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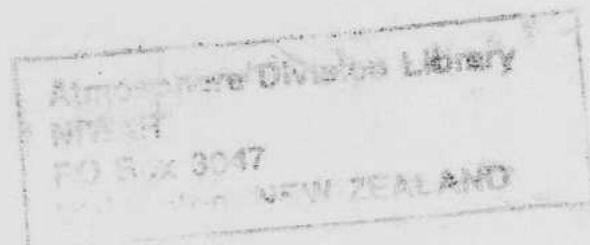
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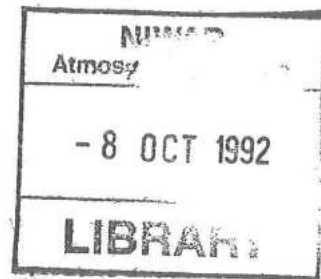
## **SOUTH PACIFIC HISTORICAL CLIMATE NETWORK**

### **TEMPERATURE TRENDS IN NEW ZEALAND AND OUTLYING ISLANDS, 1920 - 1990**

**Jim Salinger, Ron McGann, Lesley Coutts,  
Bronwen Collen, and Elaine Fouhy**



**New Zealand  
Meteorological  
Service** *Te Ratonga Tiorangi*



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**South Pacific Historical Climate Network.  
Temperature trends in New Zealand and outlying  
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**New Zealand Meteorological Service**

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## SUMMARY

The annual temperature series for 21 selected reference climate stations in the North and South Islands of New Zealand and three outlying islands, have been homogenised for the period 1920-1990. The annual and seasonal temperature anomalies are compared with the 1951-80 reference period (used by the Intergovernmental Panel on Climate Change (IPCC)) and plotted. A Gaussian filter is used to remove short term fluctuations in order to detect any long term trends. The resulting smoothed curves are discussed with respect to longer term fluctuations and trends. All stations show a cooler than normal period prior to the mid-1940s, followed by a steady temperature increase into the 1950s. At almost all stations the 1981-1990 decade was the warmest on record. Increases occurred in both maximum and minimum temperature, in contrast to warming only detected in minimum temperatures of Northern Hemisphere land station records.

Geographically, annual mean temperatures between 1941-1950 and 1981-1990 increased by 0.3°C at Raoul Island. North Island mean temperatures increased by 0.8°C, which was uniform between west and east. In the South Island, the mean temperature increase was 0.7°C, ranging from 0.8°C in the west and south, to 0.5°C in inland areas. The east warmed by 0.7°C. Mean temperatures increased by 0.8°C at Chatham Island and 0.3°C at Campbell Island respectively.

All seasons display increases in mean temperature between 1941-1950 and 1981-1990, although of varying magnitude depending on location. The seasons show a cool period prior to the mid-1940s, followed by a steady increase in temperature, although their individual behaviour is different. Summer had the largest below normal departures and this occurred in the 1940s. Seasonal temperatures increased into the 1950s and again in the 1980s. Apart from autumn, the 1980s recorded the highest seasonal temperatures on record.

It is strongly recommended that observations continue at the reference sites so that temperature trends and variations at stations with records that have been carefully homogenised can be monitored to detect climate change and variability.

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## INTRODUCTION

The work described in this report is part of a larger project which involves refining the historical climate record of the South Pacific. The refined climate records can then be used for further studies of climate trends and variability, validation of general circulation models and the study of possible socio-economic impacts of climate in the region.

This report is the first of two which describe the annual and seasonal temperature and rainfall trends, over the period 1920-1990, in New Zealand and its outlying islands. The second report is *Rainfall trends in New Zealand and outlying islands 1920-1990* (Salinger et al, 1992).

Temperature behaviour of the reference stations over the period 1920-1990 is described. The interpretation of the temperature patterns will be the subject of a separate report.

The methods used to produce homogeneous mean annual and seasonal temperature series for a number of reference climate stations in the North and South Islands of New Zealand and also for Raoul Island (part of the Kermadec group), Chatham Island and Campbell Island, are described. Further details on the homogenising methods are given in Rhoades and Salinger (1992). In addition, the homogenised temperature series are discussed for a number of reference climate stations throughout the country.

## REFERENCE CLIMATE STATIONS

Reference climate stations are those whose data are intended for the purpose of determining climatic trends and variability. This requires periods of not less than 30 years of homogeneous records, during which site and exposure changes should be minimal.

The reference climate stations were chosen on the basis of their ability to satisfy the following conditions as specified by the World Meteorological Organisation (WMO, 1986):

- i Be permanent.
- ii Be preferably located in an environment unaffected by densely populated or industrialised areas.
- iii Have trained observers, reliable instruments and be subject to regular inspections and technical servicing.
- iv Have long records, spanning as many years as possible.
- v Have few significant relocations, changes of observing times, instruments and exposure or observing techniques.
- vi Be subject to careful data quality control.
- vii Measure a minimum set of climatic elements such as maximum and minimum temperature and precipitation.

### Selection of reference climate stations

Using the above criteria, 22 climate stations were selected in the North and South Islands and three stations on islands in the New Zealand economic zone (Table 1). At least one reference station was located in each of the main climate regions of New Zealand. The reference stations were usually the current stations, but climate records from earlier stations in the immediate vicinity were also included in the reference station record after homogenisation. Detailed information on the reference climate stations is given in Fouhy et al (1992). Queenstown, in the South Island, was also selected as a reference climate station, but its temperature records have not been homogenised so its data have not been included.



Figure 1 Locations of the reference climate stations

Table 1: Reference climate stations

North Island		South Island		Offshore Islands
Kaitaia	Paraparaumu	Hokitika	Lauder	Raoul
Auckland	Wellington	Milford Sound	Timaru	Chatham
Hamilton	Gisborne	Appleby	Dunedin	Campbell
Rotorua	Whakatu	Blenheim	Invercargill	
New Plymouth	East Taratahi	Lincoln		
Taihape		Omarama		

The locations of these reference climate stations are shown in figure 1.

## HOMOGENISATION PROCEDURES

Conrad (1944) defines homogeneity of a climatological series as follows:

*A numerical series representing the variations of a climatological element is called 'homogeneous' if the variations are caused by and only by variations of weather and climate.*

The purpose of the homogenisation process was to produce as long a temperature series as possible for each reference climate station. This was done by adjusting data from *earlier sites* to the *current site*. Any valid data from earlier neighbouring stations were also included and adjusted to the reference station site. Thus the temperature series for a given climate station could be derived from data from several earlier sites and adjacent stations.

The detailed homogenisation procedure for the time series for each reference climate station is described in Rhoades and Salinger (1992).

The main steps in the homogenisation process were:

- i Conduct a systematic search for all climate data for a given climate station and nearby climate stations. These data were needed for comparison and adjustment purposes.
- ii Check the mean monthly data for obvious errors. Any missing data in the series were estimated, where possible, using data from neighbouring stations.
- iii Check irregularities in the climate data time series for possible site changes, or substantial environmental changes, or for other reasons noted in the climate stations histories (Fouhy et al, 1992). The temperature anomaly was calculated from the difference of the homogenised seasonal or annual temperature and the 1951-1980 reference values. This is in accordance with the practice followed by the IPCC (Houghton et al, 1990).
- iv Run the homogenisation computer programs (Rhoades and Salinger, 1992) using mean monthly data from the station under test and other neighbouring climate stations with good quality records (and no site changes during the comparison period). Obtain corrections to the temperature series for the station under test. It should be noted that the homogenisation procedure uses comparison periods of monthly data  $\pm 2$  or  $\pm 4$  years before and after a suspected (or actual) site change, or discontinuity in the temperature series and statistically tested for significant changes. Comparisons were also made using annual values for the entire overlapping period of record with a neighbour station (Salinger, 1981).



## TIME SERIES ANALYSIS

Anomalies of annual and seasonal values of mean, maximum, minimum and seasonal temperatures were calculated for each station and compared with the reference period taken as 1951-1980 (as used by the Intergovernmental Panel on Climate Change (IPCC, 1990)).

The anomalies were smoothed using a Gaussian filter (Jones et al, 1986). This filter suppresses periods of less than 13 years, in order to facilitate the detection of longer term trends. The filter gives more weight to the central rather than the end values of the period being smoothed. Graphs of both the annual anomalies and smoothed values of the annual and seasonal rainfall are presented and examined for any trends (figure 3-22).

## RESPONSE AREAS

The data recorded at the reference climate stations are only representative of a limited area in which the station is located. Salinger (1979, 1981) used cluster and principal component analysis techniques on the annual maximum and minimum temperatures of about 77 New Zealand climate stations for the period 1951-1975 to identify temperature *response areas* for the country. A response area is a local area which shows *homogeneous* temperature or rainfall anomalies in response to differing weather systems. Stations in a given response area exhibit a certain characteristic reaction to each synoptic scale system. The response becomes less marked as the boundary with another area is approached. The value of the correlation coefficient between pairs of stations and its significance were used to determine the response areas. Further explanation is given in Salinger (1979, 1981). The temperature response areas are shown in figure 2.

There are two response areas in the North Island, namely east and west of the main mountain ranges. In the South Island there are four response areas. These are West Coast, Southland, inland central basins and eastern South Island.

All the response areas, except the inland basin south-west of Nelson, are represented by the chosen reference climate stations. Dunedin lies close to the boundary of two response areas.

When comparing the temperature patterns of single reference climate stations in a given response area, for example the West Coast of the South Island, one would not necessarily expect the same degree of response between them as obtained by Salinger (1981). This is because more stations were included in the analysis by Salinger (1981) and these were averaged over the area, whereas there may be only one or two reference stations in a response area and no averaging has been done.

## RESULTS

The temperature graphs show many short term fluctuations from year to year. Since the longer term fluctuations and trends are of more interest for climate change studies, the behaviour of the or filtered temperature series are discussed. The temperature anomalies shown in the graphs are the departures of the homogenised seasonal or annual temperatures and the corresponding values of the 1951-1980 reference period. The term "normal" is used to indicate the 1951-80 reference.

### Mean annual temperatures for North Island stations

The mean annual smoothed temperatures for the North Island stations are shown in figure 3 a-k. The range of the annual temperature differences from the 1951-1980 reference period is about +1 to -1.5 °C.

## NORTH ISLAND TEMPERATURE RESPONSE AREAS

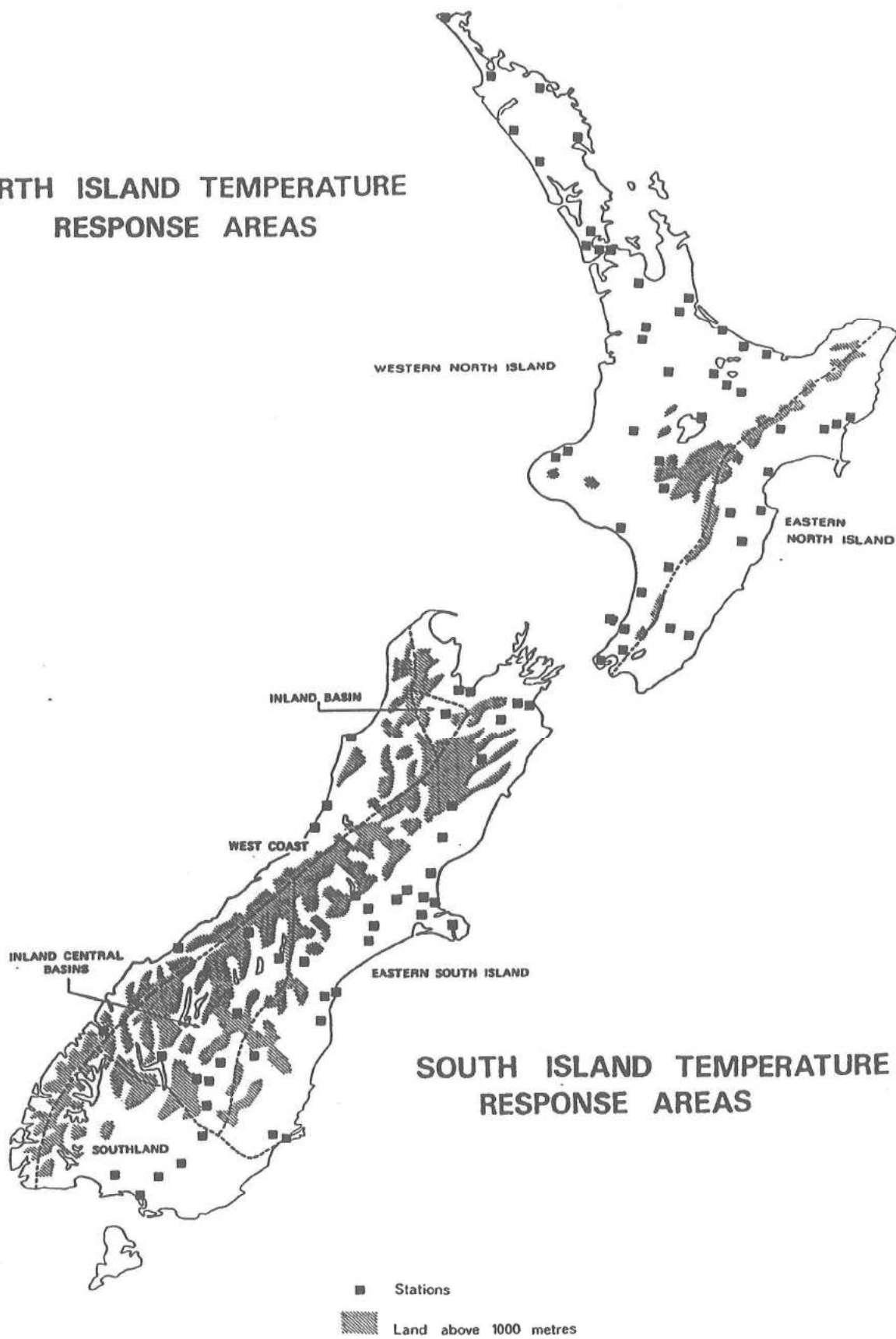


Figure 2 Temperature response areas

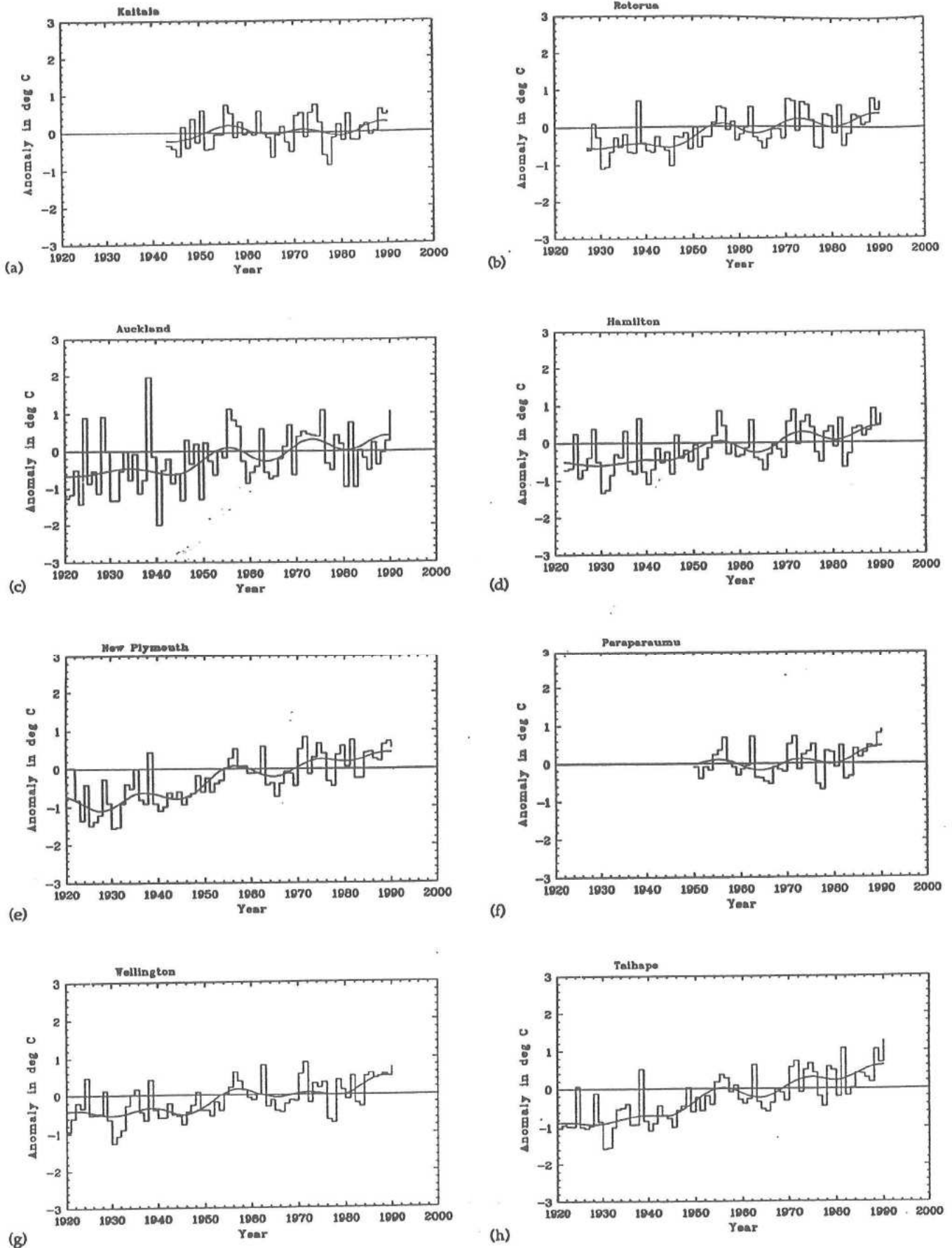


Figure 3 Mean annual temperature anomalies and filtered series at North Island stations

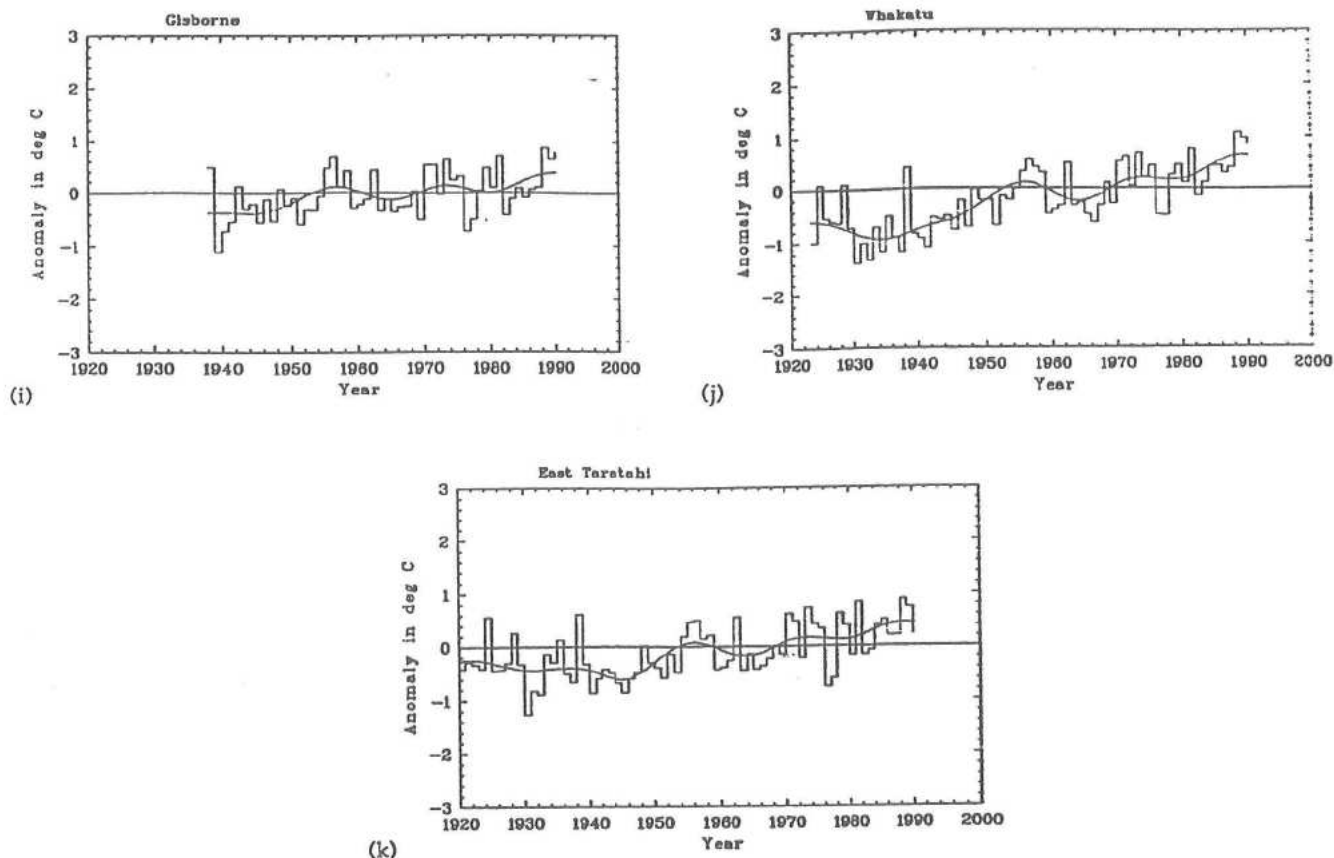


Figure 3 (continued)

The main features of the smoothed (filtered) mean temperature graphs are:

- There was a cool period prior to the mid-1940s, followed by an increase of mean annual temperature into the mid-1950s, after which there were periods of cooler and warmer than normal years.
- Auckland, Hamilton and Rotorua show very similar trends to each other.
- There was a small temperature increase in the 1930s, except at Whakatu where a steady increase occurred from the early 1930s.
- The decade 1941-1950 was between 0.5-0.6°C cooler than normal, except at Hamilton and Gisborne where the departure was 0.2-0.3°C.
- The warmest period in the record occurred in the 1980s, when most years were warmer than the 1951-1980 period. Temperatures were between 0.2-0.5 °C above the 1951-1980 period, with the smallest increase, 0.2 °C, occurring at Kaitaia.
- The temperature curves for most of the stations are in phase, that is cooler and warmer periods than normal occur about the same time, although their magnitudes differ. The major exception to this is Whakatu and to a lesser extent East Taratahi, where the temperature departure below normal in the 1920s, was less than for stations west of the axial ranges.

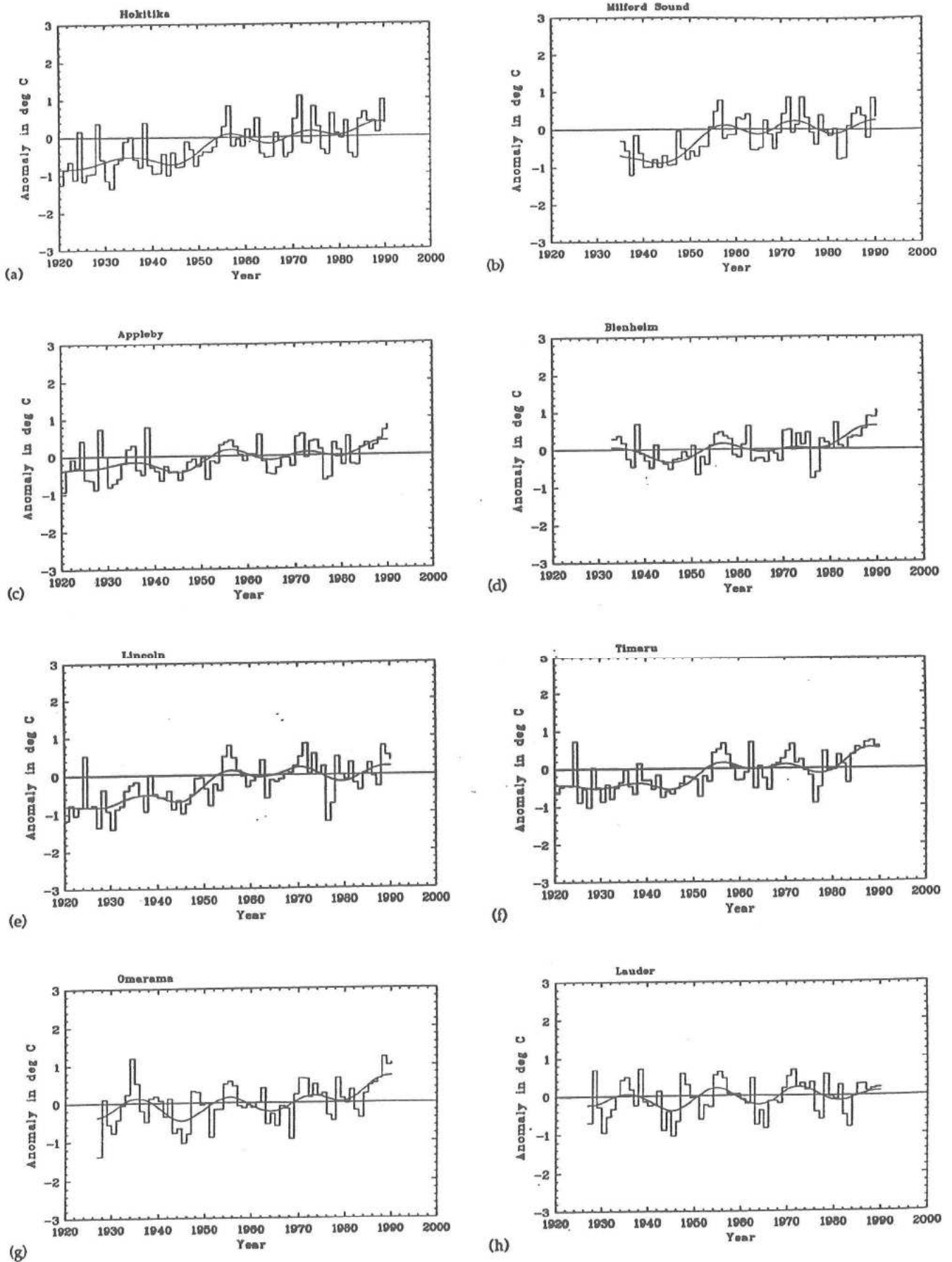


Figure 4 Mean annual temperature anomalies and filtered series at South Island stations

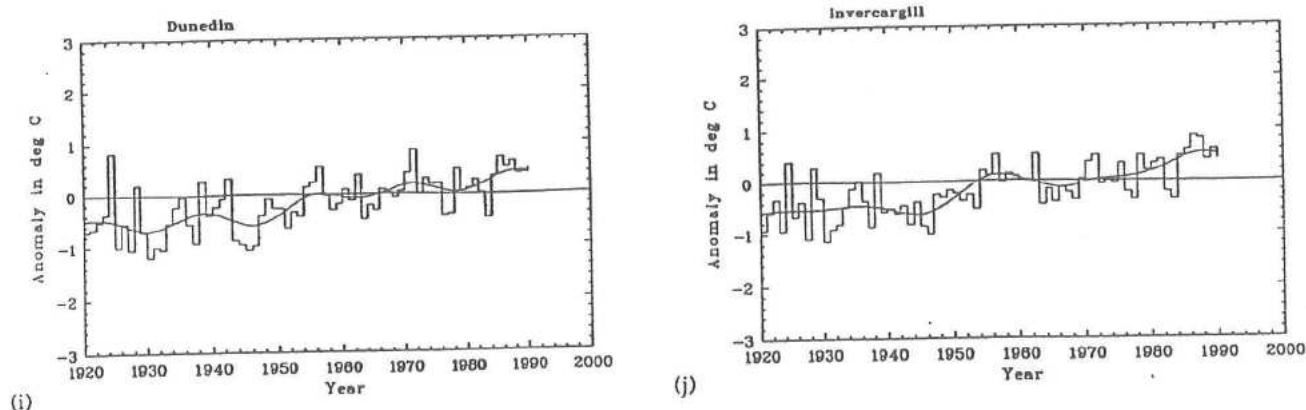


Figure 4 (continued)

At Taihape and Paraparaumu, 1990 was the warmest year in the time series, whereas at East Taratahi, Whakatu and Gisborne 1988 was the warmest year.

### Mean annual temperatures for South Island stations

The mean annual filtered temperature curves and annual anomalies for South Island stations are shown in figure 4 a-j. The format is the same as for figure 3. The range of the annual temperature differences from the 1951-1980 is similar to the North Island, although the annual anomalies at Omarama were larger. The greatest individual annual departures (up to 1.4 °C) cooler than the 1951-1980 reference period occurred at Hokitika and Milford Sound on the west coast, and Lincoln, Omarama and Dunedin in the east.

The main features of the South Island temperature curves are:

- As in the North Island, there was a cool period in the mid-1940s, which was followed by a warming period into the mid-1950s, then periods warmer and cooler than the 1951-1980 period.
- The greatest departures from normal (0.7-0.8 °C) occurred on the west coast at Hokitika and Milford Sound and on the east coast at Dunedin. The smallest departures from normal (about 0.1 °C) occurred in the inland basins at Lauder and Omarama, followed by Appleby and Blenheim (about 0.2 °C).
- There was a temperature increase in the 1930s at Blenheim, Lauder and Omarama and to a lesser extent at Appleby. This is in major contrast to all the other reference stations, which were cooler during the 1930s.
- As in the North Island the warmest period for all stations occurred in the 1980s. The exception was Lauder, which warmed in the late 1980s, but had three successive cold years (1982-1984). The largest increase in mean temperature in the 1980s (about 0.4 °C) occurred at Omarama, closely followed by Blenheim, Hokitika, Invercargill and Dunedin (about 0.3 °C). The smallest temperature increase, (about 0.1 °C), occurred at Milford Sound, Lincoln and Lauder.
- The warmer and cooler periods at South Island stations were all in phase and occurred about the same time as in the North Island.

In terms of the response areas shown in figure 2:

- Hokitika and Milford Sound show similar patterns apart from more warming at Hokitika in the 1980s.
- Dunedin and Invercargill show similar patterns apart from a more sustained warming trend in the 1980s at Invercargill.
- Appleby, Blenheim and Lincoln, which are in the same response area (Salinger, 1979; 1981), show slightly different behaviour to each other prior to the mid-1940s. Blenheim was more like Omarama and Lauder.

### Mean annual temperatures for Raoul, Chatham and Campbell Islands

The mean annual smoothed temperature graphs for the three offshore island stations are shown in figure 5. The format is the same as in figure 3. Because the islands are so widely separated the temperature patterns are not directly comparable, as was the case for land stations in the same vicinity. Therefore the following comments are more in the nature of a summary than a comparison.

The main features are:

- There is less fluctuation of the temperatures for individual years about the 1951-1980 period than with the land stations, presumably because of the moderating influence of the surrounding ocean.

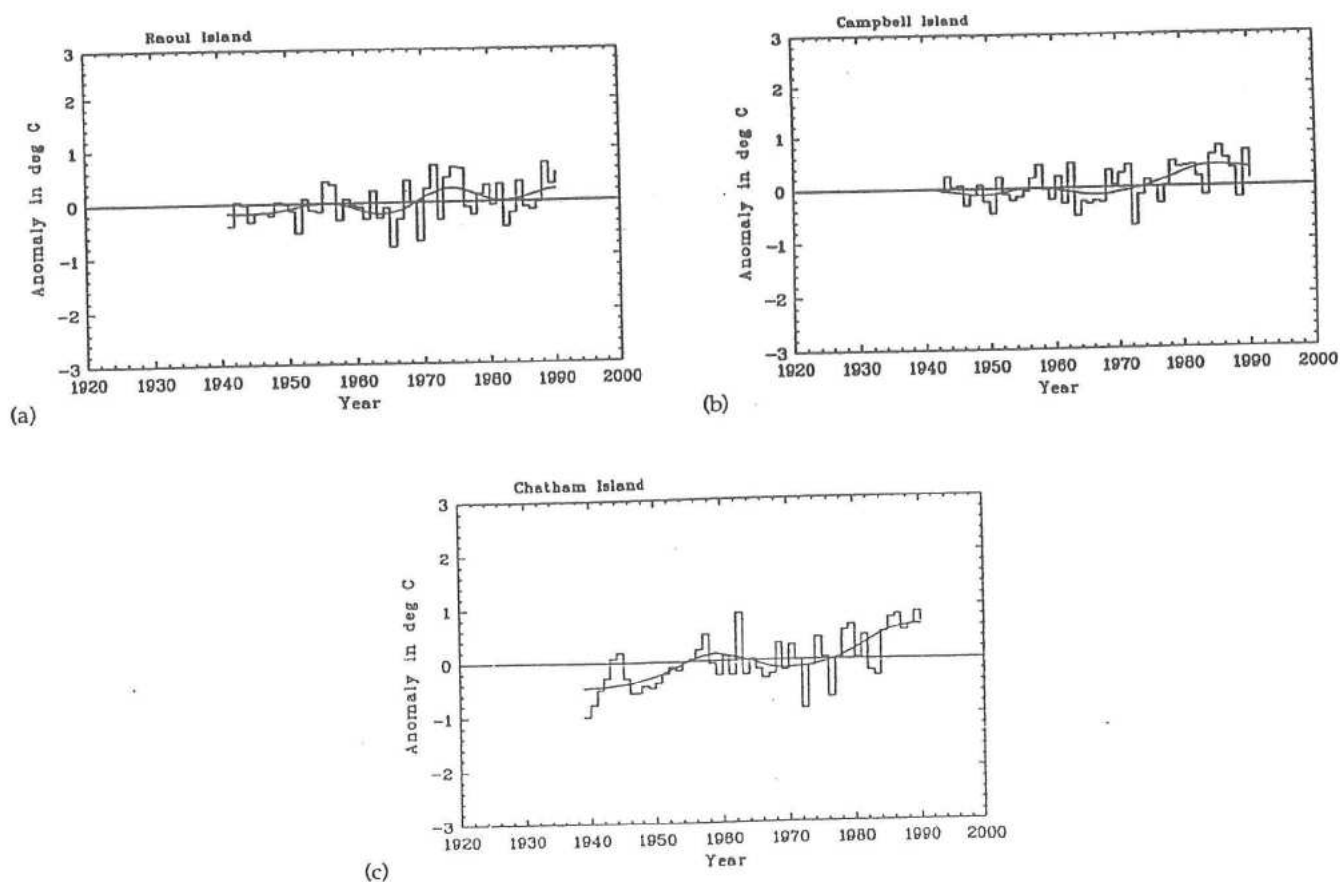


Figure 5 Mean annual temperature anomalies and filtered series at Raoul, Campbell and Chatham Islands



- There was a cool period in the 1940s and a warmer period in the mid-1950s, as was the case for the land stations. Chatham Island experienced the greatest departure below normal, followed by Raoul and the smallest departure occurred at Campbell Island.
- At Raoul Island there was a period in the 1970s when temperatures were above normal. This did not occur at the other two islands.
- The warmest period of the record was in the 1980s at Chatham and Campbell Islands. At Raoul Island, it was in the mid-1970s.
- The warm and cool periods are not in phase at the three islands, as was the case for the land stations, suggesting different climatic regimes affecting each island.
- The mean temperature curve for Raoul Island is most like the land stations.

### Decadal trends in mean temperature

Individual decades can be compared with respect to cooling or warming trends (relative to the reference period 1951-1980), by averaging the anomalies for each decade for all the stations (IPCC, 1992). The anomalies are the differences between the homogenised data values and the reference period. The results of doing this for selected decades are shown in Table 2, where the main features are:

- All the anomalies in the 1981-1990 decade are positive, apart from Raoul Island, whereas those for the 1921-1930 and 1941-1950 decades are negative, apart from Campbell Island.

**Table 2** Annual temperature anomalies (°C) relative to the 1951-1980 reference period for reference climate stations for selected decades.

Decade	1921-30	1941-50	1981-90
<b>Station</b>			
<b>North Island</b>			
Kaitaia			0.2
Auckland	-0.5	-0.5	0.3
Hamilton		-0.3	0.3
Rotorua		-0.4	0.3
New Plymouth		-0.6	0.4
Taihape	-0.8	-0.6	0.5
Paraparaumu			0.3
Wellington	-0.4	-0.4	0.4
Gisborne		-0.2	0.3
Whakatu		-0.5	0.5
East Taratahi	-0.3	-0.5	0.4
<b>South Island</b>			
Hokitika	-0.7	-0.6	0.3
Milford Sound		-0.7	0.1
Appleby	-0.3	-0.3	0.3
Blenheim		-0.2	0.5
Lincoln	-0.8	-0.5	0.1
Timaru	-0.5	-0.4	0.4
Omarama		-0.3	0.5
Lauder		-0.2	0.0
Dunedin	-0.3	-0.4	0.3
Invercargill	-0.5	-0.5	0.4
<b>Islands</b>			
Raoul Island		-0.2	-0.3
Chatham Island		-0.3	0.5
Campbell Island		0.0	0.3



- In the North Island the greatest departure below normal ( $-0.8^{\circ}\text{C}$ ) occurred at Taihape during 1921-1930 and the greatest departure above normal occurred at Whakatu ( $+0.5^{\circ}\text{C}$ ) and Taihape ( $+0.5^{\circ}\text{C}$ ) during 1981-1990.
- In the South Island, the greatest departures below normal occurred at Lincoln ( $-0.8^{\circ}\text{C}$ ) during 1921-1930, Milford Sound ( $-0.7^{\circ}\text{C}$ ) during 1941-1950 and Hokitika ( $-0.7^{\circ}\text{C}$ ) during 1921-1930. The greatest departure above normal occurred at Blenheim ( $+0.5^{\circ}\text{C}$ ).
- For the outlying islands, the largest departure below normal ( $-0.3^{\circ}\text{C}$ ) occurred at Chatham Island during 1941-1950 and at Raoul Island during 1981-1990. The greatest positive departure ( $+0.5^{\circ}\text{C}$ ) was at Chatham Island during 1981-1990.

## Maximum and minimum temperatures

The IPCC Science Update (Houghton et al. 1992) found that the main contribution to the global temperature increase at land stations in the Northern Hemisphere was a greater increase in minimum (night time) temperatures than maximum (daytime) temperatures. Therefore it is of considerable interest how trends in maximum and minimum temperature curves for New Zealand compare.

### North Island stations

The annual maximum and minimum temperature curves for the North Island are shown in figure 6 a-v. The format is the same as in figure 3. At most places the maximum curves have similar characteristics to the mean temperature curves discussed above. The main differences are in the minimum curves. Since there is considerable variation in behaviour, each station is discussed individually.

In the north, at Kaitia, it can be seen that minimum temperatures were about  $0.5^{\circ}\text{C}$  above normal till the early 1950s, whereas the maxima were about  $0.2-0.3^{\circ}\text{C}$  below normal. In the 1970s minima were up to  $0.4^{\circ}\text{C}$  below normal, while maxima were mostly above normal. In the 1980s, minima increased again more than the maxima.

At Auckland and Hamilton there was a greater decrease in minima compared with maxima till the late 1960s (except in the 1940s at Hamilton), followed by greater increases in the minima in the 1970s and 1980s, especially at Hamilton. The major part of the temperature increase in the 1980s at Hamilton resulted from increases in the minima.

At Rotorua there were only small fluctuations of the maximum about normal, whereas the minimum curve is similar to Hamilton. Increases in minima were much greater than maxima in the 1980s.

New Plymouth and Taihape are similar, with the maximum and minimum curves being more in phase at New Plymouth. From the mid-1970s, the increase in minima was greater than the maxima.

At Paraparaumu the maxima showed positive departures until the late 1970s and early 1980s, and were above normal from the mid-1980s. The minima were similar to those at New Plymouth and Taihape and did not show the decrease experienced by the maxima.

For Wellington, the decrease in minima was greater than the maxima until the mid-1950s, after which there were some fluctuations about normal until the late 1970s, when the increase in minima was slightly greater than the maxima.

East of the ranges, at Gisborne, there was a much larger decrease in the minima than maxima until the mid-1950s. Divergences from normal were comparable until the 1980s, when there was only a small increase in minima and a much larger increase in maxima. This is in contrast to all other stations in the North Island, but is similar to some stations in the South Island, such as Milford Sound and Lauder.

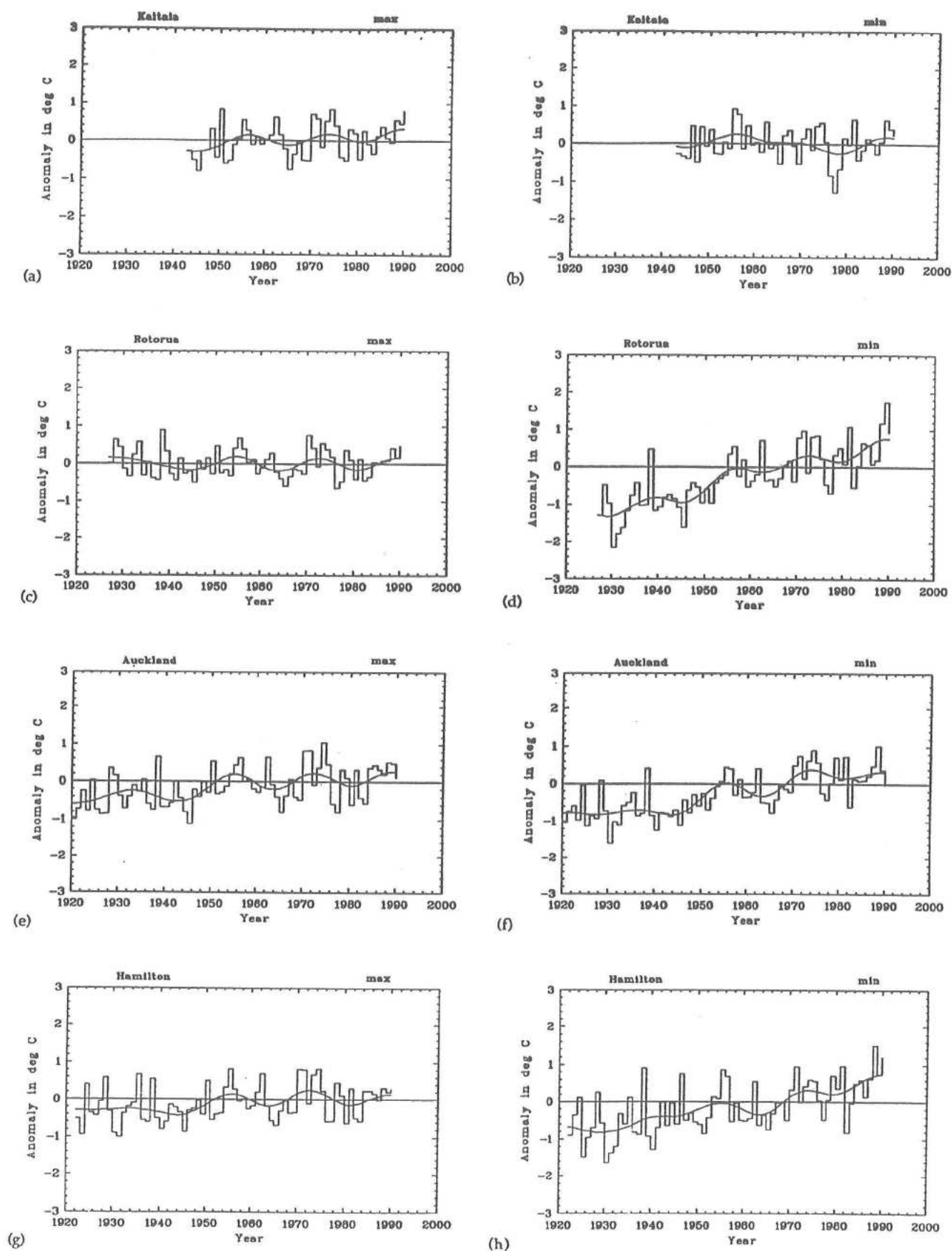


Figure 6 Maximum and minimum temperatures at North Island stations

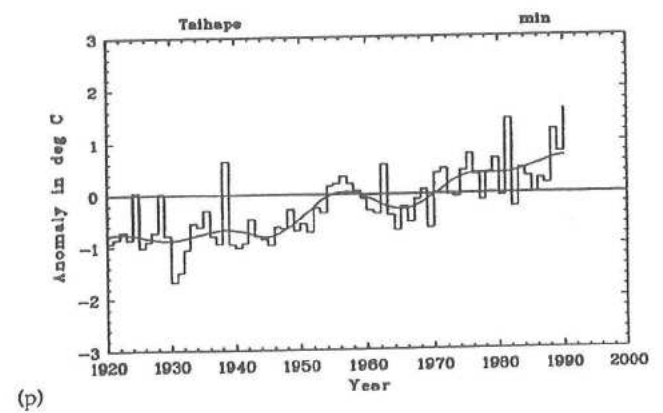
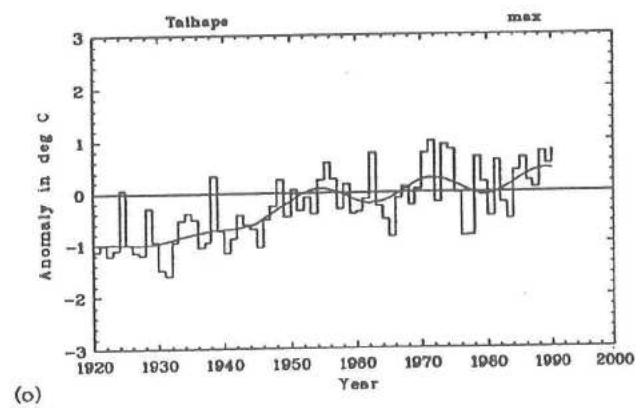
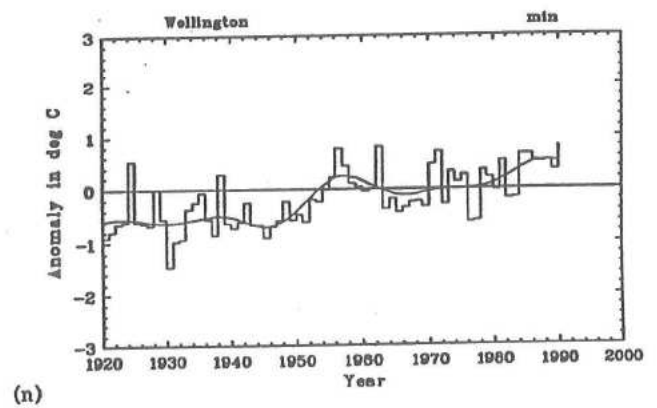
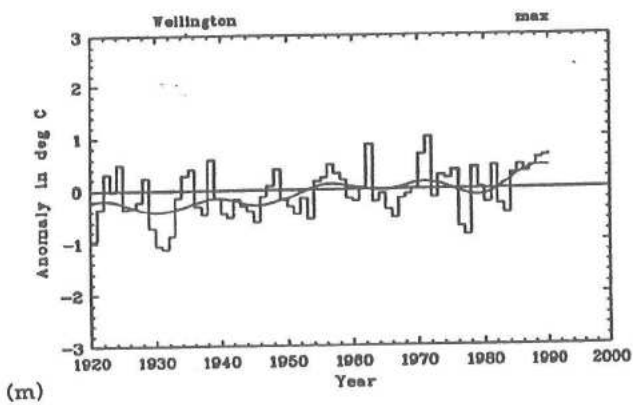
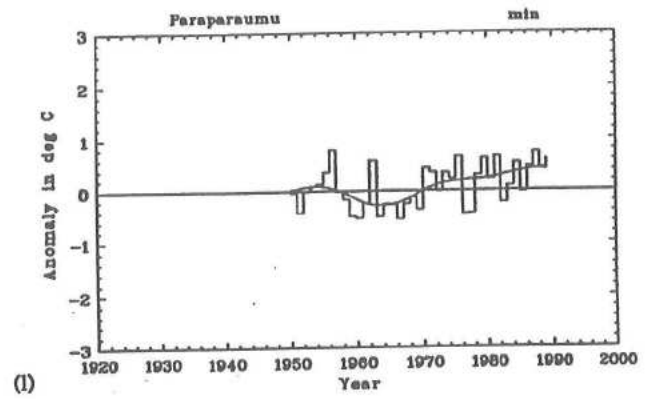
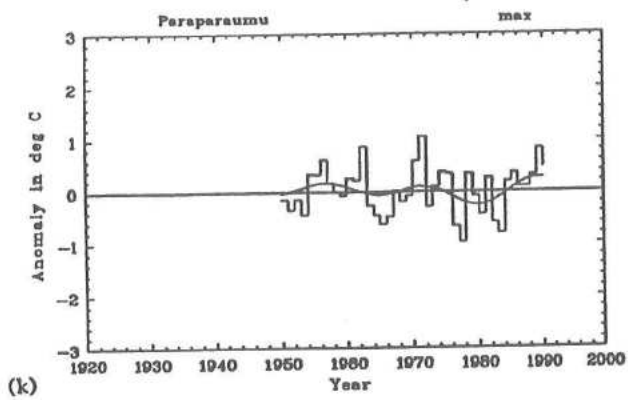
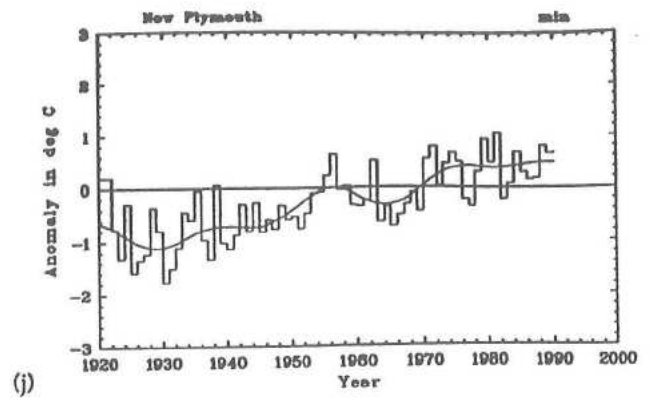
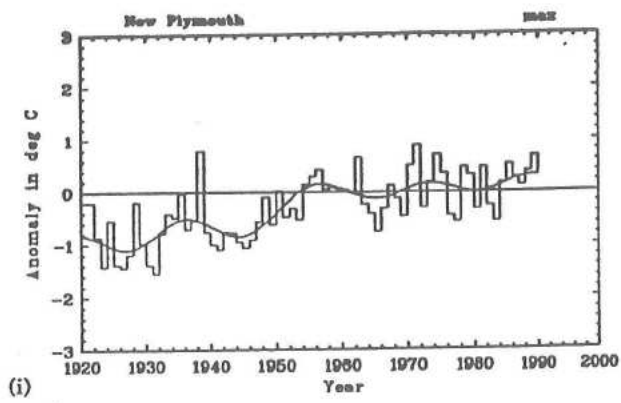


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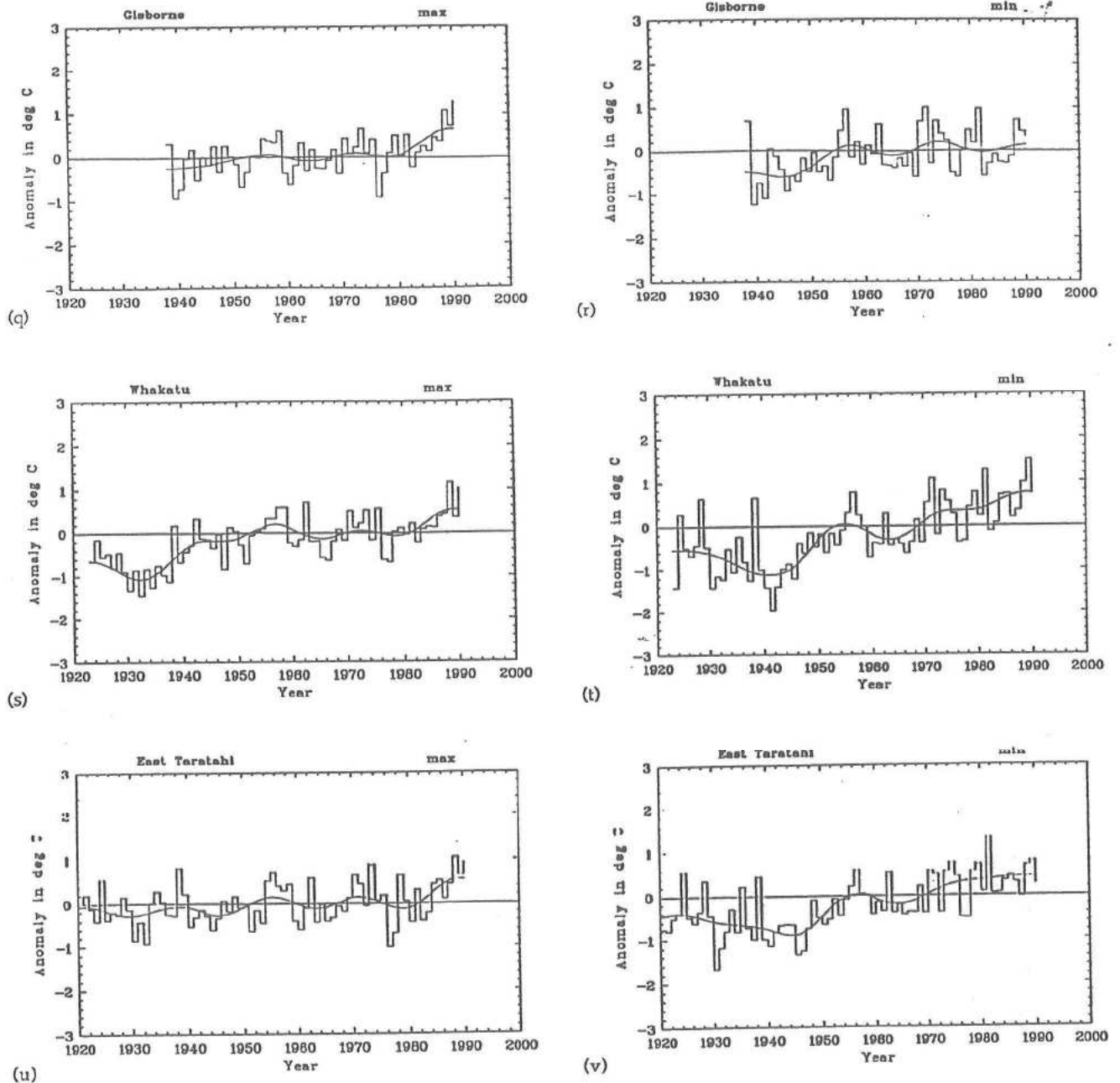


Figure 6 (continued)

Less cooling in the 1920s shown in the Whakatu curve seemed to result from smaller decreases in both minima and maxima, compared with other stations. There was a cooler period from about 1930 to the mid-1940s when minima were more than  $1^{\circ}\text{C}$  below normal.

This period overlapped the cold period in the early 1930s when maxima were about  $1^{\circ}\text{C}$  below normal. The continuation of the minima about  $1^{\circ}\text{C}$  below normal into the 1940s was compensated by the rapid increase of the maxima from the early 1930s to the early 1940s. During the 1970s and 1980s the minima increased more than the maxima, resulting in a major contribution from the minima to the 1980s warming.

The East Taratahi minimum curve is similar to Whakatu except at the beginning of the record, where minima decreased more than maxima. In the late 1980s increases in minima were comparable to the maxima.

## Summary for the North Island

Several stations west of the ranges showed greater departures below normal for the minima rather than the maxima in the early part of the record. Exceptions are Kaitaia (minima above normal in the 1940s), New Plymouth (minima decrease similar to maxima for most of the record) and Taihape (similar to New Plymouth). In the 1980s the reverse is true with the smallest departures occurring at Auckland.

East of the ranges, Whakatu and East Taratahi differed in the early part of the record. In the 1980s, Gisborne minima increased less than the maxima. Whakatu's minima increased more than the maxima. At East Taratahi the minima increased more than maxima in the early 1980s, but less than maxima in the late 1980s.

Increases in both maximum and minimum temperatures over the last two decades in the North Island contrast to the IPCC findings for the Northern Hemisphere where temperature increases are confined to minimum temperatures only.

## South Island stations

The annual maximum and minimum temperature curves for the South Island are shown in figure 7 a-t. The format is the same as figure 3. At most places the maximum curves have similar characteristics with the exceptions of Blenheim, Dunedin and Invercargill.

On the west coast at Hokitika, the difference of the maxima and minima from normal was similar until the 1980s. This differs from the North Island stations, where, in the early part of the record, minima departures below normal were greater than maxima. In the 1980s, on the other hand, minima increased more than maxima. Thus the 1980s warming is mainly a result of increases in minima. There was also a slight increase in both maxima and minima during the 1930s.

At Milford Sound minimum temperature departures below normal were less than in maxima up to about 1950, after which the anomalies from normal were similar to 1960. After 1970, the maxima increased more than the minima, which were close to normal by the late 1980s, whereas the maxima had increased to about 0.4 °C above normal by this time. Hence most of the warming in the 1980s was because of increases in *maxima* rather than minima, as was the case at Hokitika.

Appleby and Blenheim have similar trends for maxima and minima for most of the period of record. Temperature departures were above normal in minima in the 1930s and early 1940s at both stations, after which the changes from normal of both maxima and minima were small until about 1970 at Appleby. Minima increased more than maxima. At Blenheim, maxima and minima departures were comparable in the late 1980s.

At Lincoln, the minima were about 0.2 °C below normal to the mid-1940s, while the maxima were about 1 °C below normal. Minima were close to normal in the 1950s, while maxima were above normal. From the mid-1960s departures above normal in minima were slightly greater than maxima.

Timaru is similar to Lincoln apart from the early part of the record when minima were mostly above normal to about 1940. Both maxima and minima were similar in the 1980s.

The inland basin stations, Omarama and Lauder, have similar maximum and minimum trends for most of their records. Minimum temperature departures were well above normal in the 1930s, while the maxima were about 0.6 °C below normal. Minima remained below normal through the 1950s and mid-1960s, after which they increased above normal more than maxima at Omarama. At Lauder, minima and maxima changes relative to normal were similar by the mid-1980s. In the late 1980s, maxima departures were above normal, while minima remained close to normal.

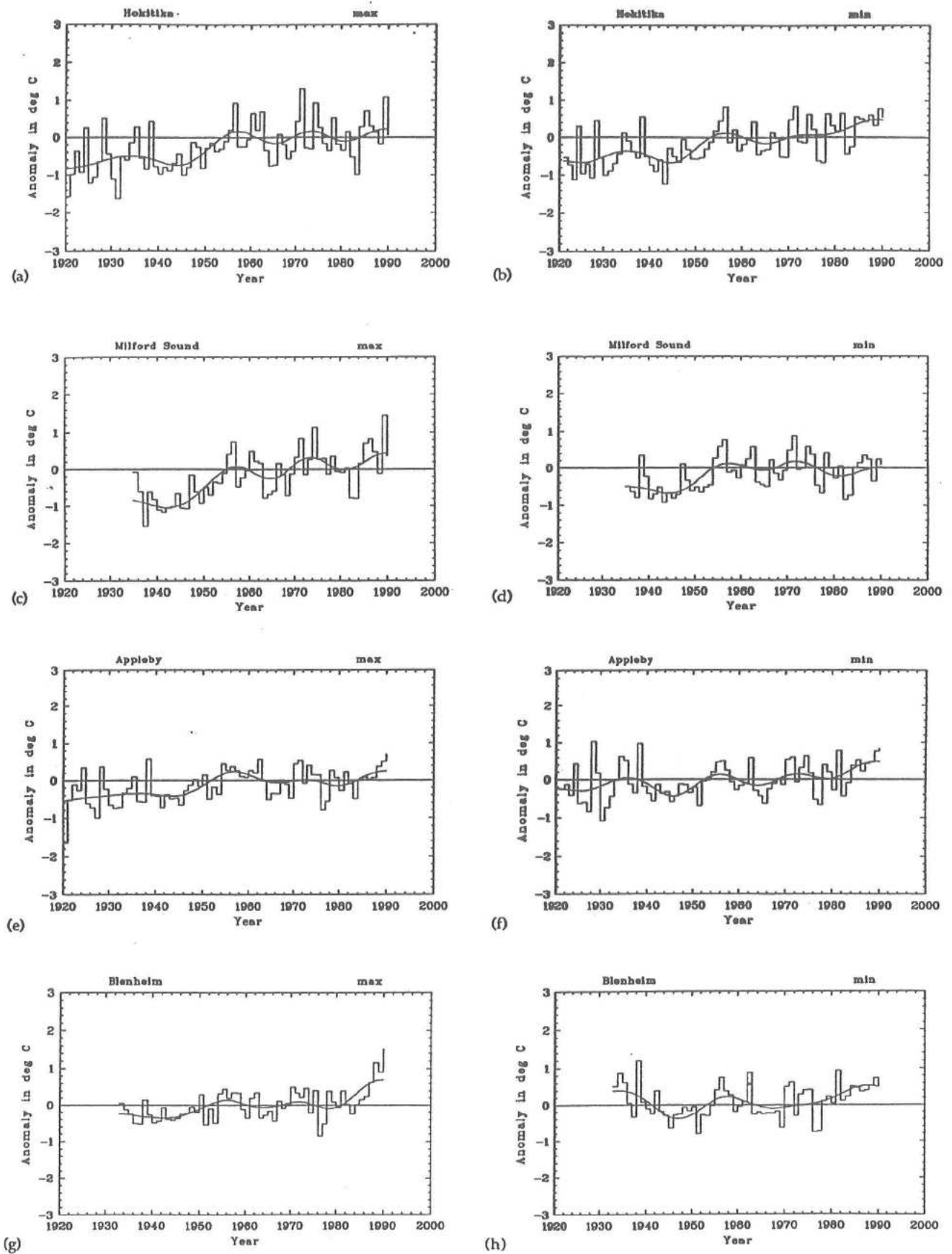


Figure 7 Maximum and minimum temperatures at South Island stations



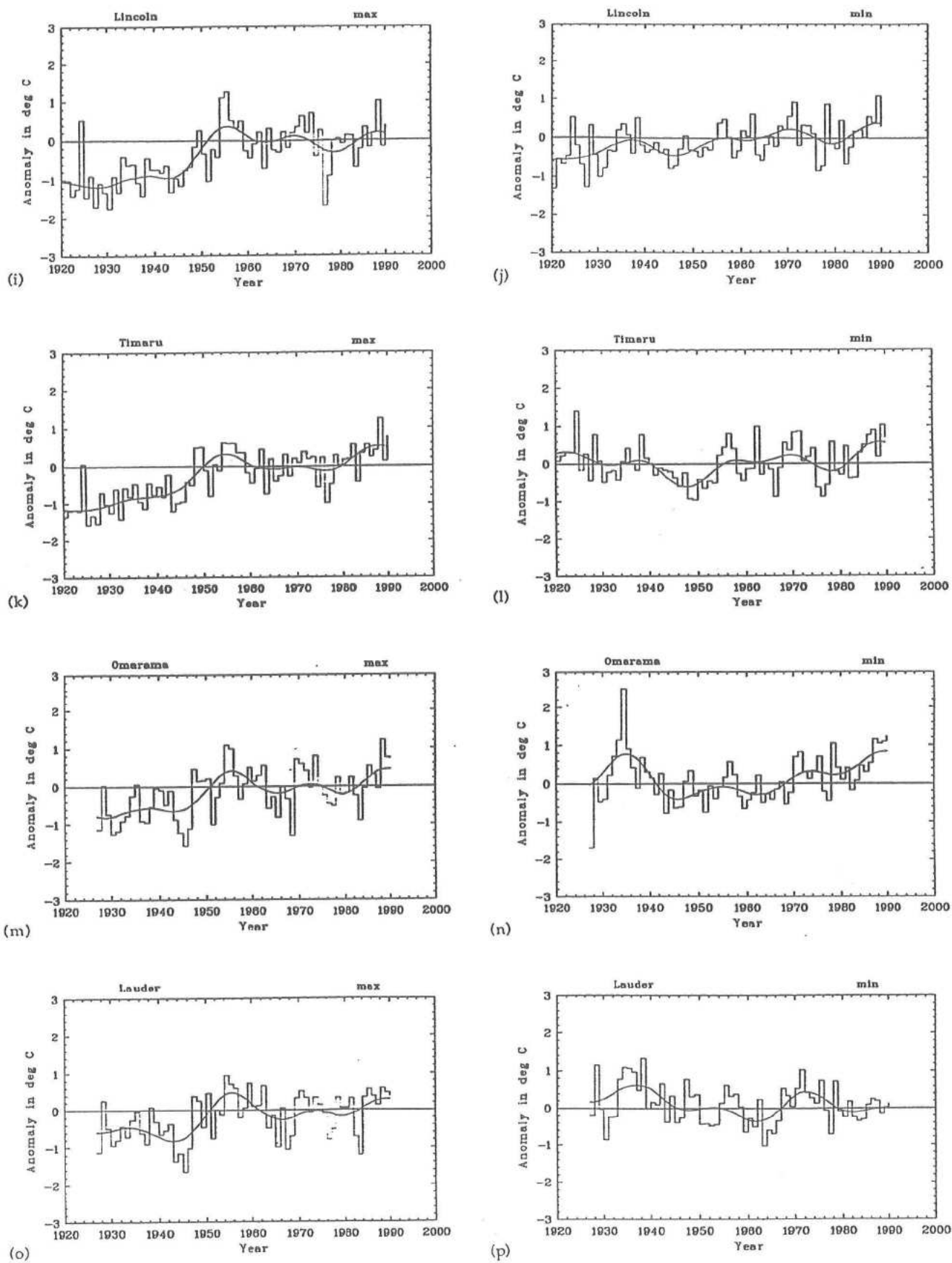


Figure 7 (continued)

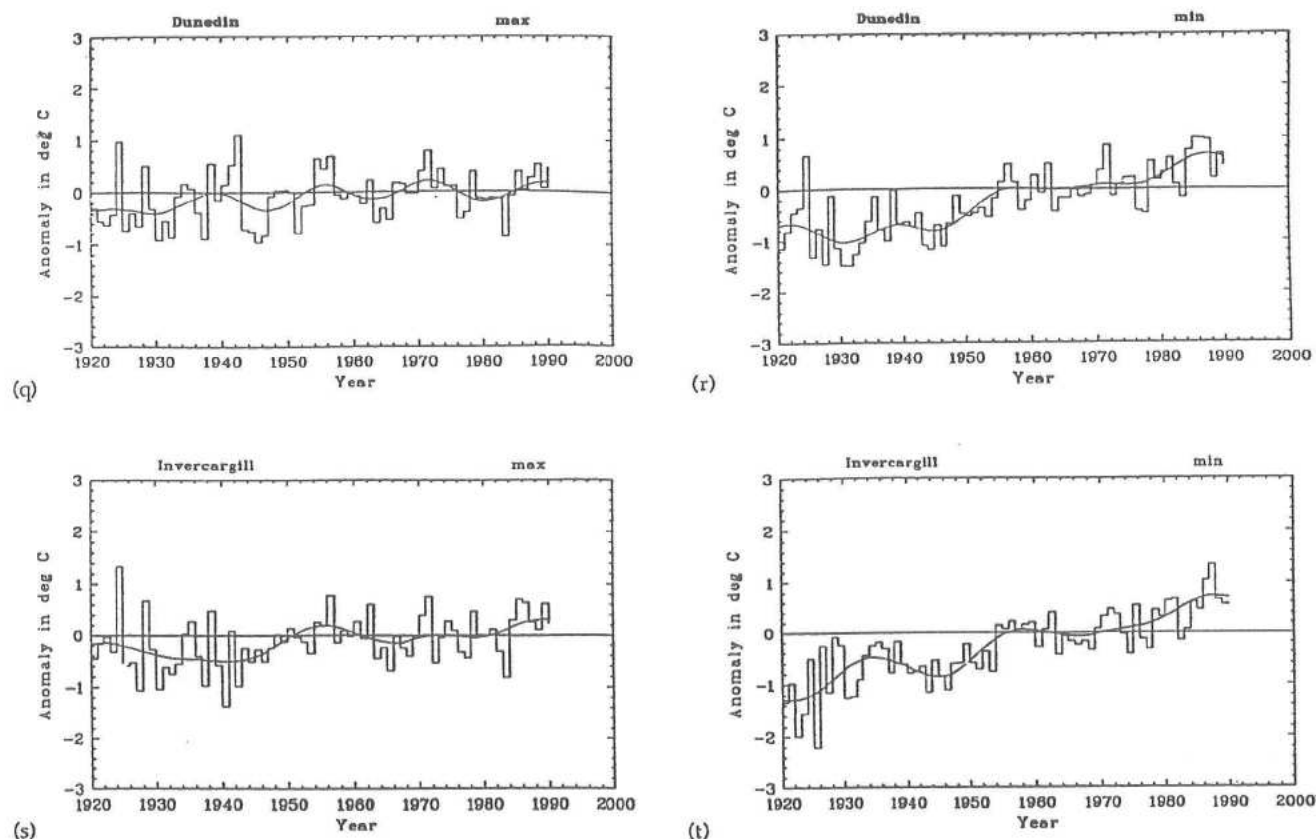


Figure 7 (continued)

In the south at Dunedin, trends in maximum temperatures showed, after a cool period up to 1930, warm and cold periods for the rest of the record. This included a warm period in the late 1930s which did not occur at other South Island stations. The minima, on the other hand, show decreases of more than  $1^{\circ}\text{C}$  below normal until the mid-1940s, after which temperatures increased. This is more like some North Island stations. From the mid-1970s increases in minima exceeded those in maxima.

At Invercargill, the main differences from the Dunedin curves are an absence of warming in the late 1930s and early 1940s in the maximum curve, but there was a temperature increase shown in the minimum curve for Invercargill, which did not occur at Dunedin. Minima increased more than maxima in the 1980s.

#### Summary for the South Island

Most South Island stations have smaller temperature departures below normal for the minima than for maxima in the early part of the record. This is different from most North Island stations. The opposite occurred at Dunedin and Invercargill which were more like North Island stations. At most stations, minimum temperature increases were larger than maximum temperatures in the 1980s. Exceptions were Milford Sound and Lauder. At Blenheim and Timaru, increases in minima and maxima in the 1980s were similar.

#### Raoul, Chatham and Campbell Islands

The annual temperature curves for maxima and minima for the three islands are shown in figure 8 a-f. The format is the same as figure 3. As with the land stations the maxima show similar characteristics to the mean curves, but there are differences in the minima.



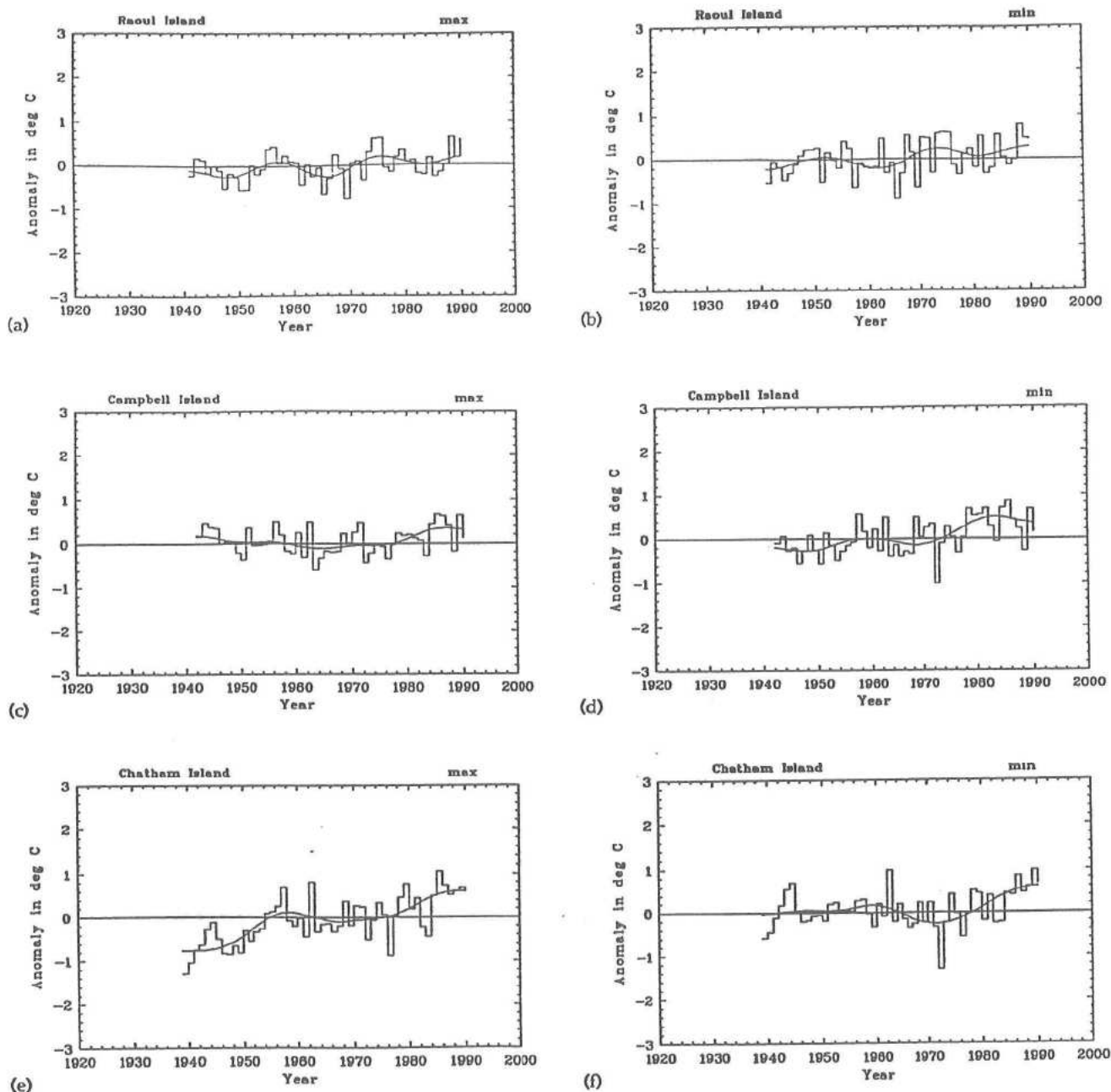


Figure 8 Maximum and minimum temperatures at Raoul, Campbell and Chatham Islands

At Chatham Island, the trends in maximum temperatures were similar in character to the land stations, with a cool period in the 1940s, then some fluctuations close to normal, followed by a warming in the 1980s. The minima were close to normal to the mid-1960s and there was a marked increase above normal from the late 1970s. The contribution from increases in maxima and minima to the warming in the 1980s is similar. Maximum temperature departures below normal in the early part of the record and above normal in the 1980s were both greater than at Raoul Island. Minima at both stations were closer to normal except in the 1980s, when departures above normal were greater at Chatham Island. The temperature patterns at Chatham Island were similar to South Island land stations.

For Campbell Island, the maxima were close to normal until the 1980s, when temperature departures of  $+0.2^{\circ}\text{C}$  occurred. The minima were below normal in the 1940s and remained close to normal until the mid-1970s when positive departures occurred. This increase occurred a few years earlier than the increase in maxima. By the late 1980s the maxima and minima departures above normal were comparable.

The main contrasts between the land stations and the islands are:

- anomalies from normal at Raoul and Campbell Islands were smaller in magnitude than the land stations, presumably because of the surrounding ocean;
- the warming in the 1980s had similar contributions from increases in both maxima and minima, rather than more in the minima, as was the case with many of the land stations;
- Chatham Island is similar to South Island land stations.

### Decadal trends in maximum and minimum temperatures

As for the mean temperatures individual decades can be compared with respect to cooling or warming trends (relative to the reference period 1951-1980) by averaging the maximum and minimum temperature anomalies for each decade for all the stations. The results of are shown in Table 3.

The main features of the maximum temperature table are:

- All the anomalies in maxima for the 1981-1990 decade are positive, whereas those for the decades 1921-1930 and 1941-1950 are negative (except Omarama and Campbell Island which are slightly positive).
- In the North Island negative anomalies were greatest at Taihape ( $-0.9^{\circ}\text{C}$ ) during 1921-1930 and positive anomalies greatest at Gisborne ( $+0.5^{\circ}\text{C}$ ) during 1981-1990.
- In the South Island the largest negative anomalies occurred at Lincoln ( $-1.1^{\circ}\text{C}$ ) and Timaru ( $-1.1^{\circ}\text{C}$ ) during 1921-1930. The largest positive anomalies occurred at Blenheim ( $+0.5^{\circ}\text{C}$ ).
- For the outlying islands, Chatham Island had the greatest negative anomaly ( $-0.6^{\circ}\text{C}$ ) during 1941-1950 and the greatest positive anomaly ( $+0.5^{\circ}\text{C}$ ) during 1981-1990.

The main features of the minimum temperature table are:

- All the anomalies during 1981-1990 are positive except Gisborne, Milford Sound and Lauder which have small negative values.
- In the North Island the greatest negative anomaly ( $-0.8^{\circ}\text{C}$ ) occurred at Auckland and Taihape during 1921-1930 and the greatest positive anomaly ( $+0.6^{\circ}\text{C}$ ) at Whakatu during 1981-1990.
- In the South Island the greatest negative anomaly occurred at Invercargill ( $-1.0^{\circ}\text{C}$ ) during 1921-1930. The greatest positive anomaly occurred at Omarama ( $+0.6^{\circ}\text{C}$ ).
- For the outlying islands, Campbell Island had the largest negative anomaly ( $-0.2^{\circ}\text{C}$ ) during 1941-1950 and Chatham Island had the largest positive anomaly ( $+0.4^{\circ}\text{C}$ ) during 1981-1990.

### Seasonal variations at North Island sites

Figures 9-12 a-k show the temperature anomalies and filtered series for North Island stations. The format is the same as figure 3. For comparison purposes, all four seasonal smoothed curves are plotted for each station in figure 13 a-k. Each station is discussed separately.

At Kaitaia, in the 1940s, summer was the season with the negative departures. Both winter and spring were warmer than normal in the 1940s. In the late 1950s, summers were warmer than normal. During the 1980s, autumn showed the smallest positive temperature departures of the

**Table 3** Maximum and minimum annual temperature anomalies (°C) relative to the 1951-1980 climatology for reference climate stations for selected decades

Decade	Annual Maxima			Annual Minima		
	1921-30	1941-50	1981-90	1921-30	1941-50	1981-90
<b>North Island</b>						
Kaitaia			0.2			0.3
Auckland	-0.4	-0.3	0.2	-0.8	-0.6	0.3
Hamilton		-0.3	0.1		-0.4	0.5
Rotorua		-0.1	0.1		-0.8	0.6
New Plymouth		-0.8	0.2		-0.6	0.4
Taihape	-0.9	-0.5	0.3	-0.8	-0.7	0.6
Paraparaumu			0.1			0.4
Wellington	-0.2	-0.2	0.3	-0.6	-0.6	0.4
Gisborne		-0.1	0.5		-0.5	-0.1
Whakatu		-0.2	0.4		-0.8	0.6
East Taratahi	-0.2	-0.2	0.4	-0.4	-0.7	0.5
<b>South Island</b>						
Hokitika	-0.6	-0.6	0.3	-0.3	-0.6	0.4
Milford Sound		-0.8	0.2		-0.6	-0.0
Appleby	-0.6	-0.4	0.1	-0.3	-0.3	0.4
Blenheim		-0.2	0.5		-0.2	0.5
Lincoln	-1.1	-0.7	0.0	-0.4	-0.3	0.2
Timaru	-1.1	-0.4	0.4	0.2	-0.4	0.4
Omarama		0.0	0.3		-0.2	0.6
Lauder		-0.6	0.1		0.1	-0.0
Dunedin	-0.3	-0.2	0.0	-0.3	-0.5	0.6
Invercargill	-0.2	-0.3	0.2	-1.0	-0.7	0.6
<b>Islands</b>						
Raoul Island		-0.2	0.1		-0.1	0.2
Chatham Island		-0.6	0.5		0.1	0.4
Campbell Island		0.1	0.3		-0.2	0.4

the seasons, with spring showing the greatest increase. Over the period of the record winter showed no change compared with normal and spring was cooler than normal only in the late 1970s and early 1980s.

New Plymouth had the distinction of having the largest negative seasonal (except winter) departure of all the North Island stations. This was because summers were about 1.5 °C below normal in the 1920s and slightly less in the 1940s. Winter showed the least departure from normal, especially in the 1940s. Spring and summer were mostly in phase. As with the other stations, autumn showed the least warming in the 1980s, while the other seasons showed similar warming.

Like New Plymouth, summer was coolest in the 1920s and again in the 1940s at Taihape. The 1920s' summer departure from normal was slightly less than at New Plymouth. In the 1980s, as at other stations, autumn had the least warming and spring the greatest.

For Auckland summers were initially cool (1920s) but warmed during the 1930s and the coolest period occurred in the 1940s. From the mid-1960s the seasons were in phase. During the 1980s, autumn had the smallest temperature increase and the spring the largest.

At Hamilton, winters were very cool in the 1930s and summer in the 1940s. The seasons were mostly in phase from the mid-1960s. As for Auckland and Kaitaia, autumn showed the least temperature increase in the 1980s and spring the most.

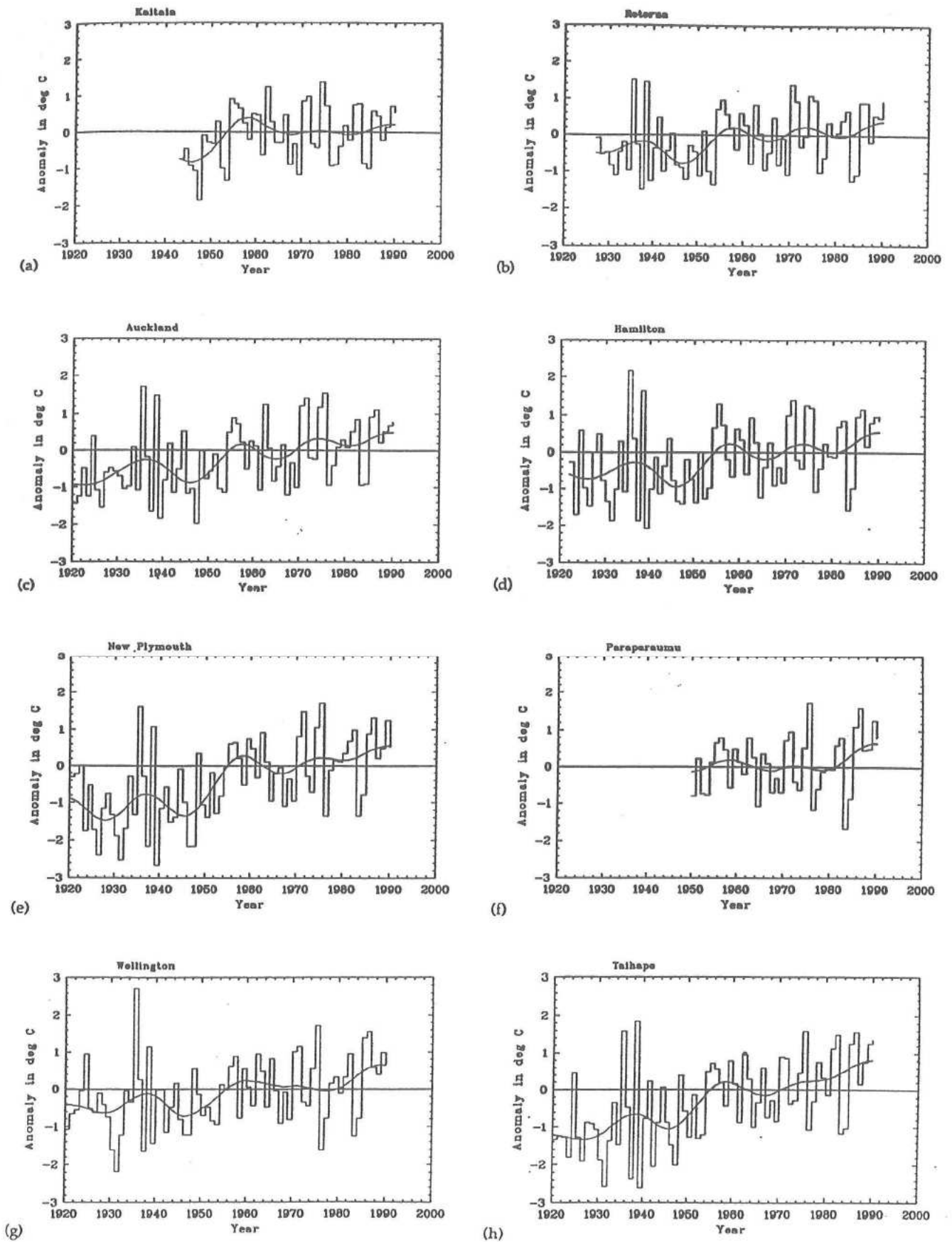


Figure 9 Summer temperature anomalies and filtered series at North Island stations

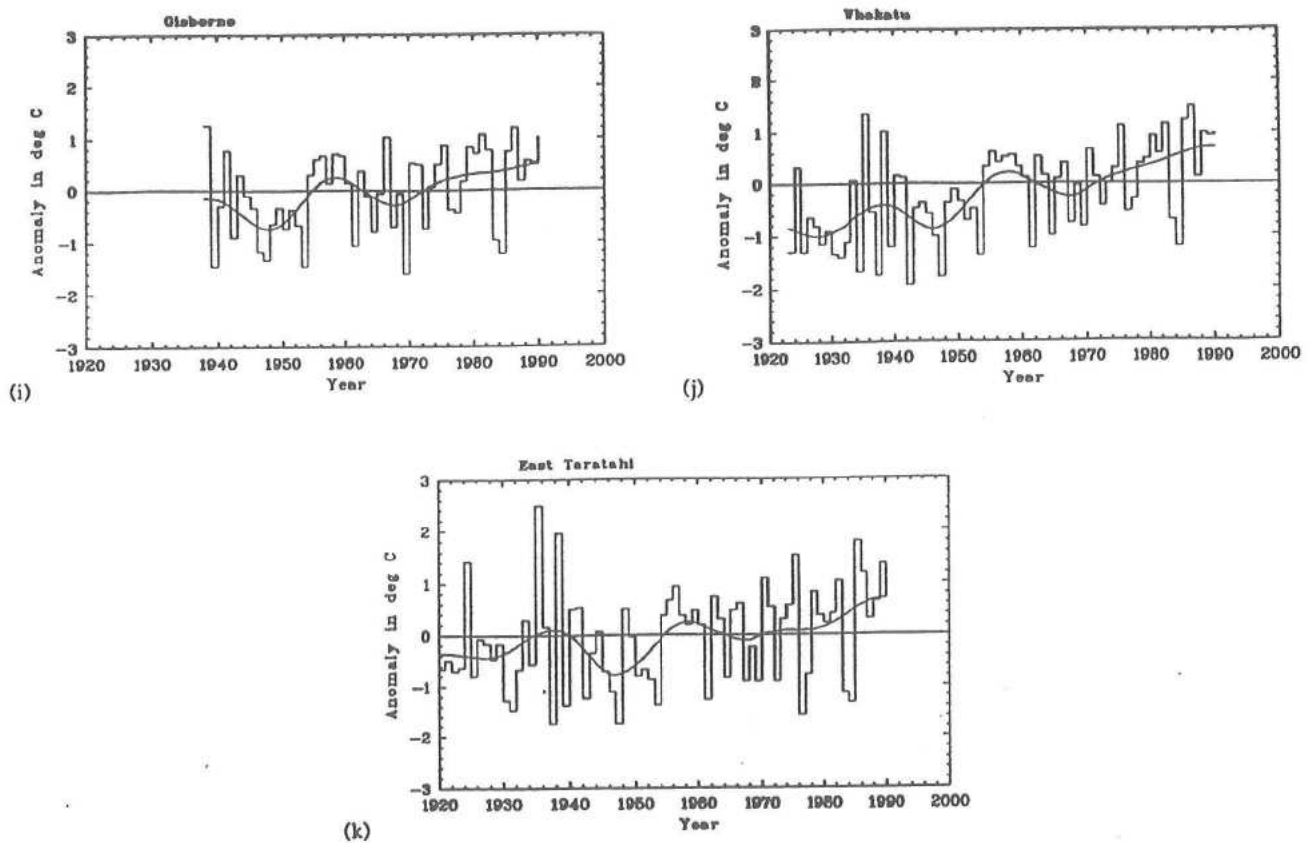


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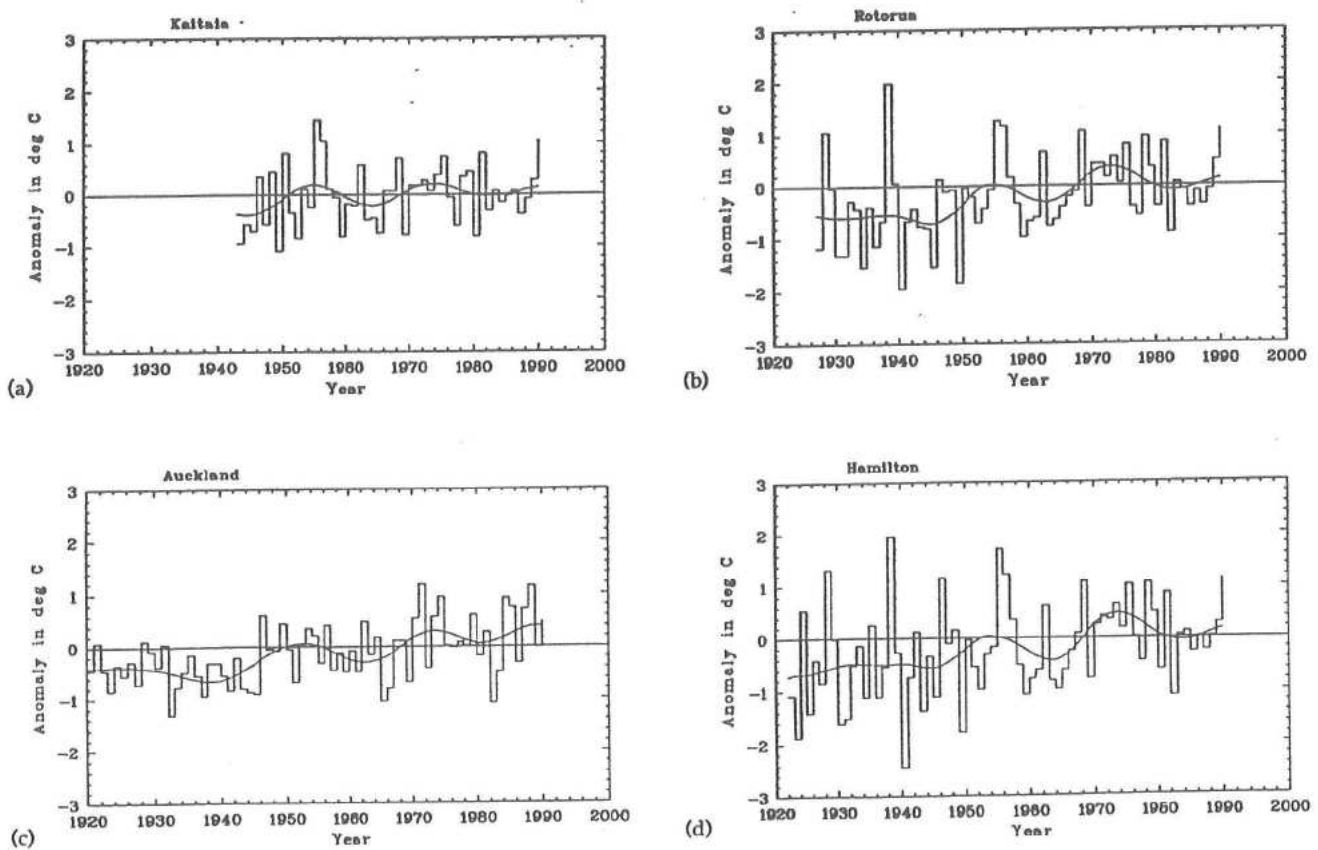


Figure 10 Autumn temperature anomalies and filtered series at North Island stations

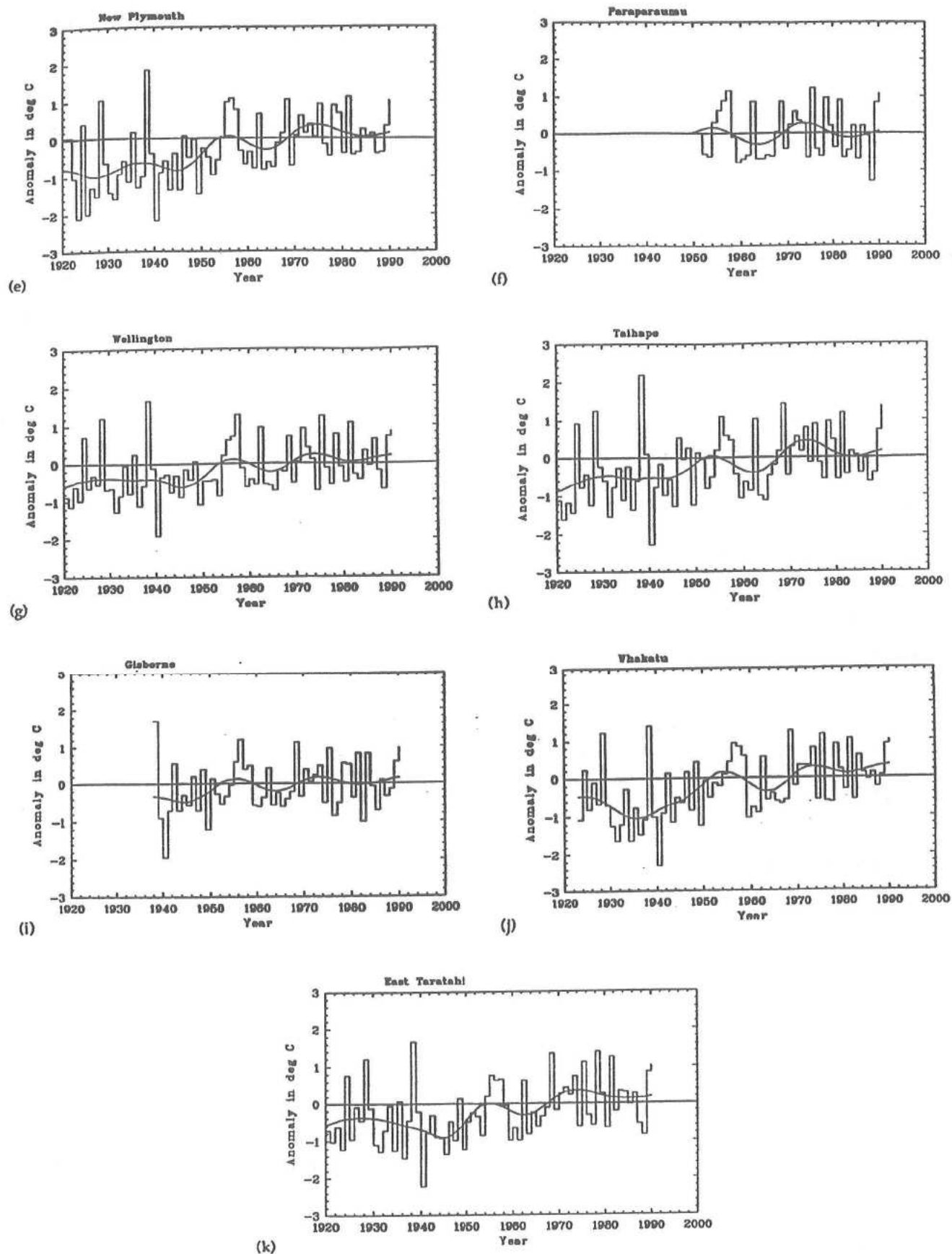


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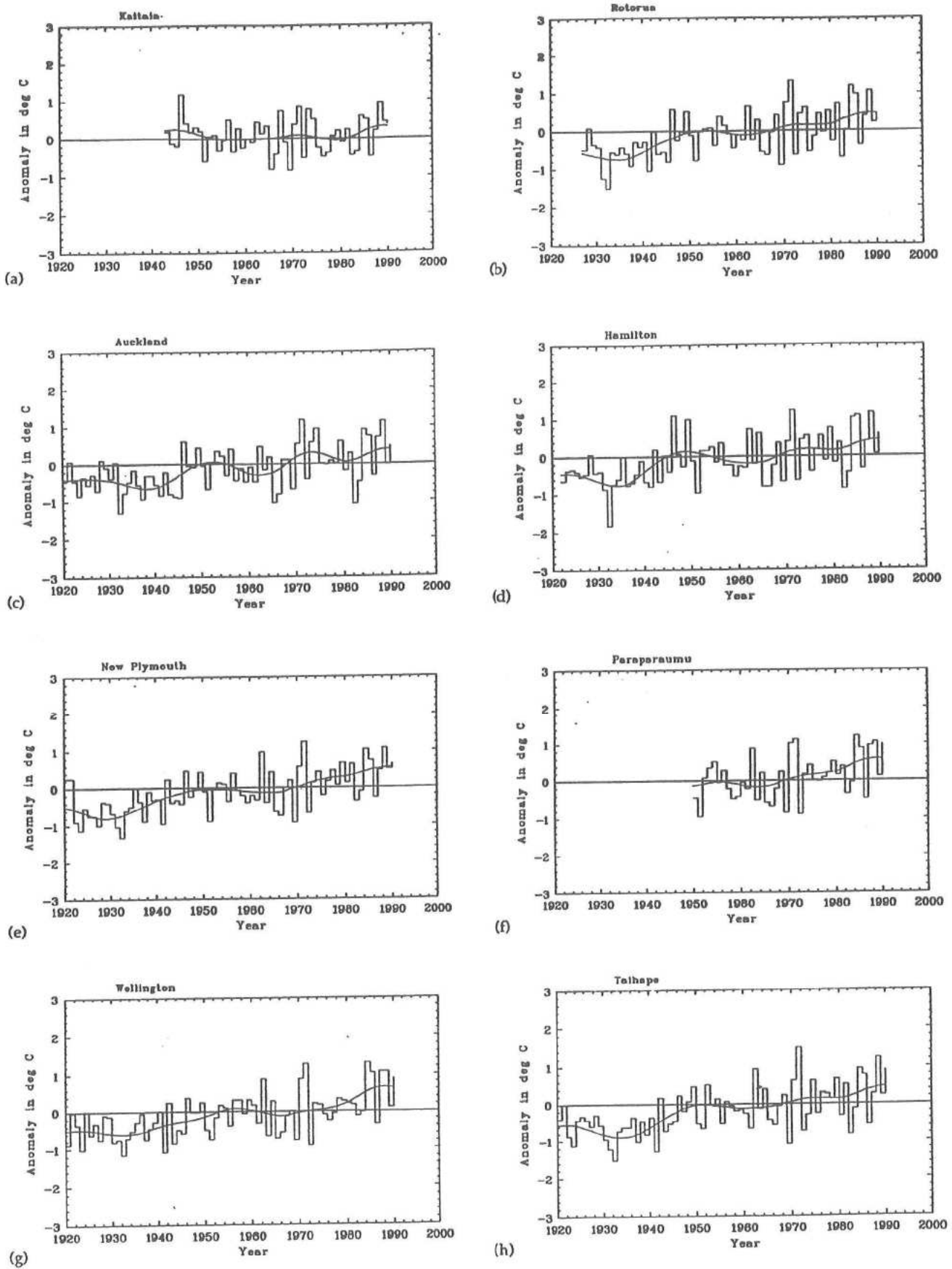


Figure 11 Winter temperature anomalies and filtered series at North Island stations



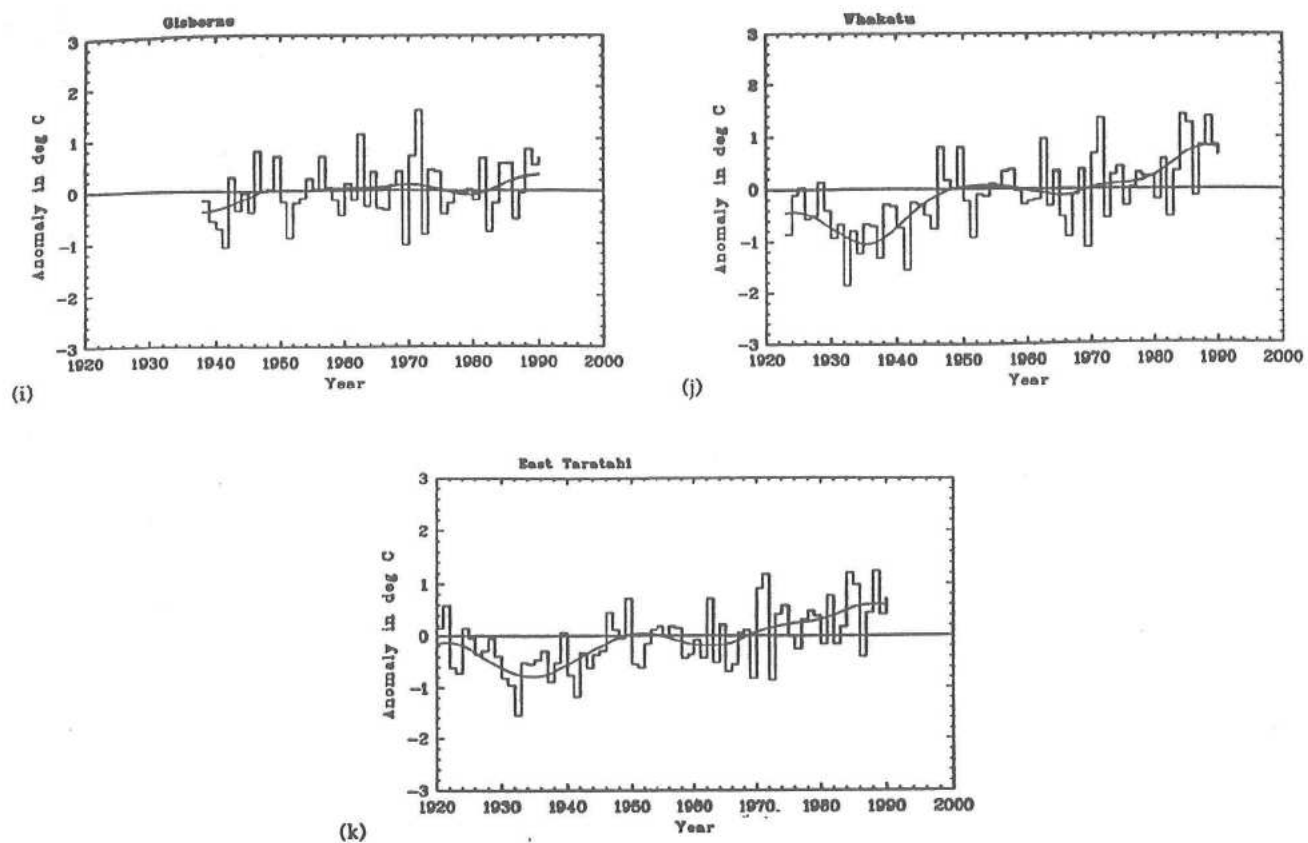


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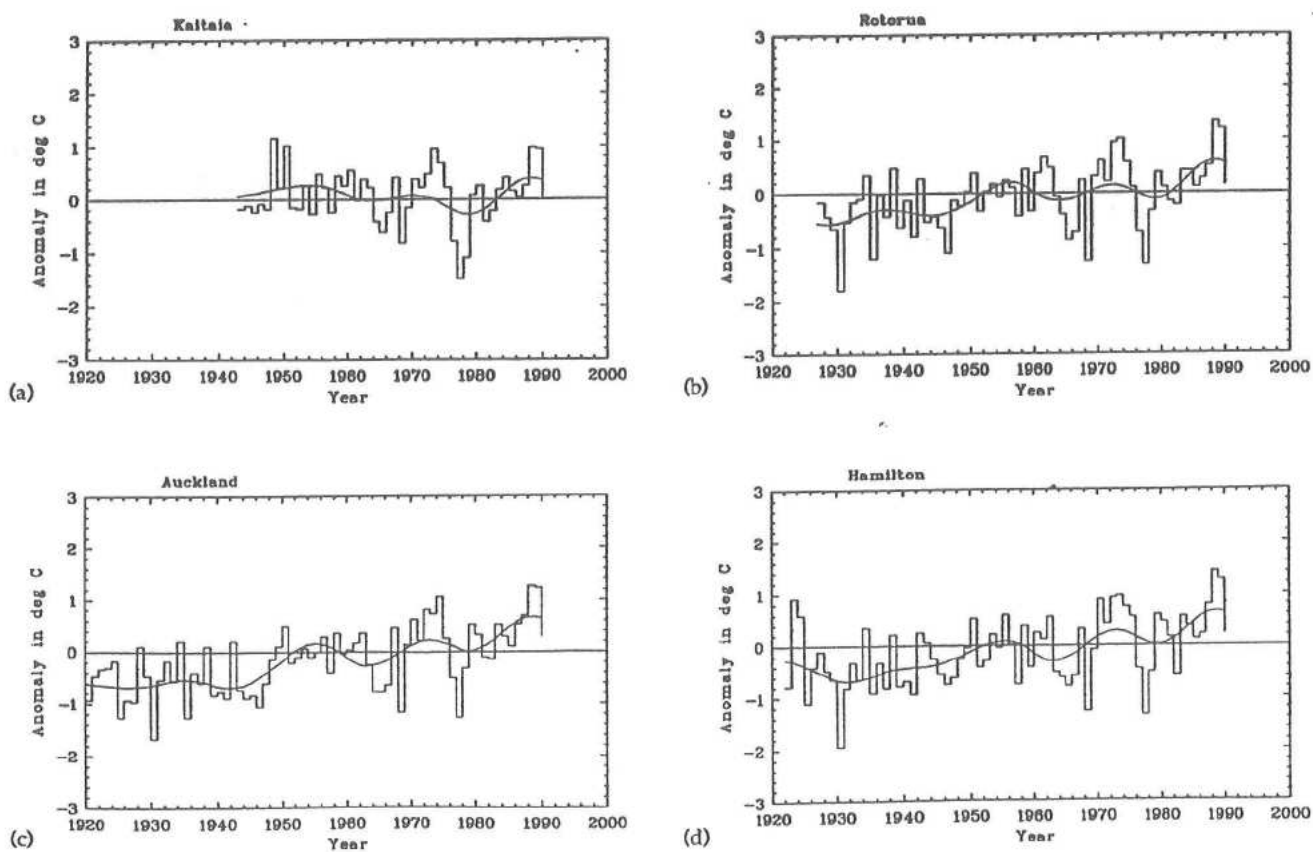


Figure 12 Spring temperature anomalies and filtered series at North Island stations



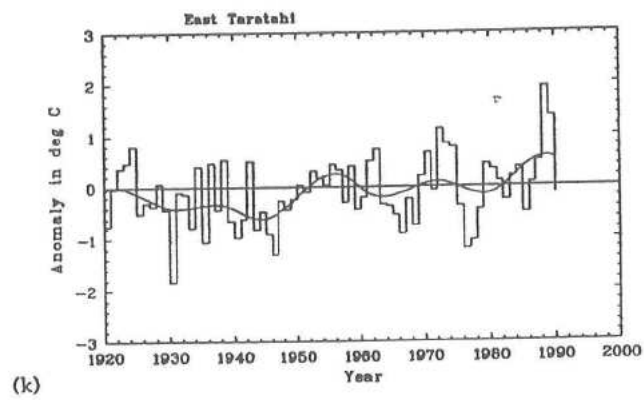
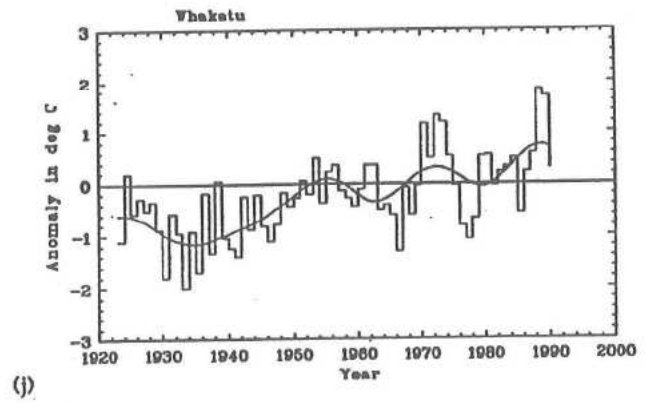
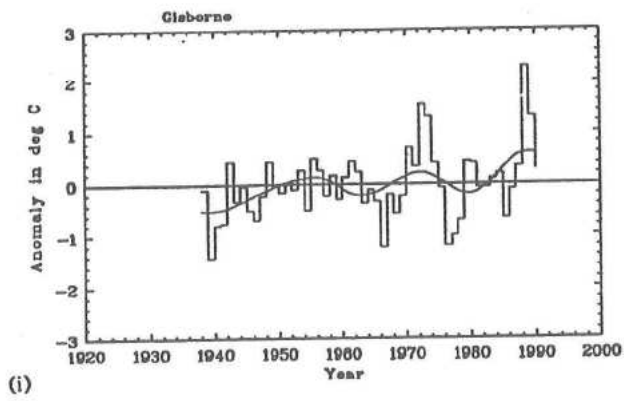
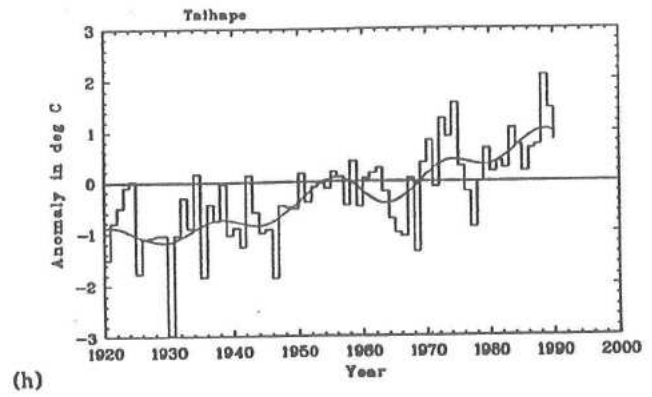
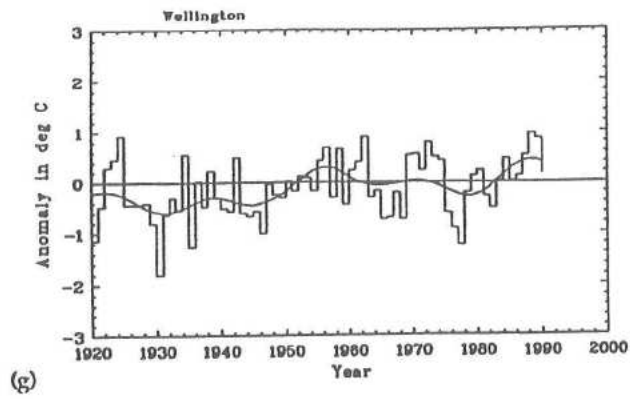
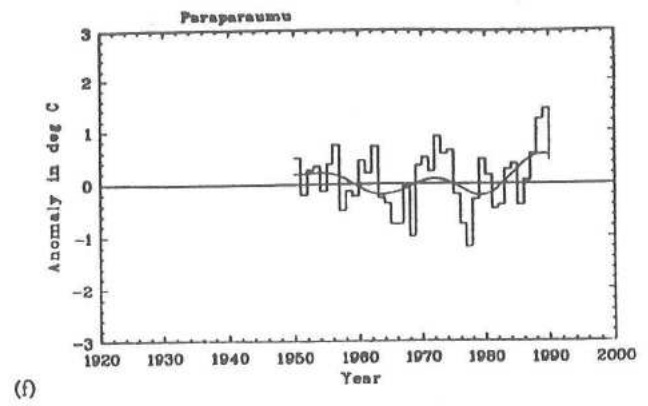
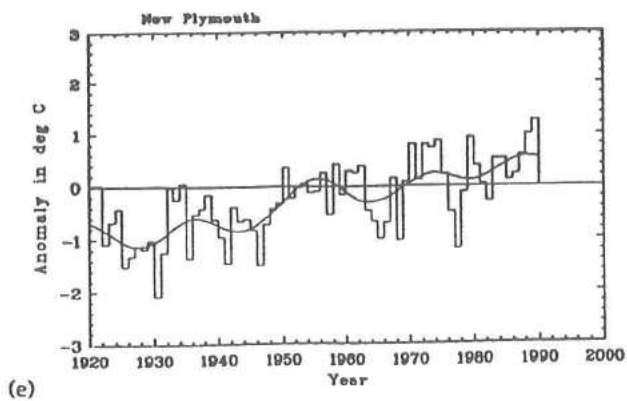


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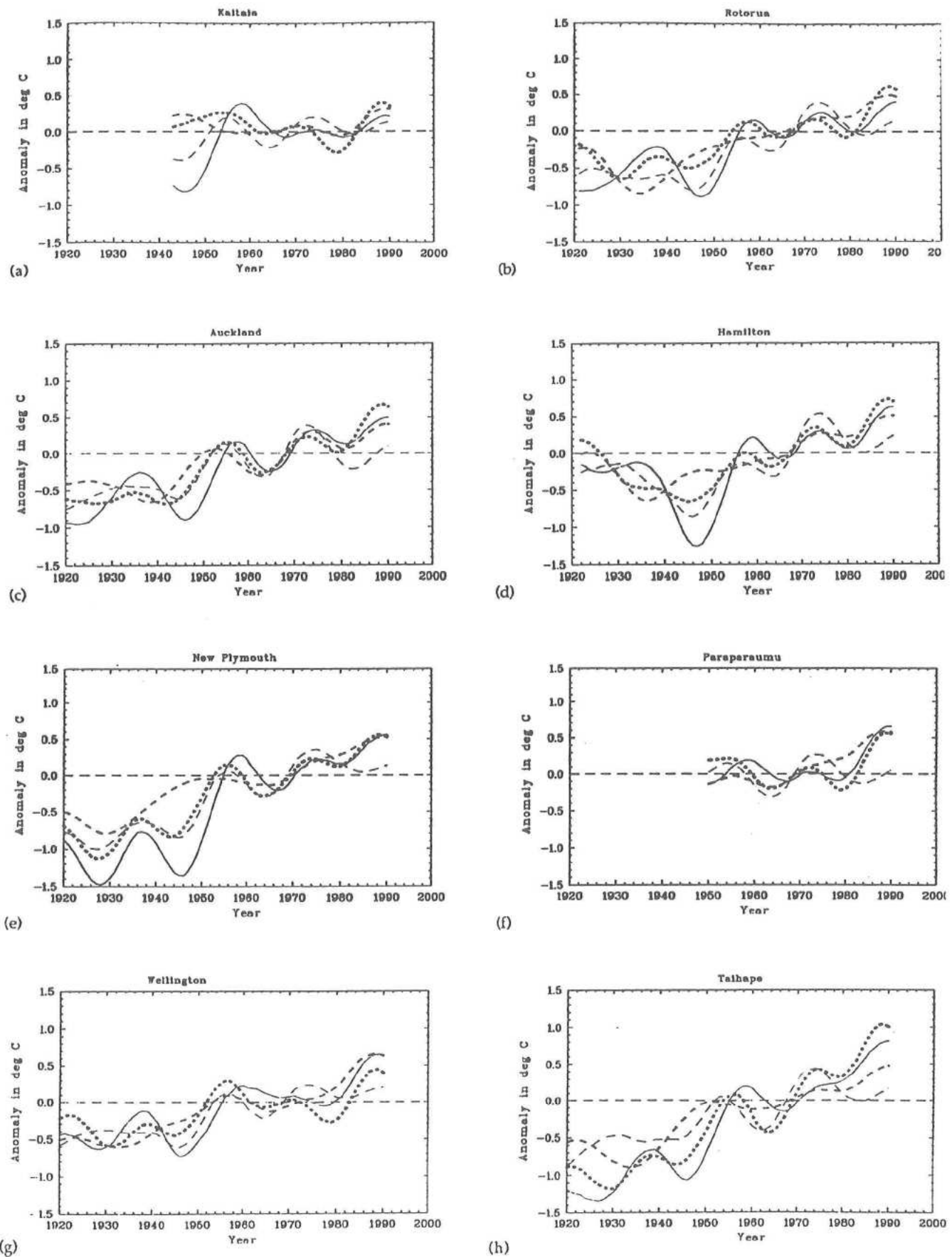


Figure 13 Filtered seasonal temperature anomalies at North Island stations

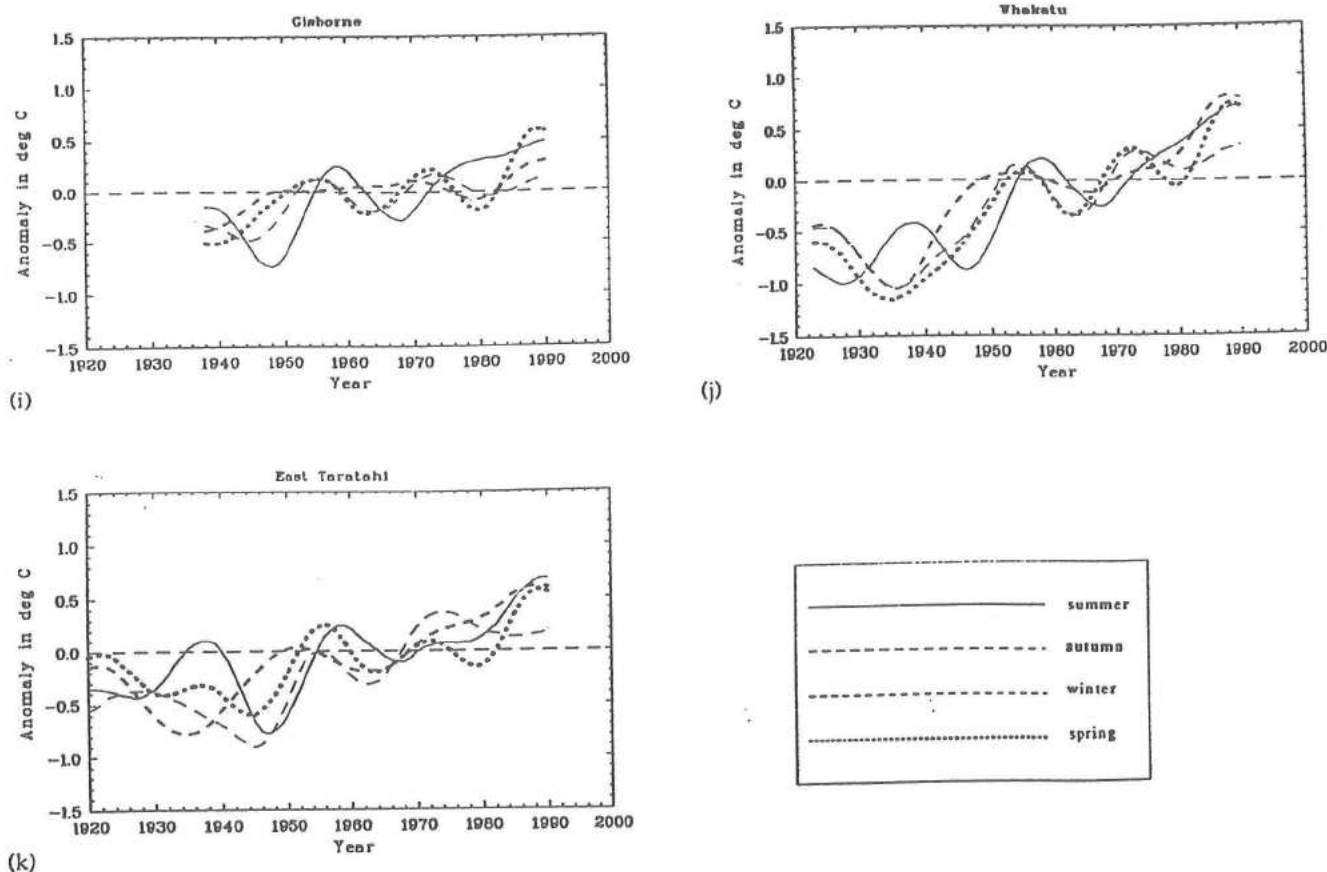


Figure 13 (continued)

Rotorua was similar to Hamilton. Initially winter was different from the other seasons which were mostly in phase, especially from the mid-1950s. By the late 1980s all seasons were warmer than normal with spring and winter having greater increases than the other seasons. Autumn had the smallest departures above normal.

Paraparaumu showed similar characteristics to other stations in autumn having the smallest temperature increase in the 1980s, and comparable increases in other seasons. The seasonal curves were mostly in phase.

Wellington's seasonal curves had no clear pattern. All seasons showed temperature increases above normal in the 1980s, with autumn having the least and winter and summer the most.

In the east at Gisborne, summers were coolest in the 1940s. Winters were close to normal from the late 1940s to the late 1970s. In the 1980s all seasons warmed, with autumn the least and spring the most.

Whakatu was different from the other North Island stations because of temperature departures below normal were smaller in the 1920s compared with other stations. At other stations, summers were much cooler in the early part of the record. In the 1930s spring had the greatest departure (1.3 °C) below normal and summer the least. In the 1980s, all seasons showed warming with autumn the least and winter the most.

East Taratahi showed some similarities to Whakatu, such as the summer temperature increases in the 1930s. Autumns were coolest in the 1940s, which was different from most other stations. In the 1980s all seasons showed temperature departures above normal with autumn having the least and the other seasons similar warming.

### Summary for the North Island

Almost all stations have below normal seasonal temperatures until the early 1950s. Summers were coolest in the early part of the record, especially at New Plymouth and Taihape. Most of the major differences among the seasons occurred in the period prior to about 1950 and in the last decade at many stations. In the 1980s autumn showed the smallest temperature increases and summer and winter often the greatest. A cool period occurred prior to the early 1950s, followed by fluctuations about normal. In the 1980s seasons other than autumn have shown varying degrees of warming. No overall trend is apparent after the 1950s.

### Seasonal variations at South Island sites

Figures 13-16 a-j show the seasonal annual temperature curves for the South Island stations. The format is the same as figure 3. For comparison purposes, all four seasonal smoothed curves are plotted for each station in figure 17 a-j. Each station is discussed separately.

On the west coast, at Hokitika, departures were largest in autumn in the 1920s, while the other three seasons were not as great. After a small temperature increase in the 1930s all seasons, except winter, had temperature decreases in the 1940s, with the largest decrease occurring in summer. Winter temperatures, on the other hand, continued to increase until about 1950, after which winters were close to normal until the mid-1970s, when further increases occurred. Autumns were warmer in the mid-1970s, before returning to normal in the 1980s. The other three seasons all showed warming in the 1980s, in sharp contrast to autumn.

At Milford Sound, the below normal departures in the 1940s were similar to Hokitika, with summer again showing the greatest decreases and winter the least. From the mid-1950s to mid-1970s, the temperatures for all seasons increased by about 0.4-0.5 °C, but at different times. After the cool period of the 1940s, summer experienced the next greatest seasonal cooling during the late 1970s-early 1980s. Winter, summer and spring temperatures increased 0.3-0.6 °C in the 1980s, while those for autumn decreased about 0.2 °C, which was greater than Hokitika.

In the northern part of the South Island, at Appleby and Blenheim, there are some similarities and some major differences shown by the seasonal graphs. There was less cooling at Appleby and Blenheim than Hokitika in the early part of the record.

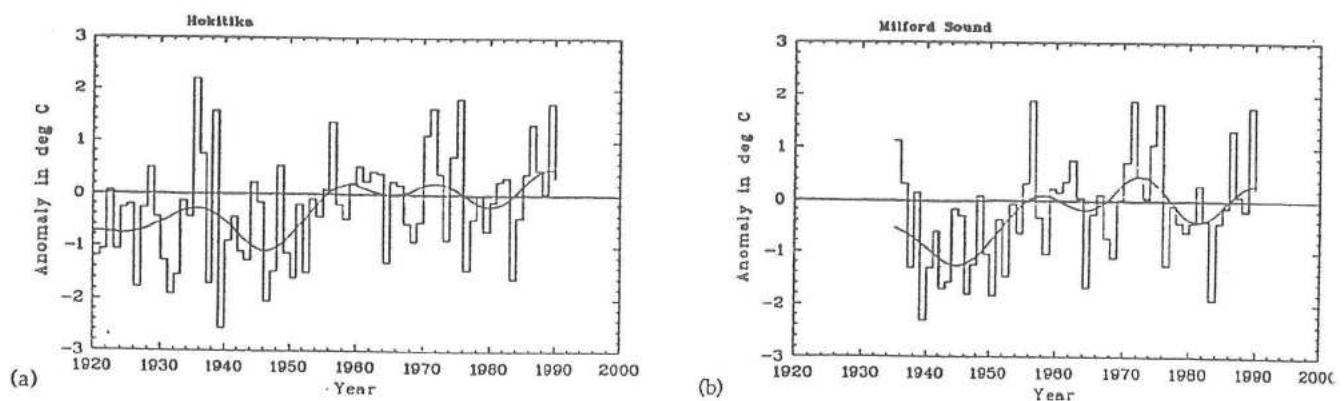


Figure 14 Summer temperature anomalies and filtered series at South Island stations

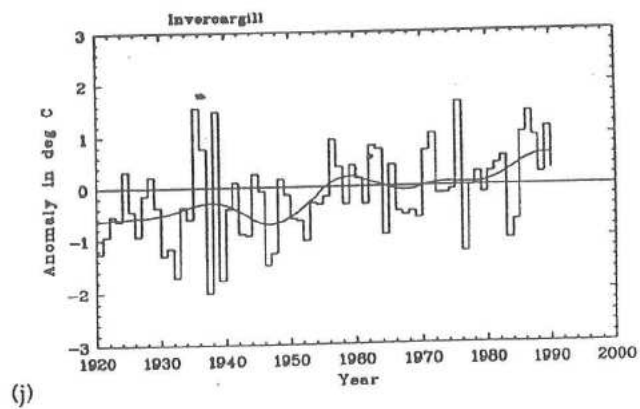
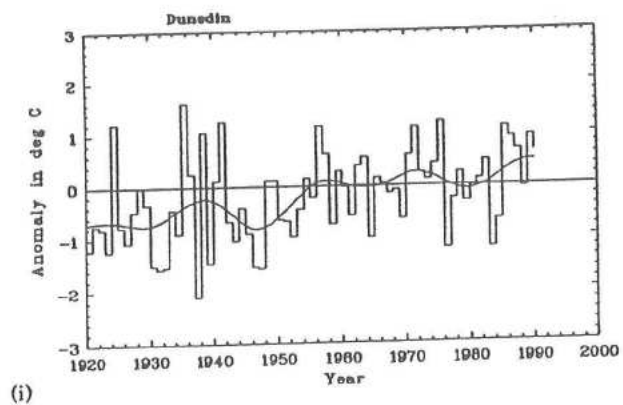
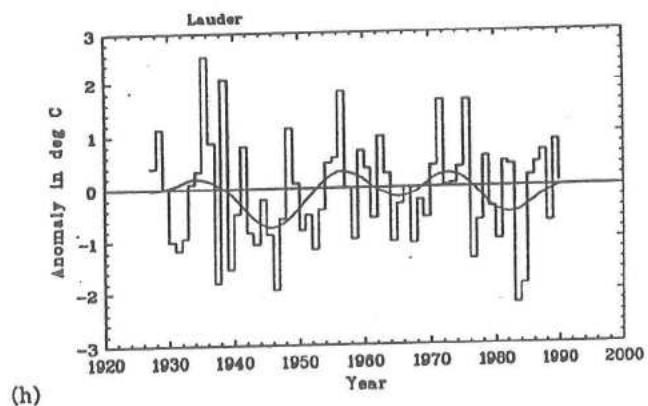
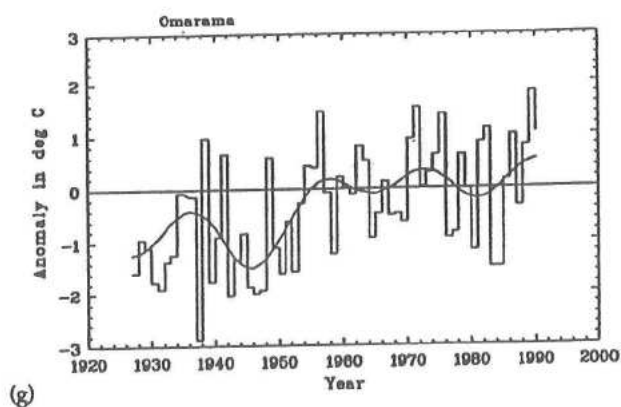
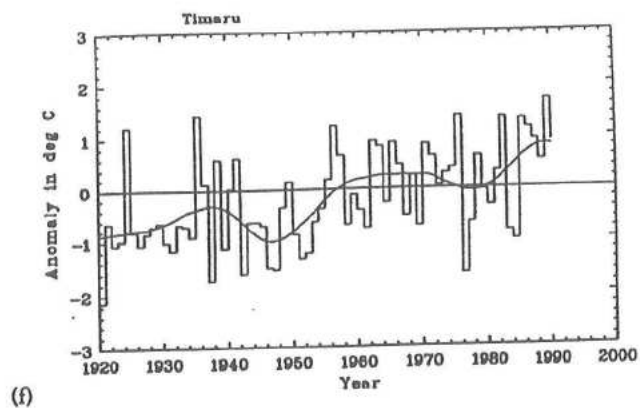
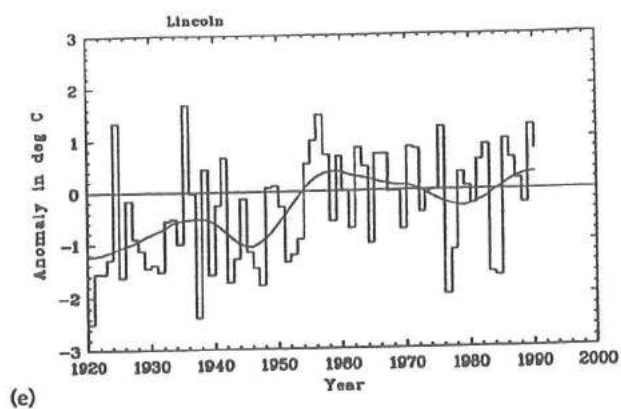
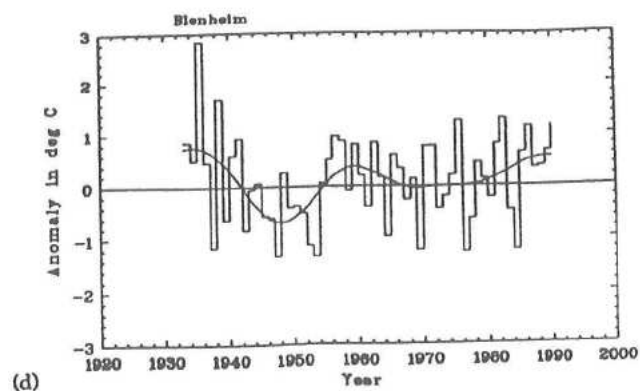
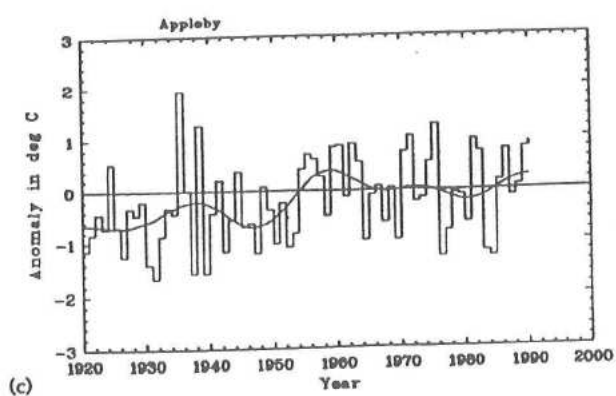


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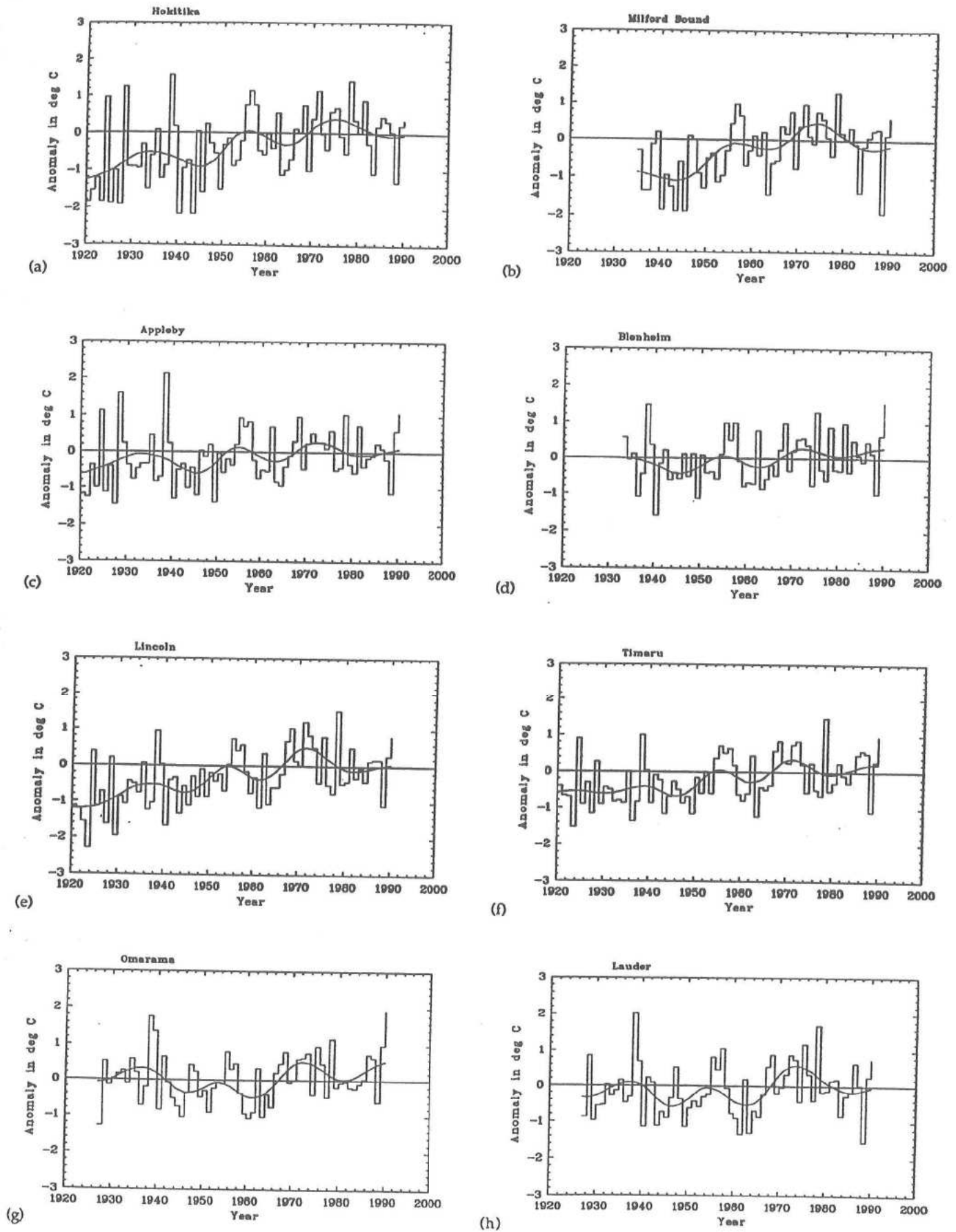


Figure 15 Autumn temperature anomalies and filtered series at South Island stations

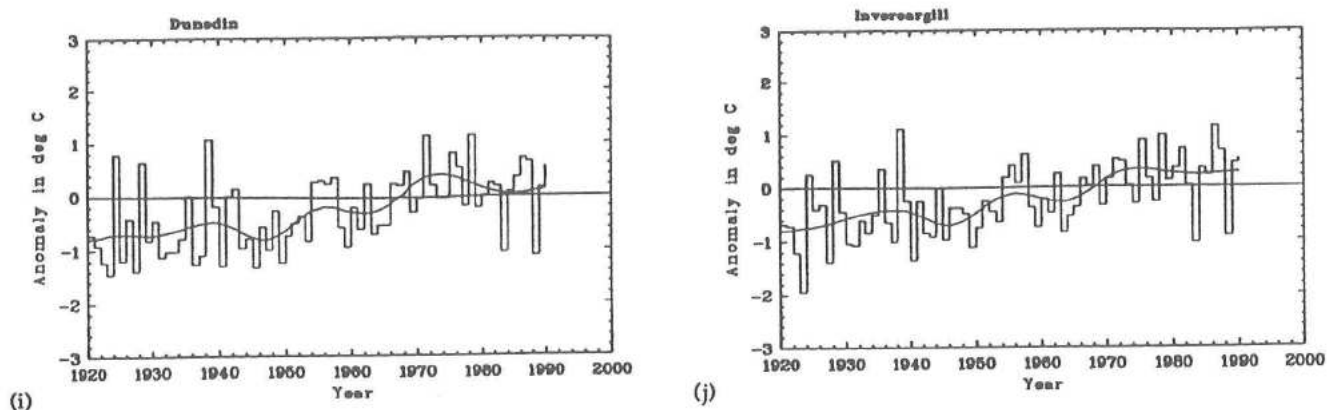


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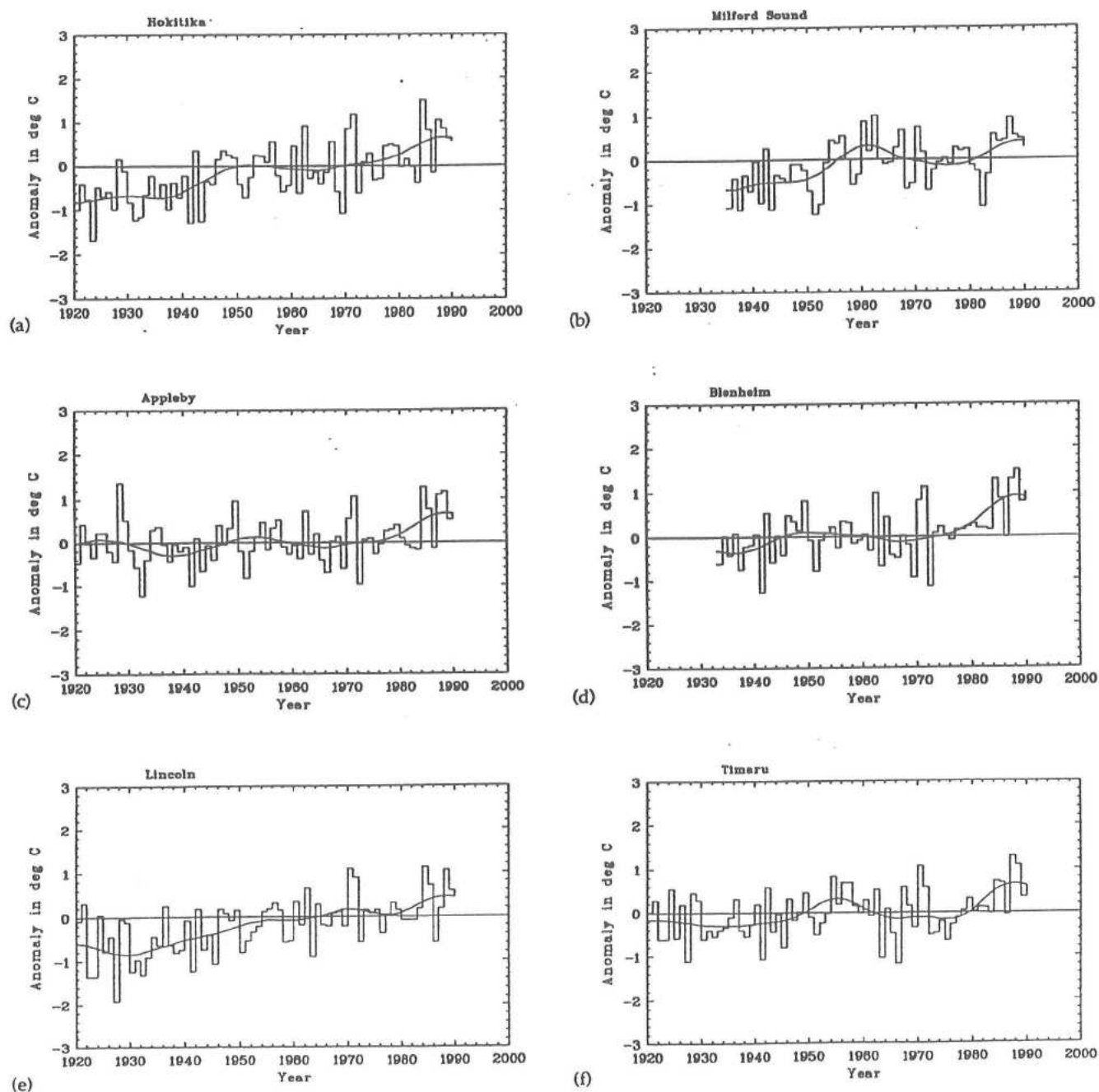


Figure 16 Winter temperature anomalies and filtered series at South Island stations



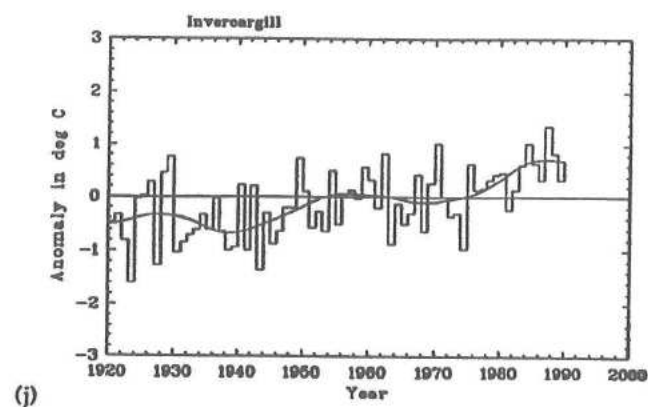
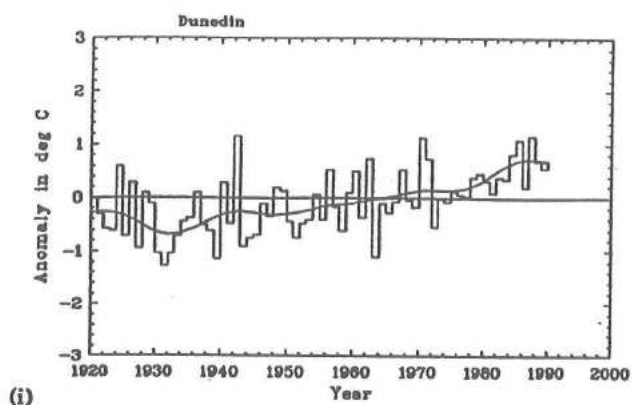
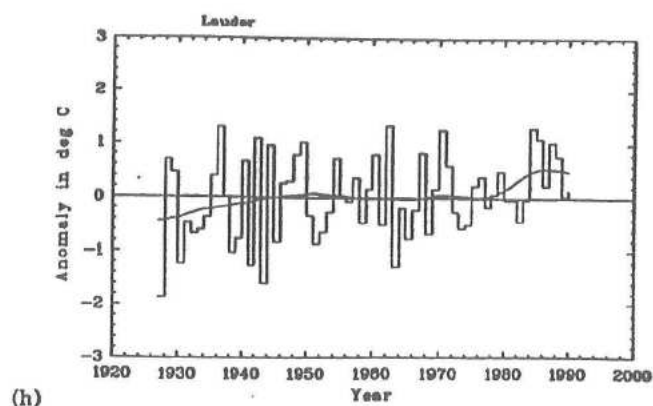
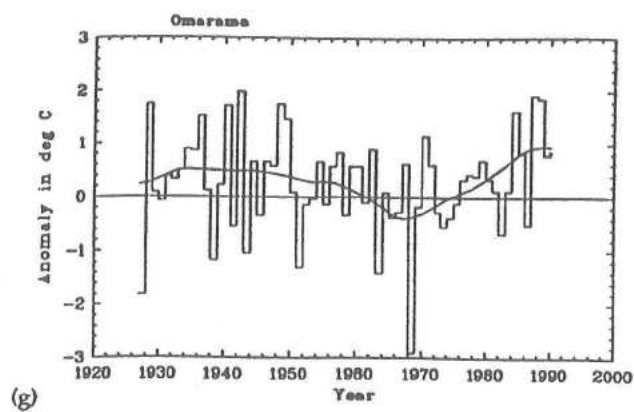


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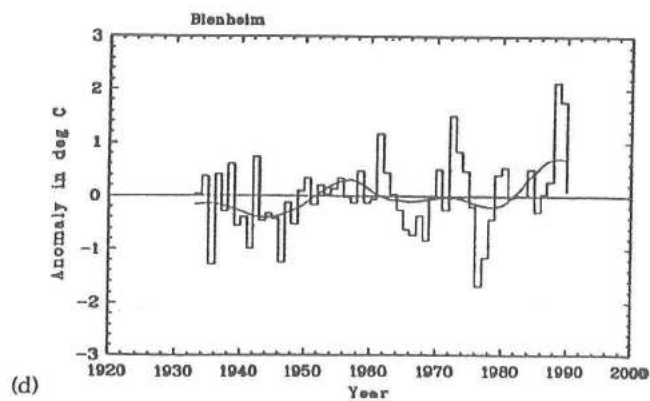
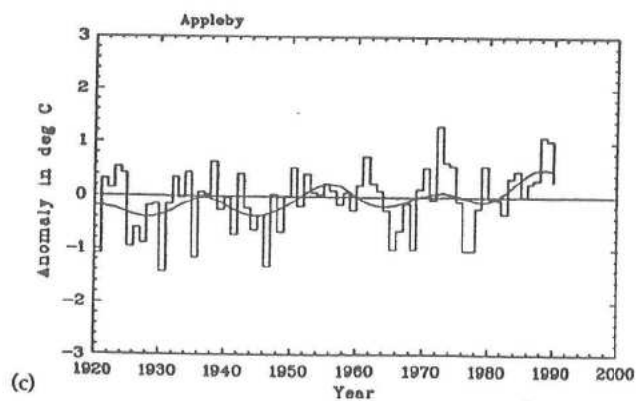
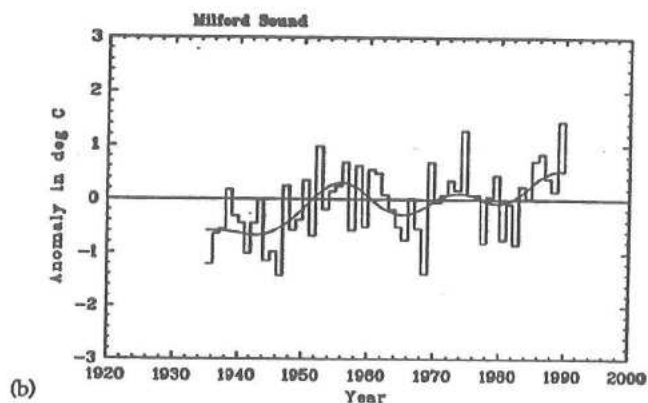
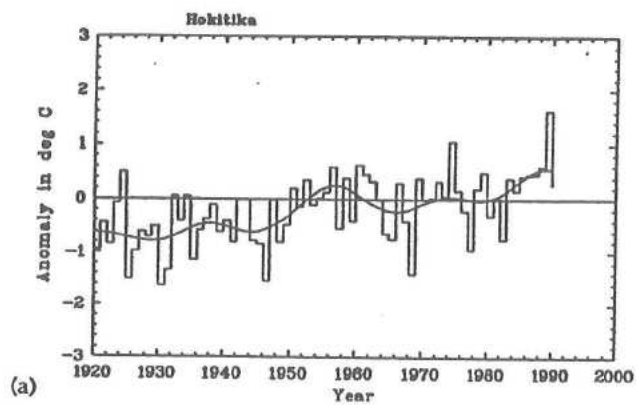


Figure 17 Spring temperature anomalies and filtered series at South Island stations

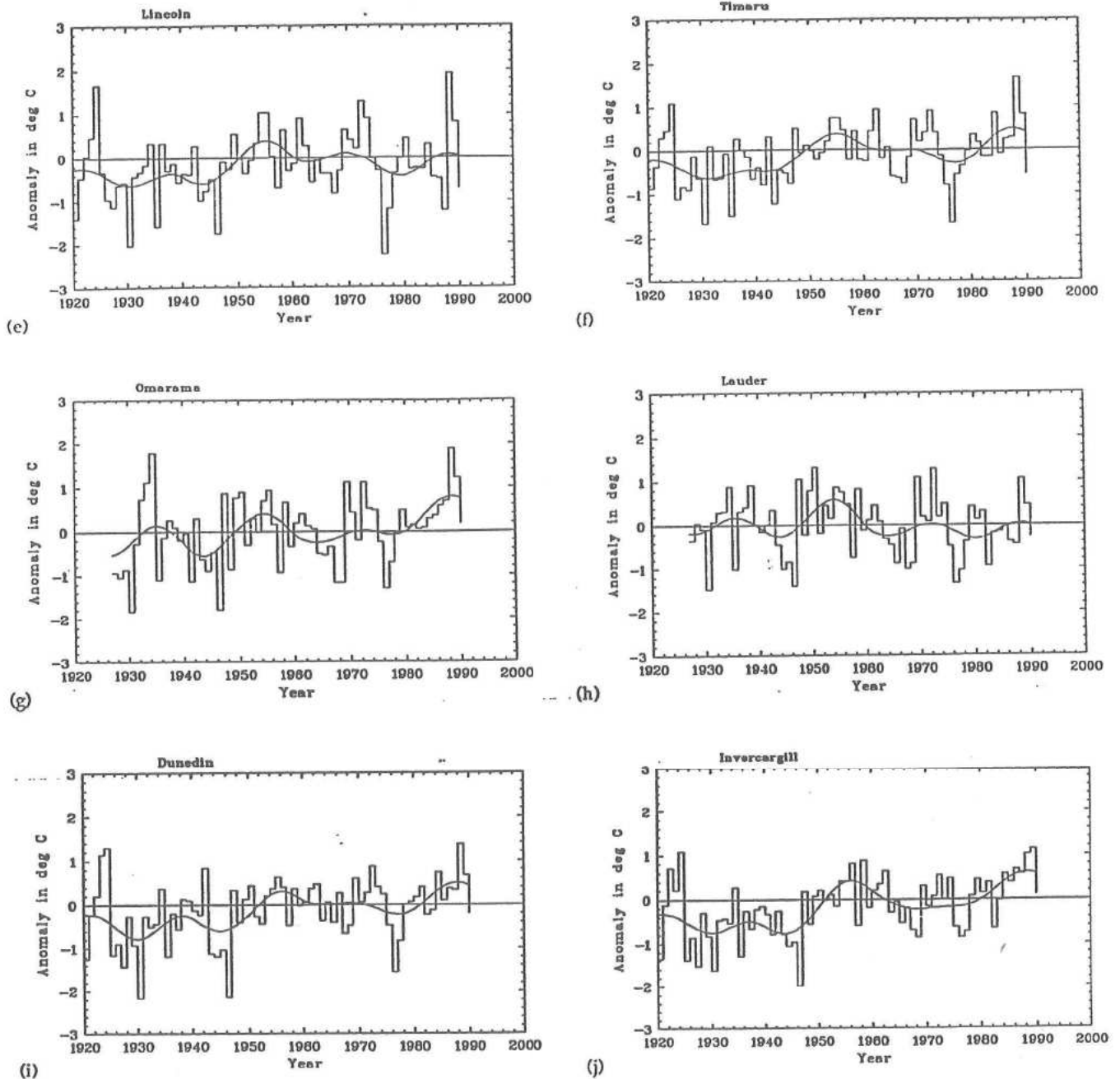


Figure 17 (continued)

At Appleby, in the 1920s, winter was the only season warmer than normal, while summer showed the most cooling. Winter also showed the smallest fluctuation about the normal of all the seasons, except in the 1980s, when it showed the largest temperature increases. After temperatures for the other three seasons increased in the 1930s, they decreased in the 1940s. Again summer had the greatest decrease. In the period 1950-1980, spring, summer and autumn were warmer than normal, although at different times. In the 1980s all seasons were above normal, with winter the most and autumn the least. From the late 1970s winter was the first season to show warming and there were lags of several years as spring, summer and autumn followed suit.

Warm summers occurred in the 1930s at Blenheim, in contrast to Appleby where summers were cool. This was followed by a marked cooling in the 1940s. The other seasons showed similar characteristics to Appleby for the common part of their record, with the temperature increase in the 1980s being slightly greater.

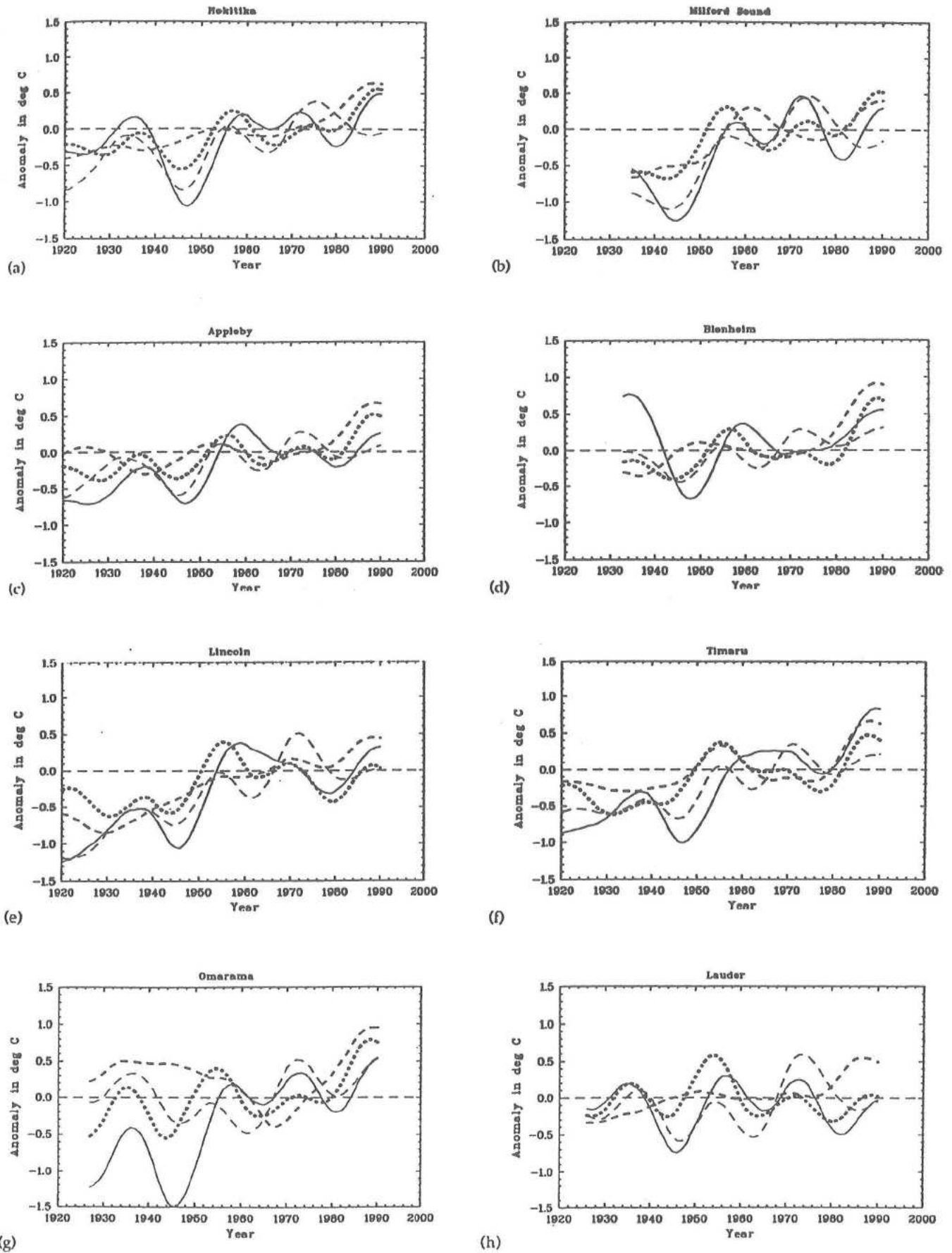


Figure 18 Filtered seasonal temperature anomalies at South Island stations

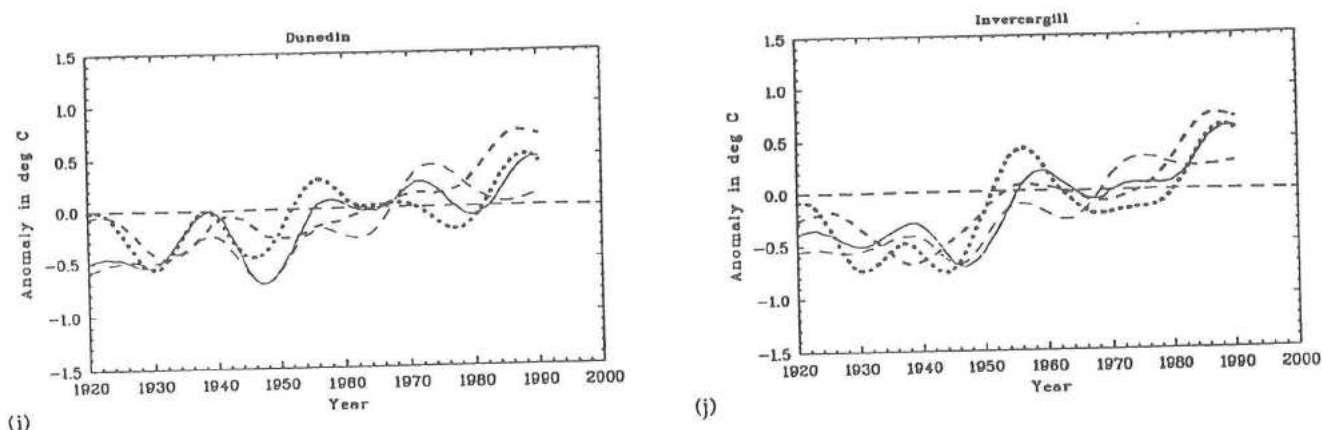


Figure 18 (continued)

Lincoln had seasonal characteristics similar to Hokitika, with slightly different values of the departures from normal. Summer showed the greatest temperature decrease in the 1940s and winter was close to normal for most of the period between 1950 and the late 1970s, before increasing in the 1980s more than the other seasons. The main difference in this latter part of the record was spring, which did not show any temperature increase comparable to those seen at Hokitika, Appleby and Blenheim. Autumn showed very little temperature increase, as for the other stations.

At Timaru, winter had the smallest negative departures and summer the largest in the early part of the record. There was a temperature increase in the late 1930s to early 1940s in all seasons except winter and was most marked in summer. Summers were warmer from the mid-1950s to the mid-1970s. In the 1980s, all seasons were warmer than normal with summer showing the largest increase and autumn the smallest.

The two inland basin stations, Omarama and Lauder have some similarities and some differences. At both places the changes in the seasons spring, summer and autumn were mostly in phase. Winter was quite different prior to the mid-1970s and the magnitude of the negative departures, especially for summer, were much larger at Omarama than Lauder and other stations as well.

At Omarama, winters were unusual because they were warmer until about 1960, with temperatures decreasing till the mid-1960s, then steadily increasing till the late 1980s. The other seasons showed temperature increases in the 1930s, major departures below normal in the 1940s and major increases into the 1950s. Summer showed the greatest extremes with respect to normal. There followed smaller temperature increases and decreases until the 1980s, when all seasons were warmer. Autumn, in the 1980s, showed a greater temperature increase than summer, in contrast to other South Island stations already discussed.

Winter was also different from the other seasons at Lauder in that initially, it had the greatest cooling in the 1930s, then increased to near normal in the late 1940s and remained close to normal until the mid-1970s. In the 1980s winter showed the largest seasonal warming. The other seasons were mostly in phase with fluctuations up to about 0.6 °C about normal during the period of record. As with other South Island stations discussed, summer had the greatest cooling in the 1940s. In the 1980s, in contrast to other stations, winter was the only season to show significant increases in temperature, whereas the others were close to normal. This is quite different from Omarama.

Further south at Dunedin and Invercargill, the seasons showed fairly similar characteristics, except that there was less cooling in autumn and summer in the 1920s, and more warming in autumn in the 1980s at Invercargill. Winter at both places showed less fluctuation about normal than the other seasons, having a steady rise after 1949 at Dunedin and only small temperature changes with respect to normal at Invercargill.

#### Summary for the South Island

As for the North Island, seasonal temperatures were cooler prior to the 1940s, then increased into the 1950s. The greatest summer decrease occurred in the 1940s, except at Dunedin. Seasonal cooling

in the early part of the record was less than other stations at Appleby and Lauder and similar to Wellington. In the early part of the record Omarama had the greatest difference between seasons. At most stations, autumn had the least warming in the 1980s. After the increase in temperatures in the 1940s there does not seem to be any trend in seasonal temperatures, although a number of stations recorded their largest increase above normal.

### Seasonal variations at Raoul, Chatham and Campbell Islands

The mean seasonal temperatures are shown in figures 19-22 a-c and the seasonal comparisons for each station in figure 23 a-c.

#### Raoul Island

The smoothed seasonal temperature curves were mostly in phase over the record. Winter showed the greatest decrease, cooling during the 1940s, and all seasons were below normal from 1940 to 1970. Spring showed the largest temperature increase in the 1970s, as well as the greatest variability. The least variability was in autumn. Temperature increases, in summer in the early 1970s, were absent in the 1980s. All seasons showed positive temperature departures in the late 1980s, with summer the greatest and autumn and winter the least.

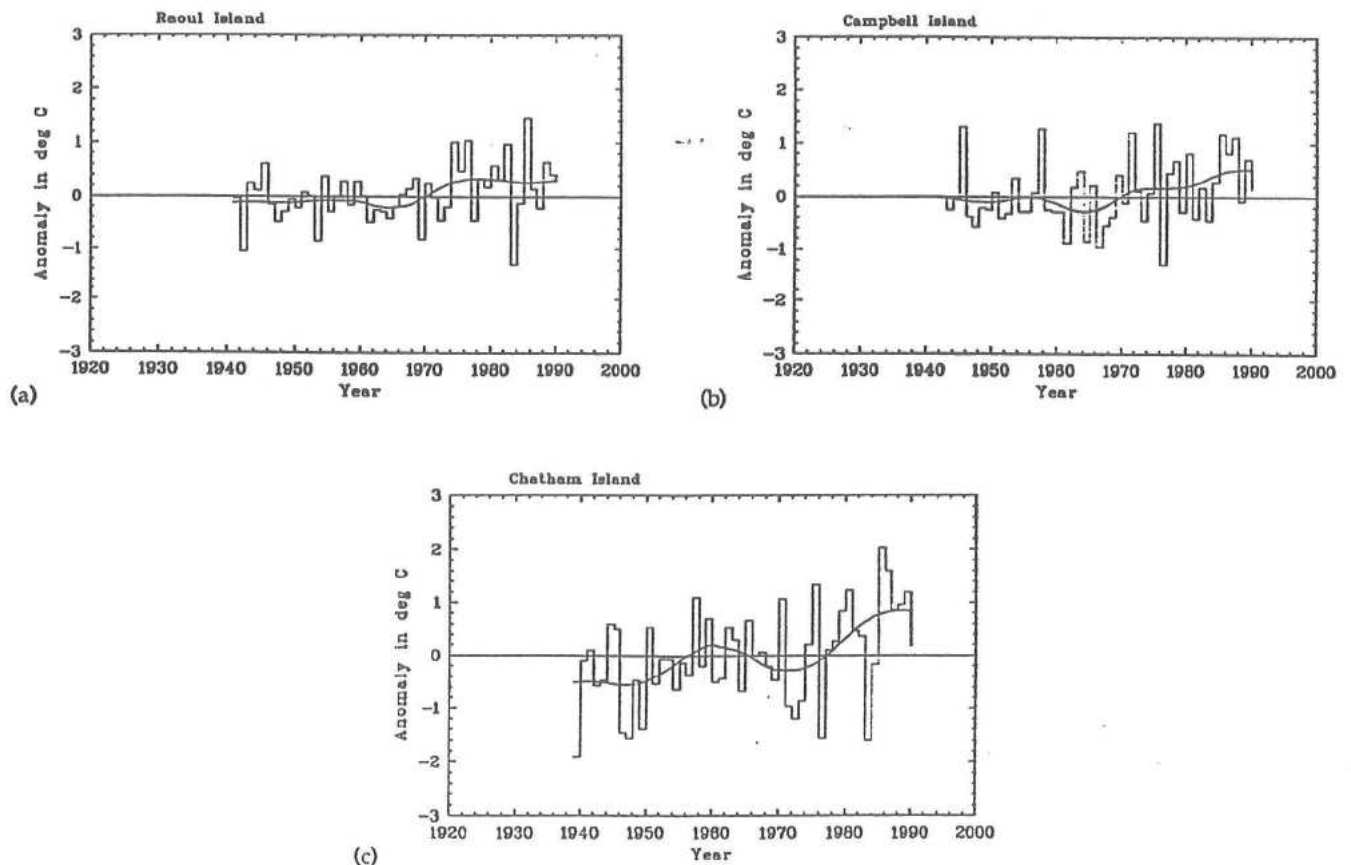


Figure 19 Summer temperature anomalies and filtered series at Raoul, Campbell and Chatham Islands

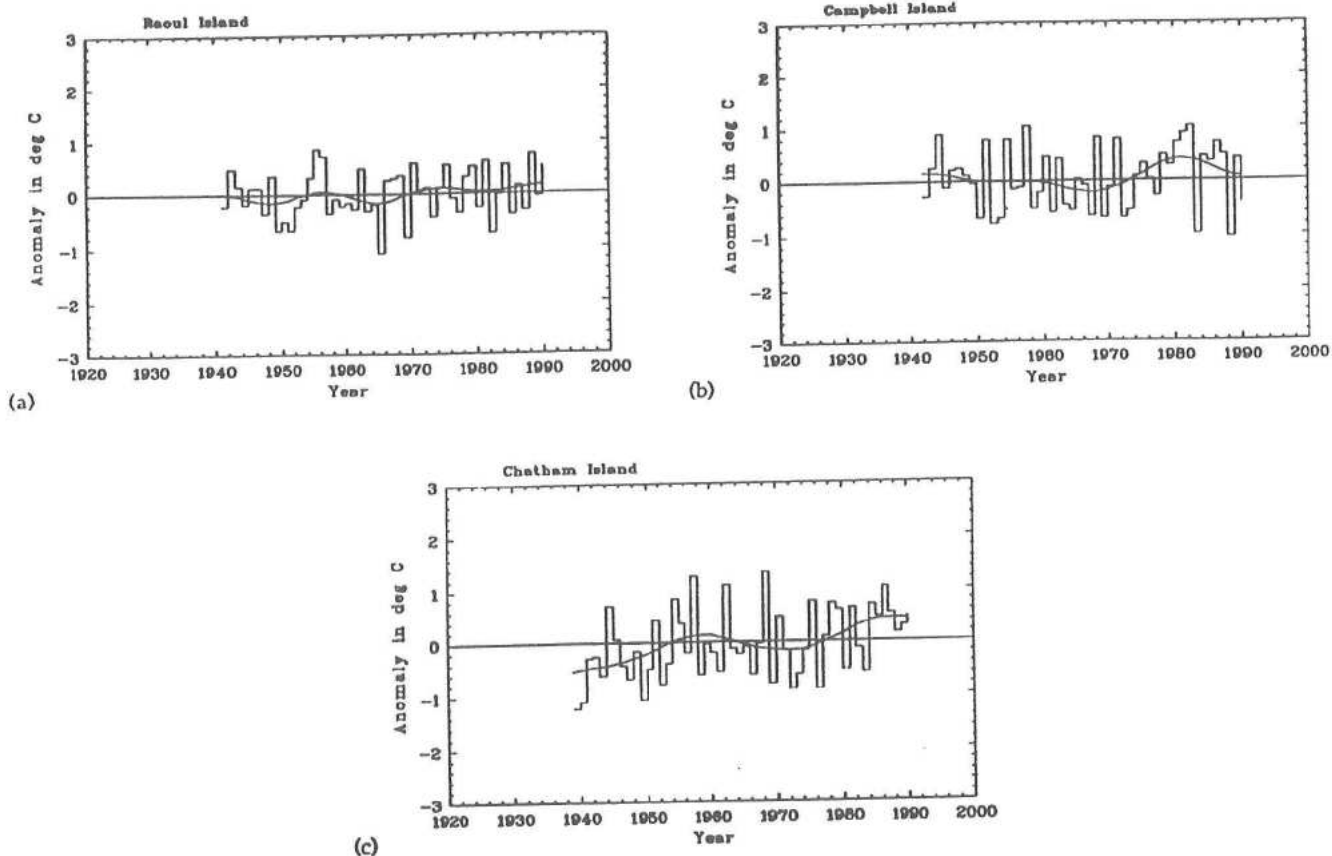


Figure 20 Autumn temperature anomalies and filtered series at Raoul, Campbell and Chatham Islands

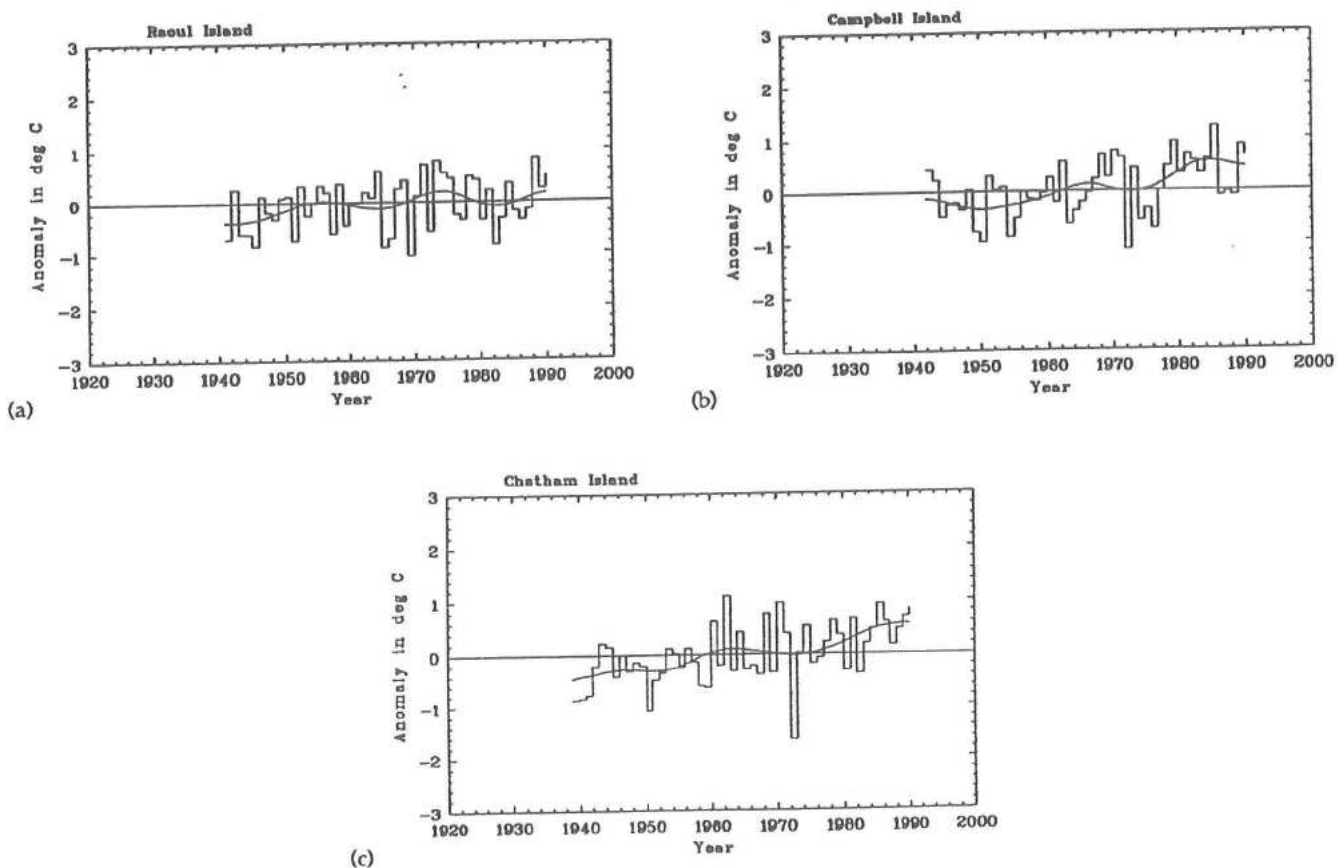


Figure 21 Winter temperature anomalies and filtered series at Raoul, Campbell and Chatham Islands

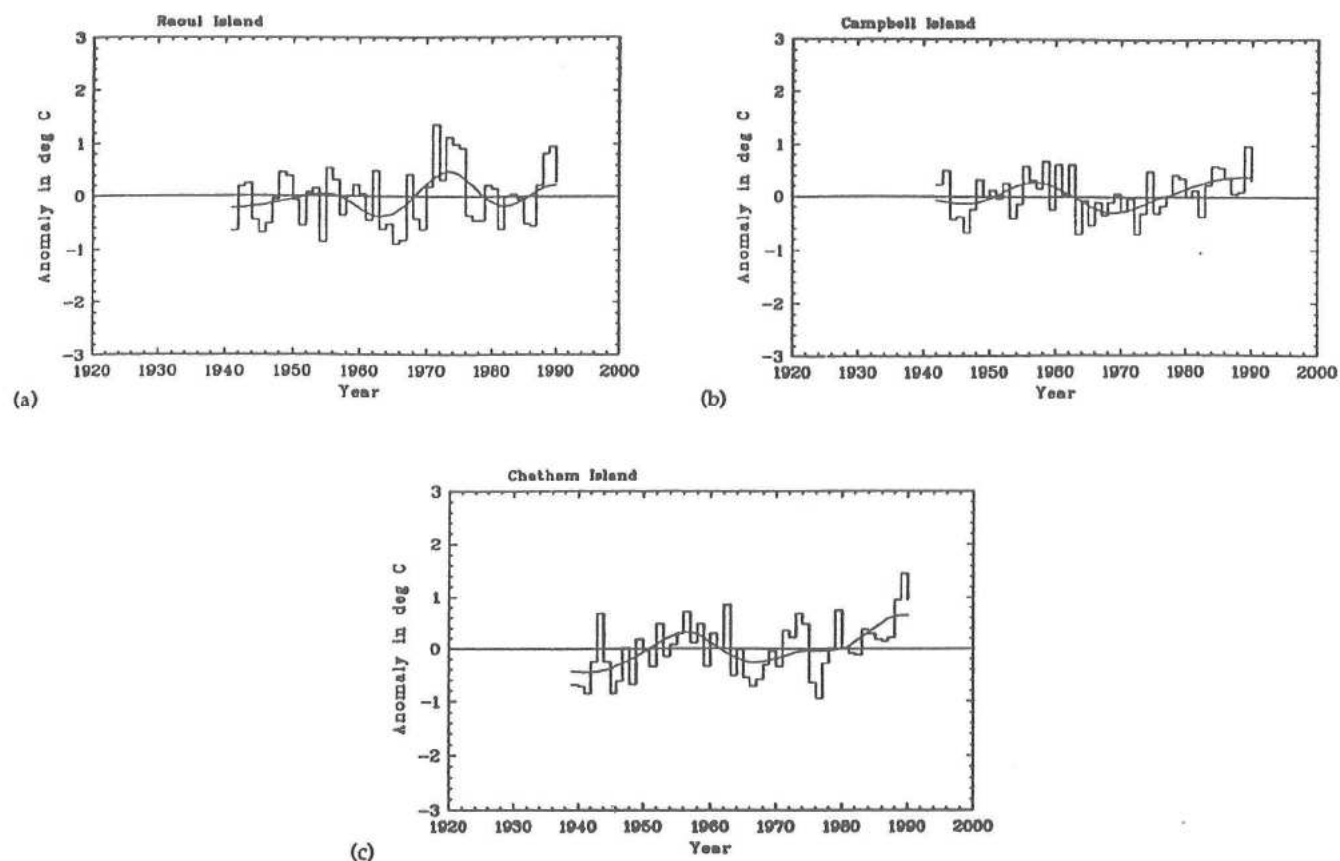


Figure 22 Spring temperature anomalies and filtered series at Raoul, Campbell and Chatham Islands

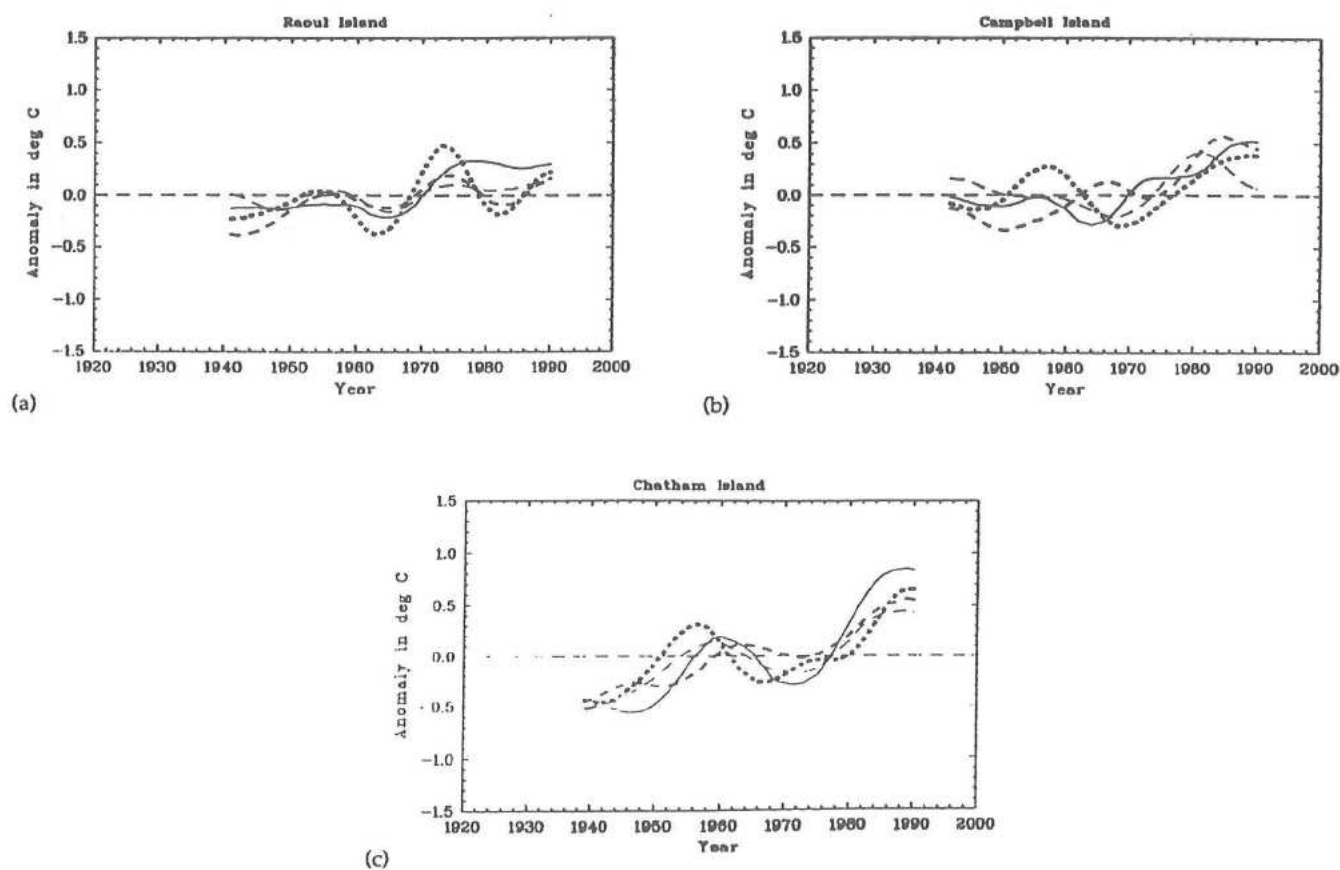


Figure 23 Filtered seasonal temperature anomalies at Raoul, Campbell and Chatham Islands



### Chatham Island

The greatest negative temperature departures at Chatham Island occurred in the 1940s. Summers were coolest in the 1940s, the greatest variability and the greatest temperature increases in the 1980s. Winter, after warming later than the other seasons in the 1950s, did not deviate from normal until the mid-1970s. Spring temperatures increased in the 1950s. This was more than any other season until the 1980s, when all seasons had major temperature increases above normal. The greatest warming occurred in summer and the least in autumn.

### Campbell Island

By chance the summer and autumn smoothed temperature curves coincided, although the individual annual departures from normal were not identical. Spring exhibited the most regular departures from normal. Winter had the greatest negative departures and for the longest time (up to about 1960). All seasons had temperature increases above normal in the 1970s and into the 1980s. Summer and autumn temperatures increased more than winter and spring temperatures.

## Decadal trends in seasonal temperatures

For seasonal temperatures, individual decades can be compared with respect to decreases or increases relative to the reference period 1951-1980 (Houghton et al, 1992). This can be done for mean, maximum and minimum temperatures by averaging the anomalies for each decade for all the stations. The anomalies are shown in table 4a (summer and autumn) and 4b (winter and spring).

The main features of the summer table are:

- All the summer anomalies in the 1981-1990 decade are positive, except Appleby and Lauder, whereas those for the decades 1921-1930 and 1941-1950 are negative.
- In the North Island, the greatest negative anomalies occurred at Taihape (-1.2 °C), during 1921-1930 and New Plymouth (-1.1 °C) during 1941-1950. The greatest positive anomaly was at Taihape (+0.7 °C) during 1981-1990.
- In the South Island, the greatest negative anomalies occurred at Omarama (-1.2 °C) closely followed by Milford Sound (-1.1 °C) during 1941-1950. The greatest positive anomaly occurred at Timaru (+0.6 °C).
- For the outlying islands, Chatham Island had the greatest negative anomaly (-0.4 °C) during 1941-1950 and the greatest positive anomaly (+0.6 °C) during 1981-1990.

The main features of the autumn table are:

- All the autumn anomalies in the 1981-1990 decade are positive, except Milford and Lauder, whereas those for the decades 1921-1930 and 1941-1950 are negative.
- In the North Island, the greatest negative anomaly occurred at East Taratahi (-0.7 °C), during 1941-1950, and the greatest positive anomaly during 1981-1990 at Whakatu (+0.3 °C).
- In the South Island, the greatest negative anomalies occurred at Lincoln (-1.1 °C) during 1921-1930. The greatest positive anomalies occurred at Omarama (+0.3 °C).
- For the outlying islands, Chatham Island had the greatest negative anomalies (-0.3 °C) during 1941-1950 and the greatest positive anomalies (+0.4 °C) during 1981-1990.

The main features of the winter table are:

- All the winter anomalies in the 1981-1990 decade are positive, whereas those for the decades 1921-1930 and 1941-1950 are negative, except Hamilton, Blenheim, Omarama and Lauder.

**Table 4** Seasonal temperature anomalies ( $^{\circ}\text{C}$ ) relative to the 1951-1980 climatology for reference climate stations for selected decades.

**a Summer and autumn**

Season	Summer			Autumn		
Decade	1921-30	1941-50	1981-90	1921-30	1941-50	1981-90
<b>North Island</b>						
Kaitiaia			0.2			0.1
Auckland	-0.7	-0.7	0.4	-0.6	-0.4	0.0
Hamilton		-0.7	0.4		-0.4	0.1
Rotorua		-0.6	0.2		-0.6	0.1
New Plymouth		-1.1	0.4		-0.7	0.1
Taihape	-1.2	-0.9	0.7	-0.5	-0.4	0.2
Paraparaumu			0.5			0.0
Wellington	-0.4	-0.5	0.5	-0.4	-0.5	0.2
Gisborne		-0.5	0.4		-0.3	0.1
Whakatu		-0.7	0.6		-0.6	0.3
East Taratahi	-0.3	-0.5	0.5	-0.2	-0.7	0.2
<b>South Island</b>						
Hokitika	-0.6	-0.9	0.3	-0.9	-0.78	0.0
Milford Sound		-1.0	0.1		-0.9	-0.2
Appleby	-0.6	-0.5	-0.2	-0.3	-0.5	0.1
Blenheim		-0.3	0.5		-0.3	0.3
Lincoln	-0.10	-0.7	0.2	-1.1	-0.6	0.0
Timaru	-0.7	-0.7	0.6	-0.5	-0.6	0.1
Omarama		-1.2	0.3		-0.7	0.3
Lauder		-0.4	-0.2		-0.4	-0.1
Dunedin	-0.4	-0.4	0.3	-0.4	-0.5	0.1
Invercargill	-0.5	-0.5	0.4	-0.7	-0.6	0.2
<b>Islands</b>						
Raoul Island		-0.1	0.3		-0.1	0.1
Chatham Island		-0.4	0.6		-0.3	0.4
Campbell Island		-0.0	0.3		0.1	0.2

**b Winter and spring**

Season	Winter			Spring		
Decade	1921-30	1941-50	1981-90	1921-30	1941-50	1981-90
<b>North Island</b>						
Kaitiaia			0.2			0.2
Auckland	-0.4	-0.3	0.2	-0.7	-0.4	0.5
Hamilton		0.0	0.3		-0.3	0.5
Rotorua		-0.2	0.4		-0.3	0.4
New Plymouth		-0.1	0.4		-0.7	0.4
Taihape	-0.6	-0.3	0.3	-1.0	-0.7	0.8
Paraparaumu			0.4			0.3
Wellington	-0.4	-0.3	0.5	-0.4	-0.4	0.2
Gisborne		-0.0	0.2		-0.2	0.4
Whakatu		-0.2	0.7		-0.6	0.5
East Taratahi	-0.3	-0.2	0.5	-0.2	-0.5	0.4
<b>South Island</b>						
Hokitika	-0.6	-0.2	0.5	-0.7	-0.5	0.7
Milford Sound		-0.4	0.2		-0.4	0.3
Appleby	-0.2	-0.1	0.2	-0.3	-0.3	0.2
Blenheim		0.0	0.7		-0.3	0.5
Lincoln	-0.7	-0.2	0.4	-0.4	-0.4	-0.1
Timaru	-0.2	-0.1	0.5	-0.4	-0.3	0.3
Omarama		0.5	0.7		-0.3	0.6
Lauder		0.0	0.5		-0.0	-0.1
Dunedin	-0.1	-0.1	0.6	-0.2	-0.3	0.3
Invercargill	-0.4	-0.4	0.6	-0.5	-0.6	0.4
<b>Islands</b>						
Raoul Island		-0.3	0.0		-0.1	0.1
Chatham Island		-0.3	0.5		-0.3	0.4
Campbell Island		-0.2	0.5		-0.1	0.3

- In the North Island, the greatest negative anomalies occurred at Taihape ( $-0.6^{\circ}\text{C}$ ), during 1921-1930, and the greatest positive anomalies at Whakatu ( $+0.7^{\circ}\text{C}$ ) during 1981-1990.
- In the South Island, the greatest negative anomalies occurred at Lincoln ( $-0.7^{\circ}\text{C}$ ) and Hokitika ( $-0.6^{\circ}\text{C}$ ) during 1921-1930. The greatest positive anomalies occurred at Timaru ( $+0.7^{\circ}\text{C}$ ) during 1981-1990.
- For the outlying islands, Raoul and Chatham Islands had the greatest negative anomalies ( $-0.3^{\circ}\text{C}$ ) during 1941-1950 and the greatest positive anomalies ( $+0.5^{\circ}\text{C}$ ) occurred at Campbell Island during 1981-1990, although Chatham Island had virtually the same temperature rise ( $+0.5^{\circ}\text{C}$ ).

The main features of the spring table are:

- All the spring anomalies in the 1981-1990 decade are positive, except Lincoln and Lauder, whereas those for the decades 1921-1930 and 1941-1950 are negative.
- In the North Island, the greatest negative anomalies occurred at Taihape ( $-1.0^{\circ}\text{C}$ ), during 1921-1930, and the greatest positive anomalies also at Taihape ( $+0.8^{\circ}\text{C}$ ), during 1981-1990.
- In the South Island, the greatest negative anomalies occurred at Hokitika ( $-0.7^{\circ}\text{C}$ ) during 1921-1930 as well as the greatest positive anomalies ( $+0.7^{\circ}\text{C}$ ) during 1981-1990.
- For the outlying islands, Chatham Island ( $-0.3^{\circ}\text{C}$ ) had the greatest negative anomaly during 1941-1950 and the greatest positive anomaly ( $+0.4^{\circ}\text{C}$ ) during 1981-1990.

## CONCLUSIONS

For mean annual temperatures, all stations experienced a period prior to the mid-1940s which was cooler than the 1951-1980 reference period. Temperatures increased steadily from the mid-1940s to the mid-1950s. The warmest period in the record of most stations occurred in the 1980s. The largest annual temperature departures below normal occurred west of the ranges at Taihape in the North Island during 1921-1930, whereas the largest departures in the South Island occurred at Hokitika, on the west coast and Lincoln on the east coast, also during 1921-1930. During the 1980s the largest increases in temperature occurred at Taihape and Whakatu in the North Island, and at Omarama, in the South Island. For the outlying islands, departures below normal during 1941-1950 were usually smaller than land stations except at Chatham Island and increases in the 1980s were comparable to the larger increases at land stations.

While the maxima tended to follow the shape of the mean annual curves, the minima differed in that their departures below normal in the early part of the record, for most North Island stations, was greater than for most South Island stations. Increases occurred in both maximum and minimum temperature. This contrasts with the IPCC findings (Houghton et al. 1992) that at Northern Hemisphere land stations studied only minimum temperatures increased.

Seasonally, there was a cooler than normal period prior to the mid-1940s, followed by a steady warming into the 1950s, as was the case with the mean annual temperatures. Summer had the greatest cooling in the 1940s. After the increase in temperatures after the 1940s there did not appear to be any definite trend other than the large increases during the 1980s for some seasons and in the annual temperature.

Geographically, mean temperatures increased between 1941-1950 and 1981-1990 by  $0.3^{\circ}\text{C}$  at Raoul Island. North Island mean temperatures increased by  $0.8^{\circ}\text{C}$ , as did temperatures at Chatham Island. The North Island increase was uniform between west and east. In the South Island the mean temperature increase was  $0.7^{\circ}\text{C}$ , ranging from  $0.8^{\circ}\text{C}$  in the west and south, to  $0.5^{\circ}\text{C}$  in inland areas. Eastern South Island areas warmed by  $0.7^{\circ}\text{C}$ . Mean temperatures increased by  $0.3^{\circ}\text{C}$  at

Campbell Island. At all locations seasonal temperatures increased between 1941-1950 and 1981-1990, although by varying amounts.

It is strongly recommended that observations continue at the reference sites so that temperature trends and variations at stations with records that have been carefully homogenised can be monitored to detect climate change and variability.

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## REFERENCES

- Fouhy, E.; Coutts, L.; McGann, R.; Collen, B. and Salinger, J. 1992: *South Pacific Historical Climate Network - Climate Station Histories: Part 2 New Zealand and offshore islands*. New Zealand Meteorological Service, Wellington. 216 pp.
- Houghton, J. T.; Callander, B. A.; and Varney, S. K. (eds) 1992: *Climate Change 1992: The supplementary report to the IPCC scientific assessment*. Cambridge University Press, 200pp.
- Houghton, J. T.; Jenkins, G. J.; Ephraums, J. J. (eds) 1990: *Climate Change, the IPCC Scientific Assessment*. Cambridge University Press.
- Jones, P. D.; Raper, S. C. B.; Bradley, R. S.; Diaz, H. F.; Kelly, P. M. and Wigley, T. M. L. 1986: Northern Hemisphere surface air temperature variations, 1851-1984. *Journal of Climate and Applied Meteorology* 25: 145-160.
- Rhoades D. A. and Salinger, M. J. 1992: Adjustments of temperature and rainfall records for site changes. *International Journal of Climatology* (submitted).
- Salinger, M. J. 1979: New Zealand Climate: The temperature record, historical data and some agricultural implications. *Climatic Change* 2(2): 109-126.
- Salinger, M. J. 1981: *New Zealand climate: The instrumental record*. Unpublished Ph.D thesis. Victoria University of Wellington. 324 pp.
- Salinger, J.; McGann, R.; Coutts, L.; Collen, B. and Fouhy, E. 1992: *South Pacific historical climate network. Rainfall trends in New Zealand and outlying Islands, 1920-1990*. New Zealand Meteorological Service, Wellington. 32 pp.
- WMO 1986: Guidelines on the selection of reference climatological stations (RCSs) from the existing climatological station network. WMO/TD-No. 130, 12 pp plus appendices. World Meteorological Organisation.

## APPENDIX A

## Temperature normals (°C) for the reference stations

1951 - 1980

Station	Lat	Long	Mean Annual Temperature			Mean Temperature		Seasonal	
			Mean	Max	Min	Sum	Aut	Win	Spr
Kaitiaia	35 08 S	173 16 E	15.6	19.4	11.7	19.1	16.8	12.1	13.1
Auckland	36 58 S	176 46 E	15.0	18.7	11.3	18.9	16.0	10.9	14.3
Hamilton	37 47 S	175 19 E	13.5	18.8	8.1	17.6	14.3	9.0	12.9
Rotorua	38 07 S	176 19 E	12.7	17.5	7.8	17.1	13.4	8.0	12.1
New Plymouth	39 01 S	174 11 E	13.4	17.4	9.4	17.0	14.4	9.6	12.6
Taihape	39 41 S	175 48 E	11.1	16.6	5.6	15.7	11.7	6.2	10.9
Paraparaumu	40 54 S	174 59 E	12.9	16.8	9.0	16.7	13.7	8.8	12.4
Wellington	41 17 S	174 46 E	12.7	15.7	9.6	16.2	13.6	8.9	12.0
Gisborne	38 40 S	178 00 E	14.1	19.2	8.9	18.4	14.7	9.6	13.6
Whakatu	39 37 S	176 55 E	13.4	18.0	8.6	17.7	14.1	8.8	13.0
East Taratahi	41 01 S	175 37 E	12.1	17.4	6.7	16.4	12.8	7.5	11.7
Hokitika	42 43 S	170 59 E	11.6	15.7	7.4	15.1	12.4	7.6	11.1
Milford Sound	44 40 S	167 55 E	10.5	14.5	6.4	14.5	11.3	6.0	10.2
Appleby	41 18 S	173 06 E	12.7	17.5	7.8	17.1	13.4	7.8	12.3
Rlenheim	41 30 S	173 58 E	12.5	18.1	6.8	17.1	10.1	7.4	12.3
Lincoln	43 38 S	172 28 E	11.4	16.9	6.1	16.2	11.9	6.2	11.3
Timaru	44 18 S	171 14 E	10.5	16.0	4.8	15.0	11.0	5.4	10.4
Omarama	44 32 S	169 54 E	9.3	15.4	3.1	15.4	9.6	3.1	9.6
Lauder	45 03 S	170 31 E	9.8	16.4	3.2	15.8	10.0	3.1	9.6
Dunedin	45 54 S	170 31 E	11.1	14.8	7.3	14.7	11.6	6.9	11.0
Invercargill	46 25 S	168 20 E	9.7	14.3	5.1	13.4	10.1	5.6	9.8
Raoul Island	29 19 S	177 55 E	19.1	21.7	16.5	21.6	20.5	16.7	17.7
Chatham Island	45 57 S	176 34 W	11.3	14.0	8.6	14.3	12.3	8.2	10.4
Campbell Island	52 33 S	169 09 E	6.9	9.3	4.5	9.1	7.3	4.9	6.3

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