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Apparent trends of mean temperature in New Zealand since 1930

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The evidence of apparent continuous warming over New Zealand since 1940 is examined from both physical and statistical standpoints. It is found that the exposures of most of the thermometers have been affected by changes in shelter, screenage, and/or urbanisation, all of which tend to increase the observed mean temperature. A systematic analysis of all New Zealand climatological stations with sufficient length of record reveals that no important change in annual mean temperature since 1930 has been found at stations where the above factors are negligible. Neighbour station comparisons support these findings.

Keywords Climate; climatic changes; temperature; weather stations; climatology; microclimatology; meteorological instruments; statistical analysis.

INTRODUCTION

Meteorological observations have been made in several New Zealand centres since about the middle of the 19th century. As elsewhere, local site changes and changes in the methods of performing the observations have affected their homogeneity. With the upsurge in recent years of interest in climatic change associated with the extensive monitoring of atmospheric pollutants, etc., the long-period runs of mean temperature have come under scrutiny.

(Herein mean temperature refers to the annual mean of all the daily maxima and minima).

At first sight the ten year moving averages of mean annual temperature appear to have suffered unreversed upward trends over the period 1945–60 in New Zealand as represented by the four major cities (Figs 1 and 2). These have been commented on by Trenberth (1977), as have those for the five and twenty year running means by Salinger and Gunn (1975), and have been mainly attributed by these workers to changes in the general circulation in the vicinity of New Zealand.

In this paper a close examination of the conditions under which the observations were made leads to considerable doubt as to whether the warmings recorded were representative of the surrounding districts, suggesting rather that at most sites they were due to changes in the micro-climates of the enclosures and/or screen interiors.

As a result of this investigation it is found that the widely held view that the mean temperature over New Zealand is presently about 1°C warmer than in 1940 is very probably erroneous. Changes in mean temperature at rural sites averaged over ten-year periods are probably very much smaller than 1°C.

FACTORS AFFECTING TEMPERATURE OBSERVATIONS AT A PRINCIPAL OBSERVATION SITE (AUCKLAND)

The logical records to investigate for temperature trends are those long-period records from the older town and cities (e.g., Fig.2). These urban centres have usually developed around the observation sites, consequently modifying their micro-climates.

Mean temperature observations representing Auckland City commenced at the present site, Albert Park, in 1908. The annual mean temperatures, when subjected to a median runs test (Thom 1966), show a strong trend bias. For the 68 years of observations (1909–76) the mean is 15.29°C, and the median 15.25°C. The number of runs above and below the median is 23; 30 are required for a non-trend probability at the 10% level. Before 1941 the ratio of below to above median years was 2:2, and from 1941–76 was 0.4. Accordingly, a comparison of means tests for the two periods produces a highly significant result, giving the null hypothesis a one-tail acceptance probability of only 0.5%.

It appears then that the continual upward trend of mean temperatures is statistically unacceptable in relationship to their variance, and therefore that the trend is unlikely to be due to a broadscale climatic effect.

Visitors to this central city park today cannot fail to be impressed by the many large exotic trees, most of which were planted about the turn of the century and some of which, more especially those planted later, are still growing. The instrument enclosure is surrounded on all sides by trees and buildings which shelter the site to a great degree. Sheltering was much less in the years preceding 1940. This fact has been

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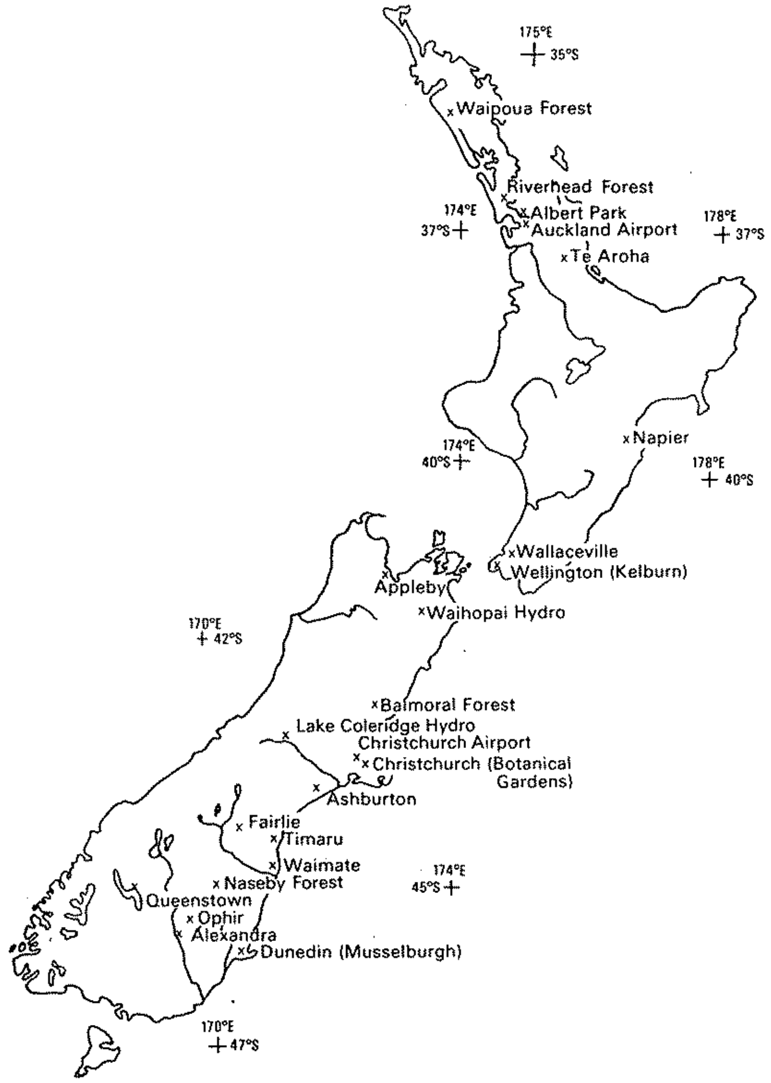


Fig.1 Reference climatological stations.

commented on by Finkelstein (unpublished annotation 1955) who pointed out that in no year since 1930 has the annual wind achieved the mean of those before. The decrease in wind run is a result of site trend, as ten year mean winds at Whenuapai for periods centred on 1946 and 1973 show an increase (respectively 7.3 kt and 7.5 kt) rather than the decrease indicated at Albert Park. Five year moving averages of mean daily wind run at Albert Park are shown in Fig.3. The apparent increase in the period 1950–55 is due to an instrument change in September 1953. Daily wind runs recorded for the separate years 1954–58 inclusive all equalled or exceeded 180 km and were the only years between 1946 and 1970 to do so. Clearly the site, at least up to 1970, was being subjected to increasing sheltering.

Sparks (1972) emphasises the importance of ventilation in obtaining consistent results from screens of the Stevenson type, and points out that Arai (1967) has evaluated errors of up to 1°C for the similar Japanese Standard Screen under differing ventilation conditions. It thus seems highly probable that the temperatures observed at Albert Park have been affected by tree growth and that the principal effect from this source should have been an increase in maximum temperature (Gloyne 1955).

Another major cause of apparent climatic change is urbanisation, which also produces an increase in

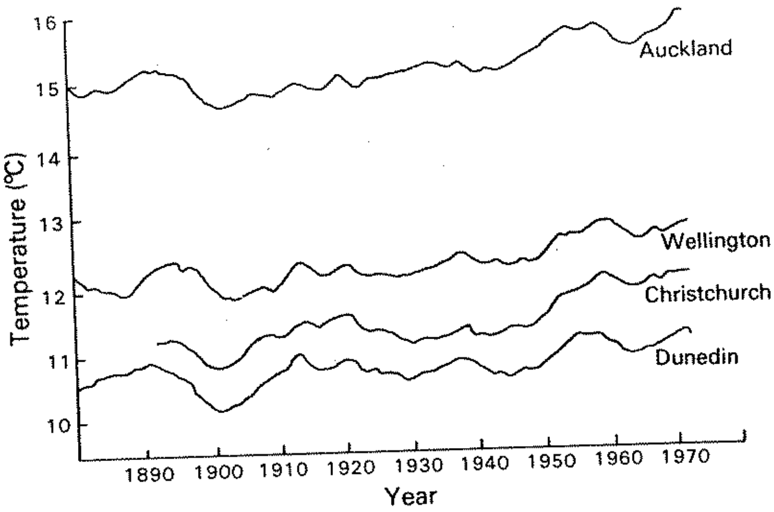


Fig.2 Urban mean temperatures in New Zealand. (Values are centred ten-year averages.)

observed mean temperature by both sheltering and radiation effects. Urbanisation of established cities also needs to be considered when the observation site (as in Auckland) lies in the central city area. An increase in the population of the "urban area" is reflected by the development of high-rise buildings in the city centre which shelter and warm the site. The urban area population of Auckland increased by 60% between 1936 and 1966, this percentage giving an index of urbanisation there. Quantitative assessments of sheltering and of urban "heat island" effects cannot be satisfactorily resolved unless either or both can be shown to be negligible.

The Albert Park data have been treated as comprising two separate periods, 1910–40 and 1941–67, which are compared in Table 1. The indications are that sheltering and urbanisation have contributed to the apparent temperature increase.

Perusal of the Albert Park files revealed that the screen was changed in September 1950. The previous screen was "... *not* a standard screen. It was locally made and in a bad state of repair and should be re-

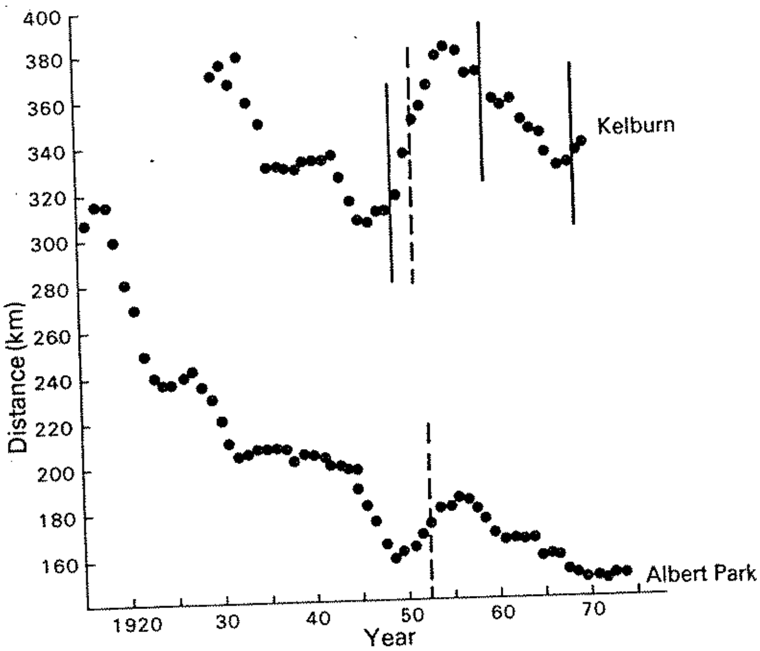


Fig.3 Five-year centred running averages of mean daily wind run at Wellington (Kelburn) and Auckland (Albert Park). Solid lines indicate shelter removal; hatched lines indicate anemometer replacement.

Table 1 Albert Park daily temperature means.

	(a) 1910–40	s.d.	(b) 1941–76	s.d.	(b) − (a)
Minimum (°C)	11.73	0.60	12.07	0.44	0.34
Maximum	18.24	0.47	19.00	0.61	0.76
Mean	14.99	0.51	15.54	0.50	0.55
Mean daily range	6.51		6.93		0.42

placed by a standard Stevenson ...". There is strong evidence that the screen change has also contributed to the trend in the observations. Table 2 compares mean maximum and minimum temperatures for five year periods each side of the year of the change-over. It was necessary to confine the data to short periods to largely eliminate any longer term trends.

The effect of the overheating of Stevenson type screens in bright sunshine under sheltered conditions (determined by Arai—quoted by Sparks) is indicated by the change in maximum temperatures. Overall these increases are rather large, and because of the shortness of the periods, they may include a short period synoptic scale secular increase, though the apparent change in the daily temperature range indicates that the screen change is an important contributor to the increase of mean temperature, probably accounting for about 0.4°C of the 0.5°C found.

The three considerations of sheltering, screen change, and urbanisation all tend to increase reported maximum temperatures. Urbanisation has been shown elsewhere (e.g., Chandler 1967) to increase minimum temperatures, more especially in summer. Although some workers report decreasing winter minima as a result of urbanisation (Lawrence 1969), the effect on annually averaged minimum temperatures is always a net increase. In the case of Auckland City the decrease in minimum temperatures due to sheltering (wind reduction) appears to have been masked by the urbanisation (building heat emittance) effect.

Table 2 Averaged temperatures before and after the screen change at Albert Park.

	(a) 1945–49	s.d.	(b) 1951–55	s.d.	(b) − (a)
Minimum (°C)	11.90	0.34	12.02	0.45	0.12
Maximum	18.30	0.42	19.18	0.31	0.88
Mean	15.10	0.38	15.60	0.37	0.50
Daily range	6.40		7.16		0.76

(a) Observations from a non-standard single-louvred screen;
(b) Observations from a double-louvred "small thermometer" screen (Meteorological Office 1956).

SITE ASSESSMENTS AT OTHER N.Z. CLIMATOLOGICAL STATIONS

The factors which have affected the reported temperatures at Auckland are common to many sites in New Zealand at which climatological observations have been made. It is not possible here to deal with all the relevant aspects of each site, but the parallels can be seen for example at another important site, Christchurch Botanical Gardens.

The screen at Christchurch was changed in May 1952, a comparison test run with the previous screen over a period of two years (and indicating an apparent increase in mean temperature of 0.74°C) being partly invalidated by a subsequent site change of 50m. Tree growth at the site, the Botanical Gardens, was similar to that at Albert Park, and population increase (used as an urbanisation index) was 85% over the same period.

These effects are to be found, though less easily demonstrable, at a third major city site, Kelburn in Wellington. This site lies in the Botanical Gardens near the crest of a hill and has a high mean wind speed of about 12kt. Although shelter is periodically removed from the immediate surroundings of the enclosure, tree growth in the Gardens generally appears to be providing more shelter to the site. The sheltering has also affected the rainfall observations at Kelburn as compared with Karori Reservoir (Hessell 1980). The downward trends in mean daily wind run can be seen in Fig.3, if allowance is made for the discontinuities apparent due to the removal of adjacent growth and instrument change. The screen was changed to a large thermometer screen in 1948. The differences between large and small double louvred screens are usually negligible but may not be so where, as here, wind is of major importance. The urbanisation effect is thought to be small as most of the buildings in the area were established before 1930, and the city "urban area" population increased only by 11% between 1936 and 1966. This generally windy site suffered a change in smoothed mean temperature between 1945 and 1970 of about one-half that at Auckland and Christchurch.

Many New Zealand climatological stations were established about 1930, there being only a few with unchanged sites and unbroken records before that date. Those considered unworthy of investigation due to periods of unsatisfactory records between 1930 and 1970 were Te Paki, New Plymouth, Waihi, Hastings, Karioi, Hiwi, Palmerston North, Golden Downs, Hokitika, Dunedin, Manorburn, and East Gore. Many of the remaining stations are New Zealand Forest Service stations and were established adjacent to, or amongst newly planted exotic forests. Others are sited in the central areas of smaller but growing towns. Only a few are unaffected by tree growth, screen changes of various sorts, or urban

Table 3 Classification of all New Zealand Stations with continuous records for the approximate period 1930–70.

Station	Tree growth[a]	Screen change[b]	Urban-isation[c] Index	Dividing year[d]	ΔT_{min}	ΔT_{max}	$\Delta \overline{T}$	Station class[e]
Waipoua Forest	*	(1)		51	0.58	0.45	0.51	A
Riverhead Forest	*	(i)		51	0.96	0.69	0.82	A
Auckland Albert Park	*	(i)	65	50	0.19	0.84	0.52	A
Te Aroha		((i))	36	55	0.56	−0.46	0.05	B
Napier	*	(i)	133	51	0.40	0.63	0.52	A
Wellington Kelburn		(iii)	11	48	0.56	0.31	0.43	A
Appleby		(iii)		60	0.16	0.09	0.13	B
Waihopai				51	0.11	0.08	0.10	B
Balmoral Forest	*	(i)		51	−0.54	0.61	0.08	A
Lake Coleridge				51	0.00	−0.10	−0.05	B
Christchurch Gardens	*	(ii)	85	53	0.27	1.20	0.74	A
Ashburton	*	((i))	123	51	0.22	0.47	0.34	A
Fairlie			2	51	0.23	0.19	0.21	B
Timaru	*	(i)	57	51	0.36	0.70	0.53	A
Waimate			43	53	0.27	0.63	0.45	A
Naseby Forest	*			51	−0.05	0.12	0.03	A
Queenstown		(i)	85	51	0.17	0.37	0.27	A
Ophir				51	−0.44	0.50	0.03	B
Alexandra		(iv)	248	51	0.20	0.59	0.39	A

(a) Stations where (since 1930) extensive tree growth within 100 m or forest growth within 100 m or forest growth within 500 m occupying at least a 90° sector, has occurred are indicated by an asterisk.
(b) Screen changes of varying types occurred during the whole period. (i) Non- or sub-standard screen to small thermometer screen or; (ii) to a large thermometer screen; (iii) small to large thermometer screen; (iv) substandard to nonstandard screen; ((i)) monitored site change for which the previous records have been adjusted.
(c) Urbanisation index is the percentage increase of population from 1936 to 1966 within borough or city "urban areas" (as defined by the N.Z. Department of Statistics).
(d) Year in which a division was made to give two comparison periods; generally 1951 but otherwise coincidental with screen changes.
(e) "A" stations have been assessed to have increased sheltering from trees during the second period and/or significant urbanisation and/or screen changes. "B" stations are those not known to be significantly affected in any of these ways.

growth. The classification of all remaining stations with valid records since 1930 is shown in Table 3.

Only stations which have had no major site changes have been included, but most stations have had minor site changes (generally less than 100 m horizontally for urban sites or 500 m for truly rural sites and in both cases less than 30 m vertically). The figures for Te Aroha and Ashburton have been adjusted for site and contemporaneous screen changes by amounts dictated by overlap comparisons between the two exposures, Te Aroha 0.16°C and Ashburton

Table 4 Averaged temperature differences in two periods for the categories of Table 3.

	"A" Stations	s.d.	"B" Stations	s.d.
$\overline{\Delta T_{min}}$	0.28	0.35	0.10	0.33
$\overline{\Delta T_{max}}$	0.59	0.26	0.05	0.32
$\overline{\Delta \overline{T}}$	0.43	0.22	0.09	0.08

$\bar{\Delta} T_{min}$ = the average difference in mean minimum temperatures for the two periods considered in Table 3, etc. s.d. derived directly from Table 3.

Table 5 Neighbour station temperature comparisons: 0.1°C departures from base differences* (1940–60).

	Riverhead Forest – Albert Park			Wallaceville – Kelburn			Lake Coleridge – Christchurch		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
1940	1	−2	−1	1	−4	−2	−1	7	3
41	4	−2	1	3	−4	0	−2	7	3
42	3	−4	−1	6	−3	2	0	4	3
43	*0*	*−1*	*−1*[a]	−2	−2	−2	−2	5	2
44	1	4	2	3	−1	1	−1	0	0
45	1	2	2	7	−2	2	0	−4	−2
46	3	1	2	2	−3	−1	3	−4	0
47	−3	3	−1	*3*	*−1*	*1*[c]	0	5	3
48	−3	3	0	6	0	3	−3	0	−1
49	−2	3	1	6	3	4	2	−4	−1
1950	−7	2	−2[b]	4	5	5	0	2	1
51	2	−3	−1	5	5	5	−2	−1	−1
52	6	−3	2	7	7	8	*−2*	*−3*	*−2*[e]
53	6	−2	2	10	7	8	3	−6	−1
54	4	−1	2	*4*	*6*	*6*[d]	4	−8	−2
55	2	2	2	0	−1	−1	0	−5	−2
56	6	−2	3	−1	−2	−1	2	−7	−2
57	2	−1	0	−2	−3	−2	−1	−12	−4
58	6	1	3	−3	−2	−2	−1	−10	−3
59	5	1	3	−4	−3	−3	−1	−2	−1
1960	5	−2	2	−4	−2	−2	−3	−4	−4
s.d.	3.6	2.2	1.6	4.0	3.8	3.4	2.6	6.7	3.2
Base* difference	−39	−1	−20	−22	12	−5	−20	−4	−12

* Base differences are approximate averaged temperature differences (1940–60). The figures in the table are the departures (unit 0.1°C) from these bases. Means are assessed from original data.
(a) Riverhead Forest screen changed February 1944
(b) Albert Park screen changed September 1950.
(c) Wallaceville site change, and Kelburn change to large screen, June 1948.
(d) Wallaceville site and screen change September 1954.
(e) Christchurch screen change May 1952.

0.58°C for mean temperature. It is possible that some screen changes occurred which have not been satisfactorily documented. The figures for Table 3 were obtained in a similar manner to those of Table 2(*b*)–(*a*). Table 4 summarises the figures of Table 3.

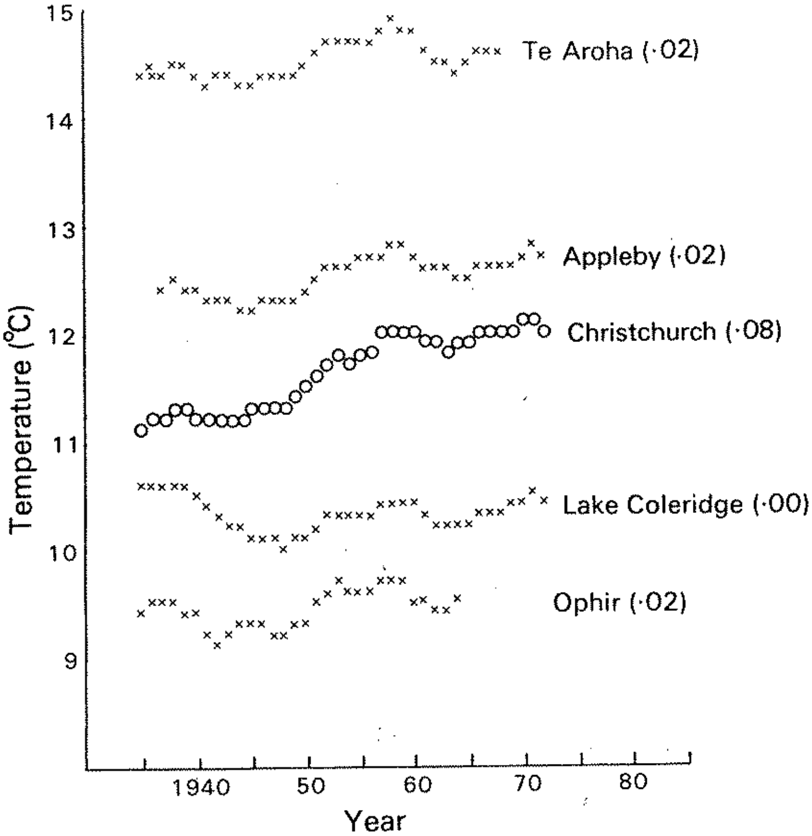
It can be seen immediately that the average increase in mean temperatures at the "A class" stations is about five times that of the "B class". It appears that the class separation has not been entirely successful. For example the minimum temperature behaviour at the northern forests, Waipoua and Riverhead, is the opposite of that at the drier southern forests, Balmoral and Naseby, where nocturnal temperature inversions seem more common. Cold air ponding in sheltered localities is a well-known phenomenon and is mentioned by Gloyne (1955) and other workers. The contrast between the two classes is more marked if maximum rather than mean temperatures are compared.

A comparison of means test on the mean temperature differences of the "A" and "B" class stations gives a highly significant result with Student's t value of 8.5, the null hypothesis being rejected for a 95% confidence level at $t = 2.1$.

NEIGHBOUR STATION TEMPERATURE COMPARISONS

An accepted technique for detecting temperature trends and discontinuities in station records is to compare the successive differences between neighbouring stations. This has been done in Table 5 for the major stations over the chief period of interest,

Fig.4 Rural mean temperatures compared with Christchurch (ten-year averages). (The numbers are linear regression slope coefficients 1935–65.)



1940–60, during which the largest trends are seen in the moving averages.

The main discontinuities in minimum, maximum, and/or mean temperatures are commented on at the foot of Table 5. The warming trend of mean temperature at Christchurch compared with Lake Coleridge is obvious and is due mainly to the change in maximum temperatures at Christchurch (Table 3). No similar effect is seen in the Riverhead – Albert Park comparison due both to discontinuities at each station and the quasi-parallel trends at both. Unfortunately no really suitable station exists for comparison with Kelburn, and the main discontinuity of interest at Kelburn coincided with a site change at Wallaceville.

TEMPERATURE TRENDS AT CLASS B STATIONS

The importance of site and/or screenage effects on the records has been found for the two classes ("A" and "B") of stations in Table 3.

Centred ten year moving averages of mean temperature for four "B" stations are shown in Fig.4, with those for Christchurch (Botanical Gardens). The difference in trend at Christchurch is clear. Least squares linear regression slope coefficients computed for these ten year means for the period 1940–64, giving an indication of temperature trend, are: Te Aroha, Appleby, and Ophir, 0.02; Lake Coleridge 0.0; and Christchurch 0.08.

It appears that during this period there was a slight secular warming over the country as a whole, but the rate of warming is less if the period is extended to 1936–38 for the longer record stations of Te Aroha and Coleridge whose respective slope coefficients are then 0.01 and −0.01.

RURAL/URBAN MEAN TEMPERATURE COMPARISONS

A further indication of the extent to which urbanisation affects mean temperature readings can be gained by comparing readings made within a built-up area with those made in adjacent rural sites. As will be seen from Table 6 many of these latter are airports which are necessarily unenclosed to any great extent.

In none of the comparisons is the rural site warmer

Table 6 Rural/urban annual mean temperature comparisons.

Rural site	Urban site	$\Delta\overline{T}$	s.d.	n	D(km)
Auckland Airport	Albert Park	−0.6	0.2	12	10
Tauranga Airport	Tauranga	−0.5	0.1	5	2
Rotorua Airport	Whakarewarewa	0.0	0.1	11	5
Palmerston North Airport	Palmerston North DSIR	−0.5	0.1	12	5
Paraparaumu Airport	Paraparaumu	−0.5	0.1	2	1
Blenheim Airport	Blenheim	−0.4	0.2	11	2
Christchurch Airport	Christchurch	−0.4	0.1	21	10
Darfield	Christchurch	−0.6	0.2	26	30
Ikawai	Waimate	−1.1	0.1	4	15

$\Delta\overline{T}$, mean of the differences in annual mean temperature, rural site minus urban site;
s.d., standard deviation of the differences;
n, number of years of data;
D, aproximate separation of the stations.

than the urban, the latter usually being significantly warmer. It is thus considered that urbanisation is a significant factor in influencing the temperature regime of a district, and that this is an important contributor to temperature trends in growing built-up areas (Kopec 1970).

CONCLUSION

For the purpose of assessing climatic change, a "rural" environment needs to be carefully defined. Climatic temperature trends can only be assessed from rural sites which have suffered no major transformations due to changes in shelter or urbanisation or from sites for which the records have been made homogeneous. Urban environments usually suffer continual modifications due to one cause or another as previously discussed.

Waimate, for example, has been cited as a rural site when the screen is now almost entirely surrounded by buildings within 50–100 m, some of them erected since 1930. The narrow grass enclosure is adjacent to a broad road–footpath system which, due to the increased sheltering of the buildings, must heat the environment considerably, to say nothing of the heating effects due to the buildings themselves. The urbanisation of the borough since 1930 can also be assessed by the population increase (from 2300 in 1936 to 3300 in 1966). For these reasons, centres such as Waimate should not be considered "rural". Rural sites could perhaps be defined as having less than 2% in floor space of any 5 ha area within 5 km of the observation site, though even definitions such as this may not be appropriate for some localities.

The stations comprising class "B" have in some cases suffered minor site changes, which were not generally directly compared by means of overlap periods. These site changes were judged to be insignificant for truly rural areas except when the distance exceeded about 500 m horizontally or 30 m vertically, in which cases the stations were rejected. There are no sites at all which have been unaffected since 1930 by site changes of less than 10 m, increased sheltering, urbanisation, or screen changes. This being so, the arguments against mean temperature increase over the period 1930–70 must be assessed on the weight of the evidence presented. This is of two types: explanations of how the apparent increases at "A class" stations probably occurred, and evidence that the "B class" stations which have suffered no significant change in thermometer exposure have shown no overall warming trend.

There no doubt exist other factors not dealt with here which affect the recorded temperatures; for example, the inclusion of autographic instruments in the large screens. These instruments have a temperature lag of their own which on occasions could significantly affect the recorded maxima or minima. They may also affect ventilation, particularly in windy areas.

It is probable that the retreat of glaciers often cited as evidence for recent warming is a result of a return to a longer period norm after the "abnormally" cold period from about 1890 to 1910 (Fig.2), during which large quantities of ice could have been accumulated at the glacier heads. This, however, is a complex question greatly in need of further research.

The apportioning of stations into two categories "A" and "B" (Table 3) is to some extent subjective. One critic has questioned the validity of breaking the observations at differing points defined by site changes. He has also pointed out invalidating site changes at Fairlie and Balmoral not previously allowed for and thought that Naseby Forest should be a "B" station rather than an "A". Complying with these criteria makes no effective difference to the analysis of Table 4, increasing rather than decreasing the contrast between the two categories ($\overline{T}$ "A" changes from 0.43 to 0.50, and $\overline{T}$ "B" remains at 0.09).

It should be appreciated that long records taken from sites which have undergone changes in exposure, or even from different adjacent sites remain of great value. It is emphasised that by reasoning on statistical and/or physical bases such long period records can often be rendered satisfactorily homogeneous, but that until this is done they cannot be used to infer climatic trends. Climatological observations are used for a wide range of purposes. Even where the records are unsuitable for studies of climatic change they may be useful for various applied meteorological research activities.

It is concluded that the warming trends in New Zealand previously claimed, are in doubt and that as has been found in Australia (Tucker 1975) no clear evidence for long term secular warming or cooling in Australasia over the last 50 years exists as yet.

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