, and relative humidity and so clearly application of the method is not possible currently, but clearly should be part of future work when other early station humidity records are digitized. Such work would help identify other causes of inhomogeneity such as screen and instrumentation maintenance which is important as the wick for wet-bulb temperatures needs to be well-maintained. The work on homogenisation was hampered by a lack of available detail in maintenance records prior to 1972.

Brown and DeGaetano (2009) describe a method to detect inhomogeneities in historical dewpoint temperature series, but their method relies on hourly records being available, which were not in this record prior to 1991.

Potential breakpoints were identified via a breakpoint detection algorithm similar to that used in Turner et. al., 2019. Only one significant breakpoint was detected for Kelburn and that was in 2012 and does not appear to be associated with any recorded issues with instrument or site maintenance. There were several statistically significant breakpoints detected for Masterton. These were in October 1937, May 1938, June 1975, June 1988, August 1990, December 1993, and August 2017 – some of which are close to breaks in the station records.

		T_a			T_w		
Station	**Years**	**slope**	**intercept**	**r 2**	**slope**	**intercept**	**r 2**
East Taratahi	1995-2009	0.9180	2.7207	0.926	0.8571	2.6097	0.929
Masterton AWS	2009-2020	0.9198	2.8088	0.925	0.8562	2.6016	0.938
Kelburn	1972-1988	1.0231	0.3251	0.943	0.9593	0.7802	0.958
Kelburn AWS	2004-2020	0.9839	1.0393	0.949	0.9578	0.9370	0.968
		RH			T_d		
		slope	**intercept**	**r 2**	**slope**	**intercept**	**r 2**
East Taratahi	1995-2009	1.0051	-5.1407	0.812	0.8295	2.1485	0.897
Masterton AWS	2009-2020	0.9753	-4.1650	0.811	0.8410	1.8891	0.907
Kelburn	1972-1988	0.8504	10.2570	0.591[1]	0.8991	1.0695	0.899
Kelburn AWS	2004-2020	1.0122	-4.2783	0.834	0.9671	0.4719	0.959

Table 2: Regression relationships and correlations between 8am and 9am temperature and humidity variables for stations where hourly records available. T_a = dry bulb air temperature, T_w = wet-bulb air temperature, RH = relative humidity, T_d = dewpoint temperature. The dependent variable is 9am NZST reading when the 9am NZDT (or 8am NZST) was available.

[1] The lower correlation between 8am and 9am RH at Kelburn is suspected to be due to different precisions in reported values at these times of the day.

	Change between 1929 and 2019			
Season	**T_d (°C)**	**RH (%)**	**T_a (°C)**	**T_w (°C)**
Summer	+0.4	+0.4	+0.3	+0.3
Autumn	+0.8	+2.1	+0.3	+0.6
Winter	+1.7	+3.6	+0.9	+1.2
Spring	+0.1	+0.1	+0.1	+0.1

Table 3: Change in average seasonal values in "9am" dewpoint temperature (T_d), Relative Humidity (RH), dry-bulb air temperature (T_a) and wet-bulb air-temperature (T_w) for the Kelburn, Wellington site between 2019 and 1929. This is regression based with starting and end years being 1929 and 2019. Note: summer averages start in 1928.

3. RESULTS

In this section key results and trends are presented for Kelburn and then for Masterton.

3.1 Wellington

Time series of average values for each season (summer, autumn, winter, and spring) for each year from 1929 to 2019 for Kelburn for RH, T_a, T_w, and T_d. are shown in Figure 5. Potential breakpoints in the time-series due to an exposure change in 1949 and the station change in 2004 and those indicated by the detection algorithm are indicated in these figures. Minor bias corrections downwards of around -0.2°C were made to the Kelburn AWS dewpoint temperature post 2005 based on the short period of overlap when the previous Kelburn station remained operating. While this section is focused on trends and extremes in dewpoint temperatures, the other variables are presented also as a check on consistency and to aid physical interpretation. The other point to note about the other variables is that the dry-bulb air temperatures (T_a) are 9am temperatures and so trends and rankings presented here will not precisely match those of daily maximum, minimum or average temperatures such as NIWA's Seven Station Series (Mullan et. al., 2012) derived elsewhere, but should be consistent.

From these seasonal plots, it is apparent that the year-to-year variation and longer-term trends (from simple linear regression relationships) in T_a, T_w, and T_d are all very similar between season and consistent among the variables (Table 3). Overall, the trend in winter is strongest with an approximate increase in 9am dewpoint temperatures of 1.7°C over the 90 years, and an increase in RH of around 3.6% over the period. For autumn there is also an increase of around 0.8°C in T_d and around 2.1% in RH, and for summer these increases are 0.4°C and 0.4%. Meanwhile, for spring the increases to T_d and RH are 0.1°C and 0.1% respectively. The increases in RH are interesting since RH decreases as dry-bulb temperature increases (if all other air-mass parameters remain unchanged) and so it appears that in this instance, increases to dewpoint temperature are more influential than the increases in dry-bulb air temperature in determining the trend in RH. It is noted that there is a sudden increase in RH during summer between 1990 and 2004 which does not occur for the other seasons (Figure 5), and this appears consistent with the observed temperature changes at the time (which show a drop in 9am temperatures). While no information in the station histories was found that indicated any technical issues with instruments during this period, it is noted that the end of the period aligns with a station change and it is therefore possible that there could still be some underlying data issues during this period.

The top-ten and bottom-ten ranked months for average dew-point temperatures were tabulated and these showed that January 2018 had the highest average T_d values of 16.6°C and February 1998 was ranked third, where these two years are tied for second-warmest years for Aotearoa-New Zealand (according to NIWA's Seven Station Series). Also interesting is that, in spite of the long-term upward trend, February 1938 (2nd) and February 1935 (10th) were ranked within the top ten. In terms of bottom ranked years, seven of the ten months occurred in the 1930s and 1940s. Another way to visualise the long-term trend is to contrast

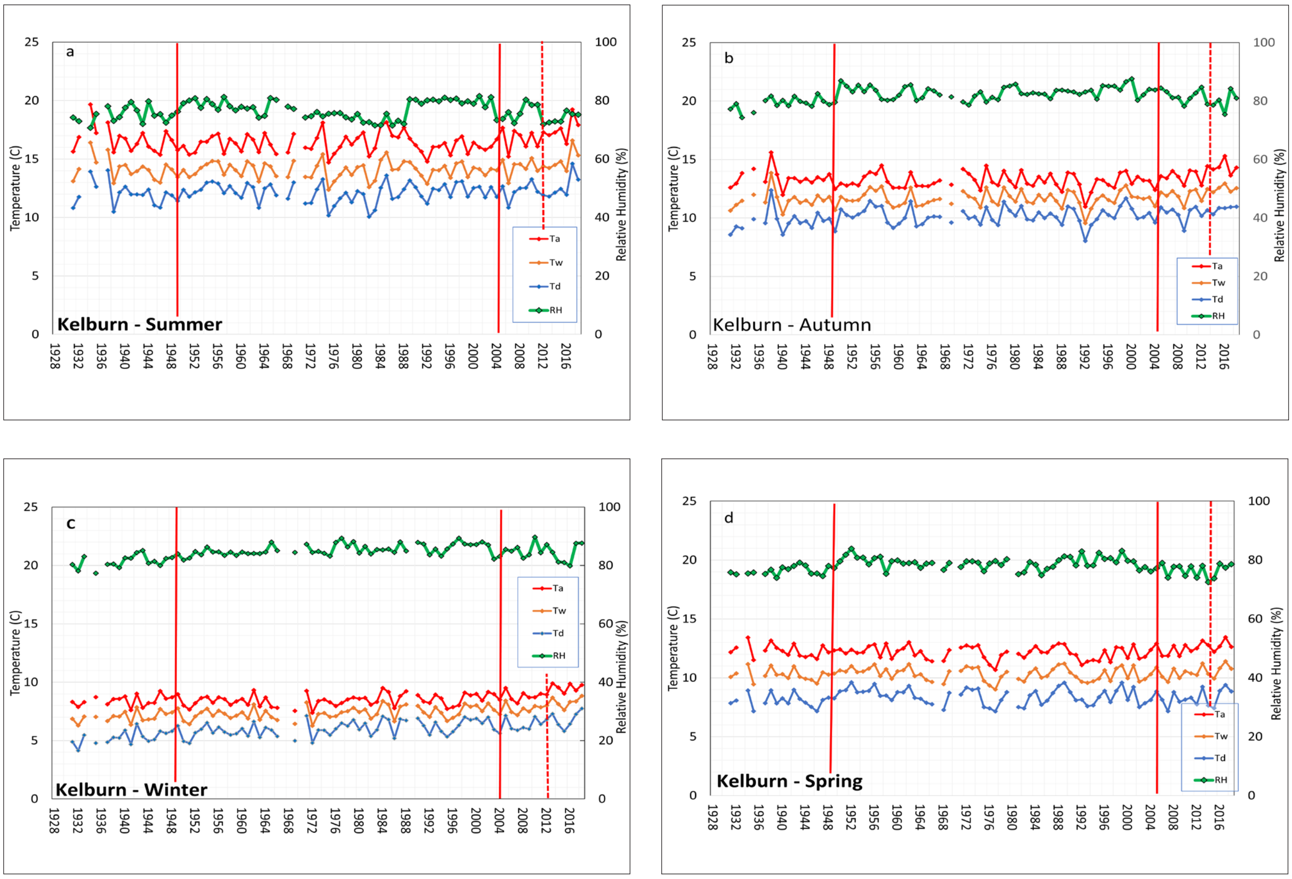

Figure 5: Time series for each season "9am" averages for dry-bulb air temperature (T_a; red-line), wet-bulb air-temperature (T_w; orange line), dewpoint temperature (T_d; blue line) and Relative Humidity (RH; green line) for the Kelburn, Wellington site for the period 1928 to 2020.The red vertical lines mark an exposure change in 1949 and the switch to records from Kelburn (CliDB agent no. 3385) to Kelburn AWS (25354) in 2004. The red-dashed line denotes the break-point as detected with the breakpoint detection algorithm.

the decades 2011-2020[1] and 1932-1940 as expressed in a psychrometric chart as in Figure 6 which shows a general warming/moistening pattern. As an example, to help interpret the plot, we see there were around three to four more days per year in 2011-2020 than 1931-1940 when 9am temperatures were around 18°C and mixing ratios around 10g/kg. Conversely, in the period 2011-2020 there were three to four fewer days where dry-bulb temperatures were around 7 °C and mixing ratios around 6g/kg.

Monthly averages, minimums, and maximum of dry-bulb air temperature (T_a), wet-bulb temperature (T_w), relative humidity (RH) and dewpoint temperature (T_d) for Kelburn are shown in Figure 7. The thick bold lines are running 12 month means of the average, minimum and maximum. Trends in the averages correspond to the overall annual trends in these values and are +0.8°C for T_a, T_w, and T_d and +1.3% for RH over the 90 years. It is gratifying to note, in Figure 7a, the consistency with the NIWA Seven Station Series average monthly temperature series with the dry-bulb temperature series given the simple nature of adjustments made here.

The ten most extreme maximum values of 9am dewpoint temperature and the dates on which these occurred are provided in Table 4 while the values of the extreme minimums and dates are provided in Table 5. The most extreme high 9am dewpoint temperature was 20.3°C on 10 March 1981. Interestingly, only the events of 18 February 1955 and 30 January 1956 occurred in months that had averages ranked in the top-ten. Extreme minimum events occurred in winter, with the record minimum of -6.8°C on 7 June 1944. Again seven of the 10 bottom ranked events occurred in the 1930s and 1940s.

It is noted that this analysis only captures extremes in "9am" dewpoint temperatures and therefore will have missed other significant observations that might have occurred at different times of the day. The maximum dewpoint temperature across the entire record for Kelburn

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[1] The original time-series reconstruction was done in 2020, but the psychrometric analysis was done a year later so included the year 2020.

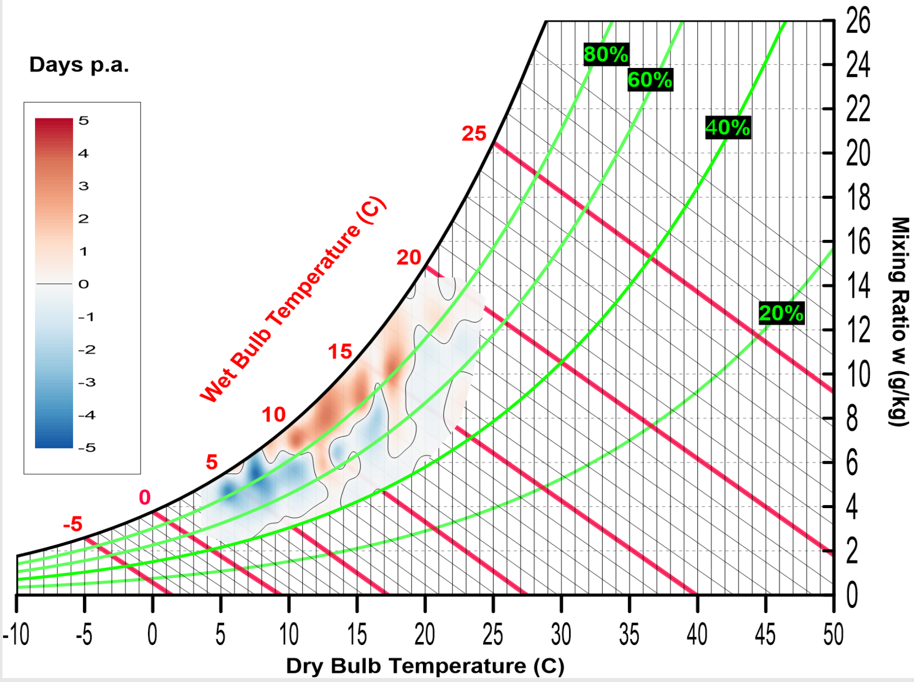

Figure 6: Colour-filled contour plot of difference (days per year) in distribution of 9am dry bulb temperatures-mixing ratio combinations for 2011-2020 versus 1931-1940 for Kelburn.

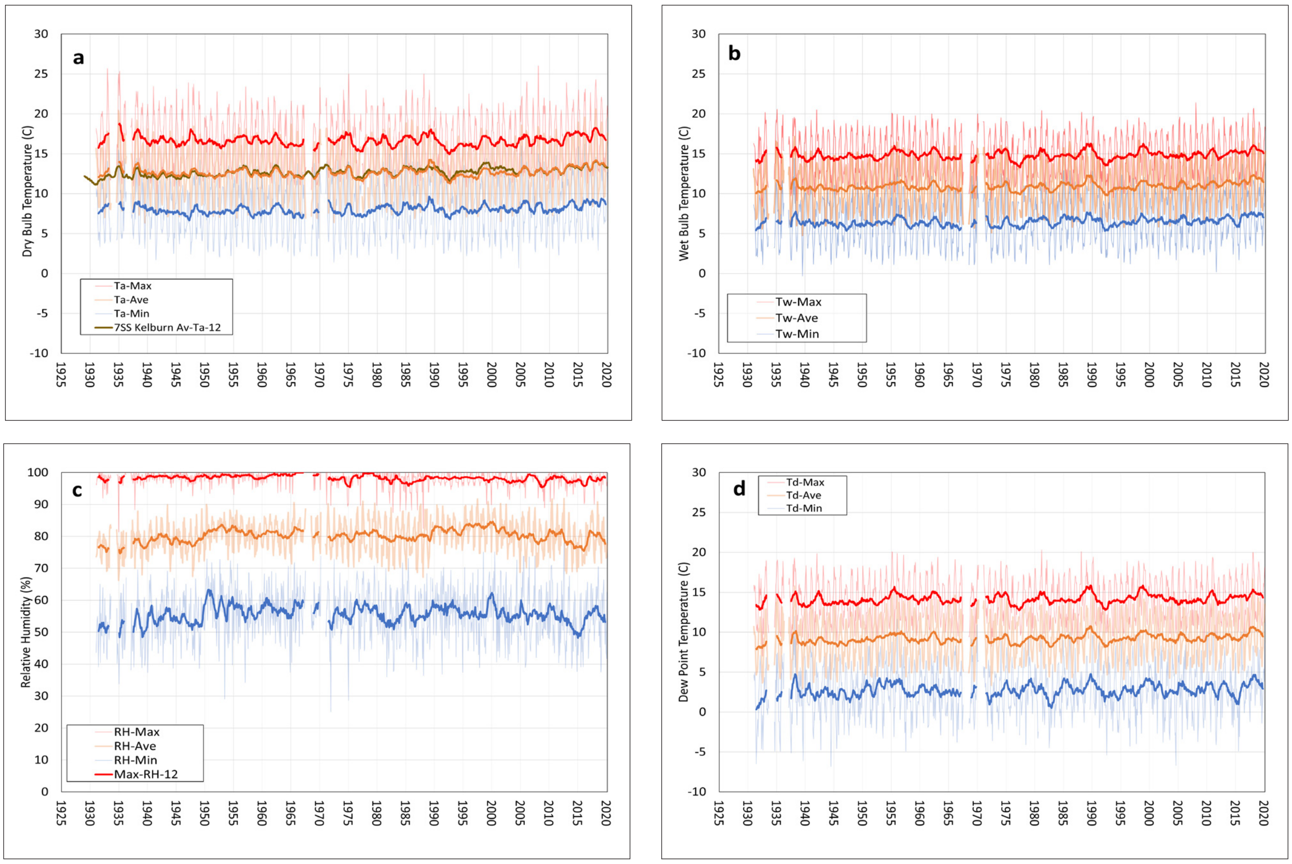

Figure 7: Monthly "9am" average (orange lines), minimum (blue), and maximum (red) time series (thin lines) of a) dry bulb air temperature (T_a) , b) wet-bulb temperature, c) relative humidity, and d) dewpoint temperature for Kelburn, Wellington for the period 1929 to 2019.The thick bold lines are running 12 month means of the average, minimum and maximum. The dark brown line in 7a is the 12-month running mean of Kelburn monthly average temperature as derived for NIWA's Seven Station Series.

Date	Rank	T_a	T_w	RH	T_d	DPP
10/3/1981	1	20.6	20.4	98.1	20.3	0.2
12/2/1988	2	20.4	20.2	98.1	20.1	0.2
18/2/1955	3	20.2	20.1	99.5	20.1	0.1
15/3/1955	4	19.9	19.9	100.0	19.9	0.0
30/1/1956	5	20.1	19.9	98.9	19.9	0.1
30/1/1942	6	21.7	20.5	89.4	19.9	1.2
4/2/1957	7	19.7	19.7	100.0	19.7	0.0
10/2/2022	-	*20.7*	*20.0*	*93.5*	*19.6*	*1.1*
10/3/1990	8	19.6	19.6	100.0	19.6	0.0
14/3/1955	9	20.2	19.8	96.3	19.6	0.4
17/2/1963	10	19.4	19.4	100.0	19.4	0.0

Table 4: Dates of extreme high values (top ten) of “9am” T_d (6th column) in the period 1928 to 2019 at Kelburn. Also listed are the values T_a, T_w, RH and dewpoint depression (DPP = T_a-T_d) on these dates.(Also listed in italics is the one occurrence since the time of analysis and submission that would be top ten).

Date	Rank	T_a	T_w	RH	T_d	DPP
7/6/1944	1	6.1	1.9	39.0	-6.8	12.9
24/8/2004	2	0.7	1.7	40.5	-6.7	7.4
5/6/1931	3	6.4	2.2	39.1	-6.5	12.1
13/8/1939	4	5.9	1.9	41.6	-6.1	12.0
27/7/1992	5	5.7	2.0	44.8	-5.4	11.1
19/7/2015	6	4.8	1.5	48.6	-5.1	9.9
7/7/1937	7	5.1	1.7	47.5	-5.1	10.2
25/8/1935	8	7.2	3.0	41.7	-4.9	12.1
2/9/1934	9	7.8	3.3	40.2	-4.9	12.7
28/7/1957	10	5.8	2.2	46.0	-4.9	10.7

Table 5: Dates of extreme low values (bottom ten) of “9am” T_d (6th column) in the period 1928 to 2019 at Kelburn. Also listed are the values T_a, T_w, RH and dewpoint depression (DPP = T_a-T_d) on these dates.

was 22.0 °C observed at 1800 NZST hours on 11 Feb 2018 (part of the notably hot and wet summer of 2018).

3.2 Wairarapa

Average values for each season (summer, autumn, winter, and spring) for each year from 1928 to 2019 for Masterton of RH, T_a, T_w, and T_d are provided in Figure 8 and changes summarised in Table 6. Potential breakpoints in the time-series due to station changes, and those identified with the breakpoint algorithm, are also indicated in these figures. Visually, there does seem to be a decline in spring and summertime relative humidity post the 1993 breakpoint and could be related to the station shift to East Taratahi. This does not appear related to changes in irrigation as acreage of land irrigation increased in the area after around 2003 (based on inspection of Google Earth aerial imagery). Unfortunately, there are no overlaps of the records when station moves occurred from which to make adjustments, so no attempts at adjustments for this period were made.

As was found for Wellington, it is apparent that the year-to-year variation and longer-term trends in T_a, T_w, and T_d are all very similar. Again, the trend in winter is strongest where there is an increase (linear regression) in 9am dewpoint temperatures of 1.8°C and an increase in winter relative humidity of around 7.2% for the 90-year period. For autumn there is also an increase of around 0.8°C in T_d and around 3.2% in RH, and for spring they are +0.4°C and +1.7% while for summer there is an increase of 0.5°C, and a small increase of 0.2% in RH. The smaller increases in summer RH are likely impacted by recent increases in T_a. It is noted, however, if records prior to 1942 are ignored due to a potential breakpoint related to the station move, the trends in T_d are +0.9°C for winter, +0.2°C for autumn, -0.4°C for summer (decrease), and -0.2°C (decrease) for spring. The trends in RH become +5.8% for winter, +2.0% for autumn, -3.9% (decrease) for summer, and -2.8% (decrease) for spring, and the trends in T_a become -0.02°C for winter, +0.05°C for spring, +0.58°C for summer, and -0.21°C for autumn.

The top-ten and bottom-ten ranked months for average dewpoint temperatures were again tabulated and as was the case for Wellington, January 2018 in Masterton had the highest average T_d values of 16.1°C. Four of the top 10 ranked months for average T_d occurred in the 1950s. Six of the bottom ranked months occurred in the 1930s and all occurred before 1972. Extreme high summer and autumn values of T_d occurred in the 1930s where there seems to be considerable year to year variability during those seasons.

Monthly averages, minimums, and maximum of dry-bulb air temperature (T_a), wet-bulb temperature (T_w), relative humidity (RH) and dewpoint temperature (T_d) for Masterton are shown in Figure 9, Figure 10, and Figure 11. Trends in the averages correspond to the overall annual trends in these values and are +0.2°C for T_a, +0.4°C T_w, and +0.7°C T_d and +3.3% for RH over the 90 years. The consistency with the Seven Station Masterton series in Figure 9a is again noted and gives confidence that the trends and variations in other variables is robust. A notable period, apparent, was the late 1970s where minimum RH (Figure 10) values below 60% were not observed and average RH was above 80%. This could be due to humid summers and autumns at this time although it is noted that this signal is not present in the Wellington record, and it corresponds with a period marked by station changes at the beginning and at the end. Additionally ERA5 reanalyses

	Change between 1928 and 2019			
Season	**T_d (°C)**	**RH (%)**	**T_a (°C)**	**T_w (°C)**
Summer	+0.5	+0.2	+0.5	+0.3
Autumn	+0.8	+3.2	-0.1	+0.3
Winter	+1.8	+7.2	0.0	+0.5
Spring	+0.4	+1.7	-0.2	+0.1

Table 6: Change in average seasonal values in "9am" dewpoint temperature (T_d), Relative Humidity (RH), dry bulb air temperature (T_a) and wet-bulb air-temperature (T_w) for the Masterton, Wairarapa site between 1928 and 2019.
Note: Autumn and winter averages started in 1929.

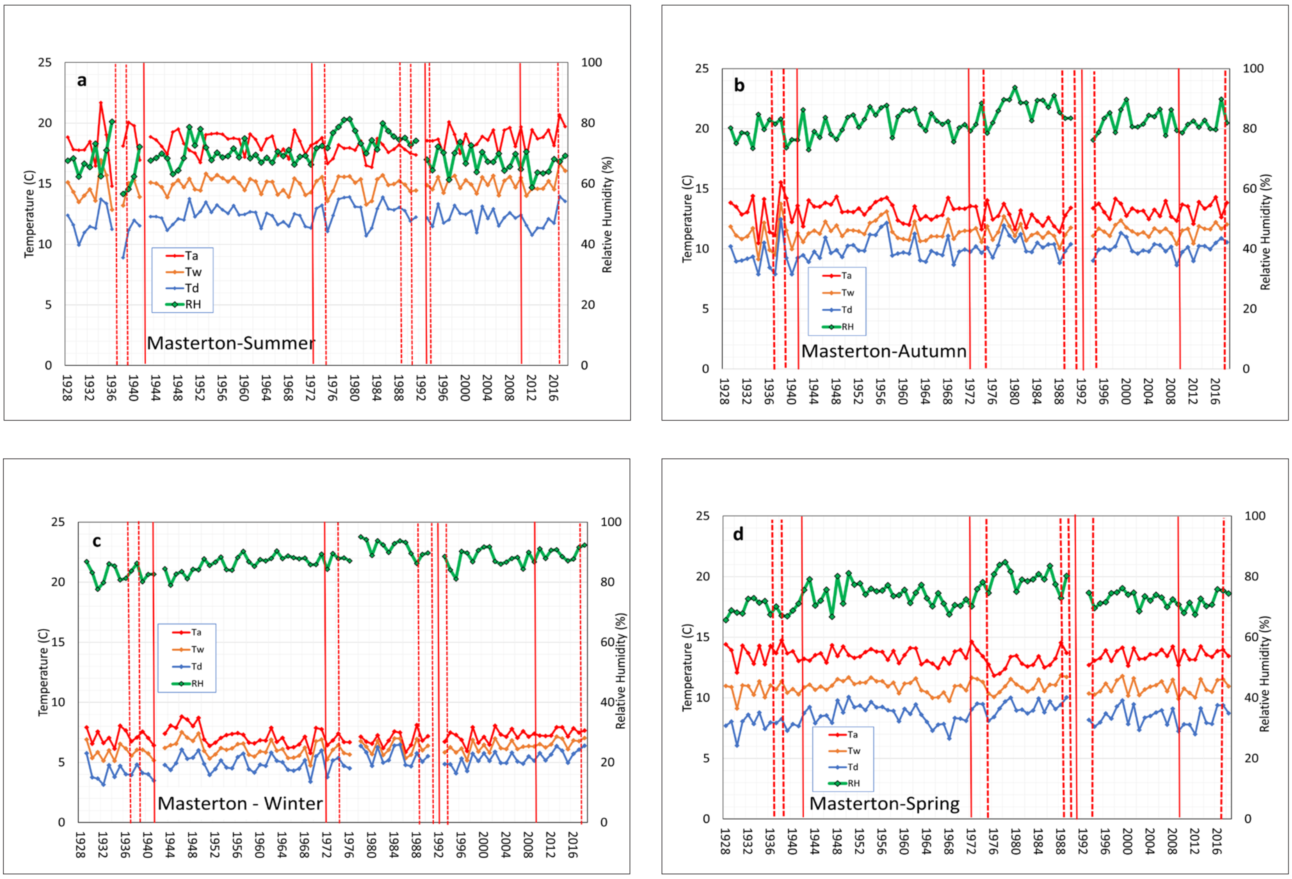

Figure 8: Time series for each season of "9am" averages for dry-bulb air temperature (T_a; red-line), wet-bulb air temperature (T_w; orange line), dewpoint temperature (T_d; blue line) and relative humidity (RH; green line) for the Masterton, Wairarapa site for the period 1928 to 2020.The red vertical lines mark station moves and red-dashed lines mark detected break points and the red line at 1972 marks the switch from earlier records recently digitized from meteorological charts to records retrieved from the national Climate Database (CliDB).

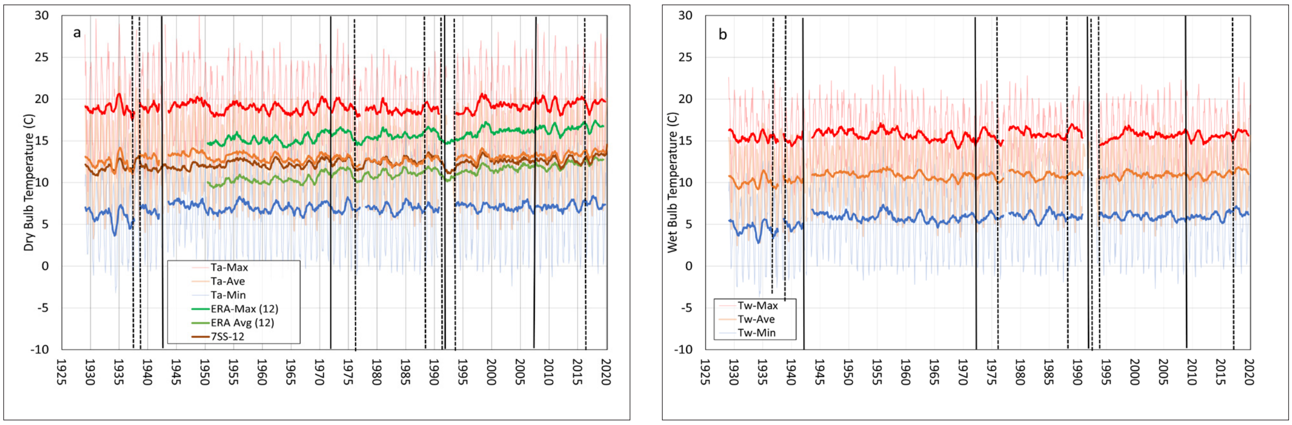

Figure 9: Monthly "9am" average (orange lines), minimum (blue lines), and maximum (red lines) time series (thin lines) of a) dry-bulb air temperature (T_a) and b) wet-bulb temperature for Masterton, Wairarapa for the period 1929 to 2019.The thick bold lines are running 12 month means of the average, minimum and maximum. Green lines are the ERA5 reanalysis for the nearest grid cell which has a higher mean orographic elevation so has a cold temperature bias. The dark brown line is the 12-month running mean of Masterton monthly average temperature as derived for NIWA's Seven-Station Series. Trendlines are represented by the faint dotted lines. Station moves and breakpoint lines are the vertical solid and dashed black lines respectively.

(https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5; accessed October 2020) for the nearest grid point (green lines Figure 10 and Figure 11) indicate nothing anomalous about this period. Further, an extended period of low flow in the Ruamahanga River (as measured at the Waihenga bridge) occurred in the summer of 1978 and periods of high humidity would likely be associated with wet periods, thus we have lower confidence in the observed relative humidity record during this period at Masterton.

The ten most extreme maximum values of 9am dewpoint temperature and the dates on which these occurred are provided in Table 7 while the values of the extreme minimums and dates are provided in Table 8 The most extreme maximum T_d value appears to have been 23.7°C, on 23 January 1958. Extreme minimum events again occurred in winter, with the record minimum of -10.3°C of 3 August 1932. All the 10 bottom ranked events occurred prior to 1945.

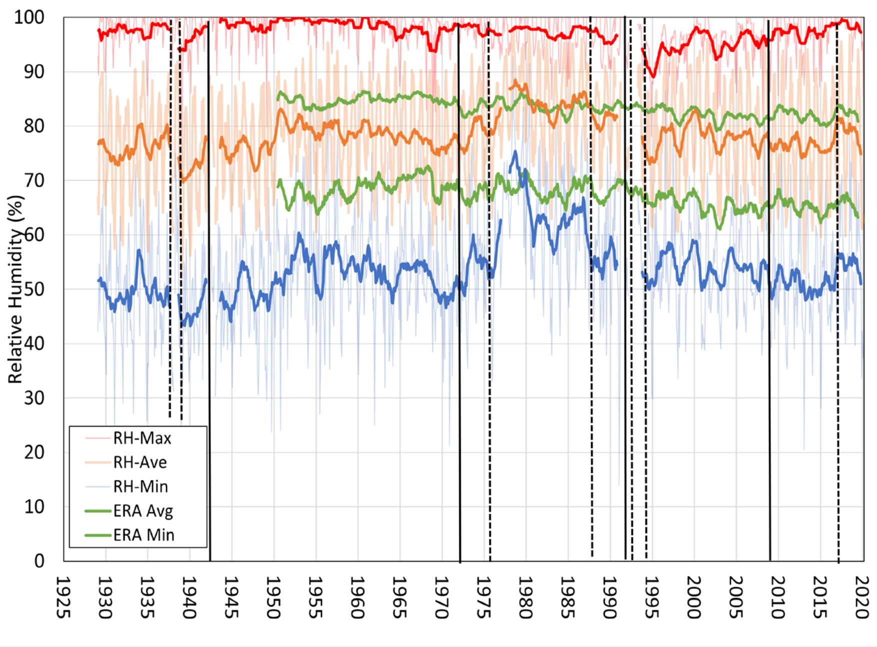

Figure 10: Monthly "9am" average (orange lines), minimum (blue lines), and maximum (red lines) time series (thin lines) of relative humidity (RH) for Masterton, Wairarapa for the period 1929 to 2019. The thick bold lines are running 12 month means of the average, minimum and maximum. Green lines are the ERA5 reanalysis for the nearest grid cell which has a higher mean orographic elevation so has a cold bias – hence the high humidity bias. Station moves and breakpoint lines are the vertical solid and dashed black lines respectively.

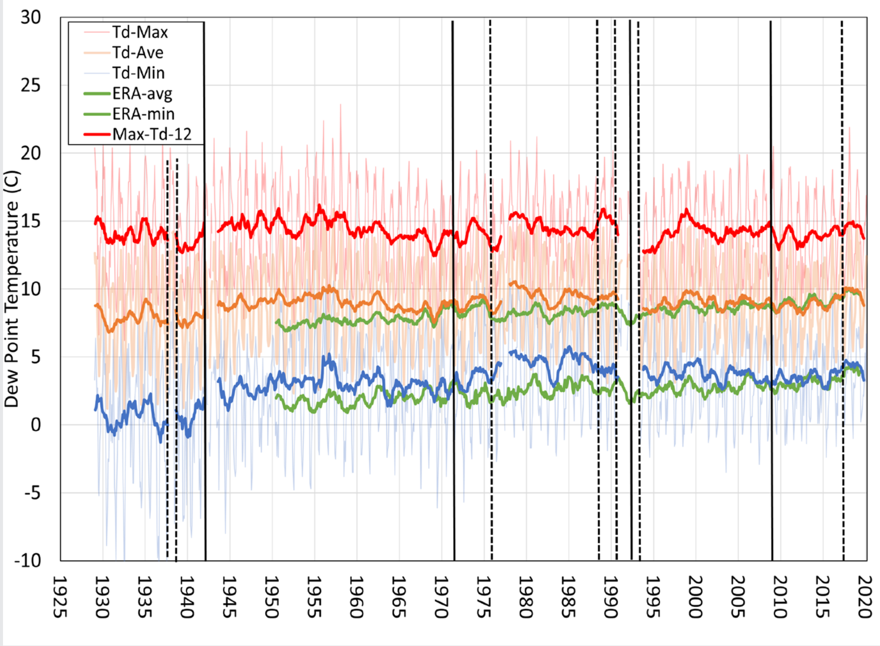

Figure 11: Monthly "9am" average (orange lines), minimum (blue lines), and maximum (red lines) time series (thin lines) of dewpoint temperature (T_d) for Masterton, Wairarapa for the period 1929 to 2019. The thick bold lines are running 12 month means of the average, minimum and maximum. Green lines are the ERA5 reanalysis for the nearest grid point

Date	Rank	T_a	T_w	RH	T_d	DPP
23/01/1958	1	24.4	23.9	95.4	23.7	0.7
27/01/1956	2	24.0	22.9	90.7	22.4	1.6
22/01/1937	3	22.7	22.2	96.1	22.0	0.7
12/02/2018	3	23.9	22.6	89.2	22.0	1.9
17/12/1946	5	23.3	22.2	90.6	21.7	1.6
14/02/1958	6	25.6	22.8	78.3	21.5	4.1
10/03/1981	7	26.0	22.8	75.4	21.3	4.7
7/02/1943	8	21.9	21.1	95.8	21.1	0.8
4/02/1957	8	21.1	21.1	100.0	21.1	0.0
30/01/1956	18	24.6	22.2	80.8	21.1	3.5

Table 7: Dates of extreme high values (top ten) of “9am” T_d (6th column) in the period 1928 to 2019 at Masterton. Also listed are the values T_a, T_w, RH and dewpoint depression (DPP = T_a-T_d) on these dates.

Date	Rank	T_a	T_w	RH	T_d	DPP
22/07/1932	1	4.2	0.0	33.8	-10.3	14.5
8/08/1936	2	5.2	0.5	30.2	-9.6	14.8
24/07/1937	3	5.3	0.7	30.7	-9.3	14.6
21/07/1931	4	2.8	-0.6	43.6	-8.4	11.2
6/06/1936	5	4.2	0.2	37.1	-8.2	12.4
10/07/1937	6	4.2	0.2	37.8	-8.0	12.2
8/06/1944	7	6.1	1.7	36.0	-8.0	14.1
27/06/1930	8	1.8	-1.0	50.4	-7.4	9.2
13/06/1936	9	3.3	0.1	46.7	-7.0	10.3
31/07/1937	10	5.3	1.2	37.7	-7.0	12.3

Table 8: Dates of extreme low (bottom ten) values of “9am” T_d (6th column) in the period 1928 to 2019 at Masterton. Also listed are the values T_a, T_w, RH and dewpoint depression (DPP = T_a-T_d) on these dates.

Finally, we present in Figure 12 the difference between the decades 2011-2020 and 1931-1940 in psychrometric chart for Masterton which shows a generally similar warming/moistening pattern as seen for Kelburn although it is somewhat “messier” than for Kelburn and reflective of the greater number of inhomogeneities at Masterton. This is displayed to demonstrate the kind of differences that could be seen in different decades.

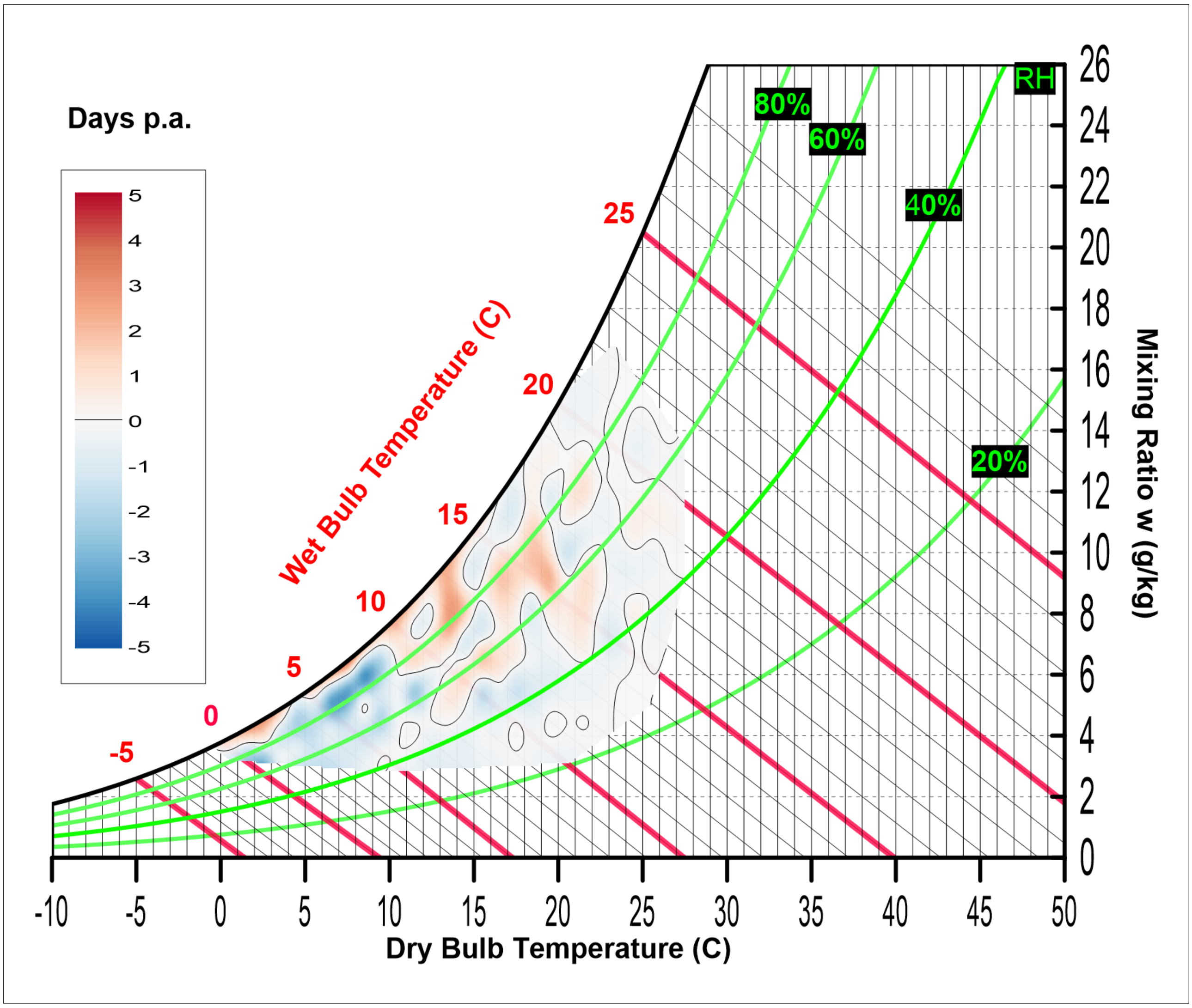

Figure 12: Colour-filled contour plot of difference (days per year)in distribution of 9 am dry bulb temperatures-mixing ratio combinations for 2011-2020 versus 1931-1940 for Masterton.

4. DISCUSSION

This article has presented the results of recent efforts to digitise daily wet- and dry-bulb temperature records for both Kelburn, Wellington and Masterton, Wairarapa sites back to 1929. The digitization of the Masterton and Kelburn records done here is to the author's knowledge the first to be done for New Zealand for dewpoint and wet-bulb temperatures, and RH. A number of breakpoints and station changes were noted for Masterton, while the Kelburn record had few. Only limited adjustments for time-of-observation changes were made and only one-period of station overlap was apparent. Unfortunately, due to the lack of other nearby digitized station records application of sophisticated homogenisation algorithms such as those of Rhodes and Salinger was not possible here. We recognise this as a gap in the work presented here. We recommend that this should be part of future work once other early station humidity records are digitized and become available.

Given the issues with homogenising the data; the trend analysis done here was kept simple and should not be over-interpreted and are presented as indicative. However, comparison with the NIWA Seven Station Series revealed broad consistency for running 12-month monthly average dry-bulb temperatures. Overall, both the Kelburn and Masterton series showed approximately a 0.7°C - 0.8°C increase in dewpoint temperature (T_d) averaged over all seasons with the strongest trend being an increase in winter, amounting to +1.7°C over 90 years at Kelburn, and +1.8°C at Masterton for the same period. Autumn also saw increasing trends at both locations whereas summer and spring saw smaller increases.

Other points of interest were that January 2018 had the highest average T_d values of any month in both the Kelburn and Wairarapa records while February 1998 was ranked third in the Kelburn record. Both 1998 and 2018 are tied for 3rd-warmest years on record for Aotearoa-New Zealand (dry bulb air temperature).

Despite the long-term upward trend, average T_d values for February 1938 and February 1935 were ranked second- and tenth-highest respectively in the Kelburn record. February 1935 is also ranked eighth-highest in the Wairarapa record.

Extreme high summer and autumn values of T_d occurred in the 1930s where there was considerable year to year variability.

Of the ten months with lowest average T_d values, seven occurred in the 1930s and 1940s for Wellington. At Masterton, six were in the 1930s and all ten had occurred by 1972.

Generally, there has been a trend to a warming and moistening for both stations examined and this is consistent with expectations, and other observed records and analyses of dry-bulb temperatures as with NIWA's Seven Station Series and with expectations around climate change such as an increased in days per year with higher temperatures and higher mixing ratios.

Finally, this effort was initially commissioned by the Greater Wellington Regional Council who were seeking to better understand climate trends in the Wellington and Wairarapa regions. It is recommended that the digitization efforts and long-term reconstruction analysis be extended to many more stations throughout Aotearoa New Zealand and include at a minimum all the stations that are part of NIWA's seven and/or eleven station long-term series and also those nearby stations used for the analysis of Mullan (2012) where the Rhoades and Salinger method was applied.

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DATA AVAILABILITY STATEMENT

Climate Data is generally available from the NIWA's Climate Database (https://cliflo.niwa.co.nz). The digitized datasets (9am) can be made available upon request to the corresponding author. Finally, we thank the two anonymous reviewers who provided comprehensive and thoughtful reviews that have improved the original submission,

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