SOUTH PACIFIC HISTORICAL CLIMATE NETWORK

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New Zealand
Meteorological
Service Te Ratonga Tirorangi

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South Pacific Historical Climate Network. Rainfall trends in New Zealand and outlying islands, 1920 - 1990

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New Zealand Meteorological Service

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SUMMARY

The annual rainfall series for 22 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 rainfall anomalies have been compared with the 1951-1980 reference period (used by the Intergovernmental Panel on Climate Change (IPCC)) and plotted. A Gaussian filter was used to remove short term fluctuations. The resulting smoothed curves are discussed with respect to long term fluctuations and trends. In the last decade most stations in the North Island, except Kaitaia and Auckland, have been drier. Some stations in the South Island (Nelson, Milford Sound, Omarama, Lauder and Invercargill) have recorded their wettest decade on record. Although the annual smoothed graphs show large fluctuations about the normal, there is no obvious long term trend.

Seasonally, summer is the season with the largest fluctuations about normal. In the 1980s Gisborne, Whakatu (near Napier) and Wellington in the North Island recorded their driest period on record, while Milford Sound, Lauder and Invercargill in the South Island, rainfall was wetter than previously. Rainfall in some seasons, for example autumn, remain below normal for two to three decades, mainly in the early part of the record. Overall, seasonal rainfall shows no long term trend.

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

CONTENTS

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 on the region.

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

Rainfall behaviour at the reference stations over the period 1920-1990 is described. Interpretation of the rainfall series will be the subject of a separate report.

This report describes briefly the methods used to adjust the mean annual and seasonal rainfall series in order to produce homogeneous series for a number of reference climate stations in the North and South Islands of New Zealand and the three outlying islands, Raoul Island (part of the Kermadec group), Chatham Island and Campbell Island. Further details on the homogenising methods are given in Rhoades and Salinger (1992). In addition, the homogeneous rainfall series are discussed in terms of rainfall trends in different parts of 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 located preferably 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

there's only 21 in Table 1 text

Using the above criteria, ~~22~~ climate stations were selected in the North and South Islands and three island stations in the New Zealand economic zone (Table 1). 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 rainfall records have not been completely homogenised so its data have not been included.

Table 1 Reference climate stations

North Island		South Island		Offshore Islands
Kaitaia	Paraparaumu	Hokitika	Lauder	Raoul
Rotorua	Wellington	Milford Sound	Timaru	Chatham
Auckland	Gisborne	Appleby	Dunedin	Campbell
Hamilton	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 rainfall 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 rainfall series for a given climate station could be derived from data from several earlier sites and adjacent stations.

The homogenisation procedure for the time series for each reference climate station is described in detail 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).

iv Run the homogenisation computer programs (Rhoades and Salinger 1992) using mean data from the station under test and other neighbouring climate stations with good quality records and no site changes during the comparison period. Obtain computed corrections to the rainfall series for the station under test. It should be noted that the homogenisation procedure uses comparison periods of monthly values ± 2 or ± 4 years before and after a suspected (or actual) site change or discontinuity in the rainfall series and statistically tested for significant changes.

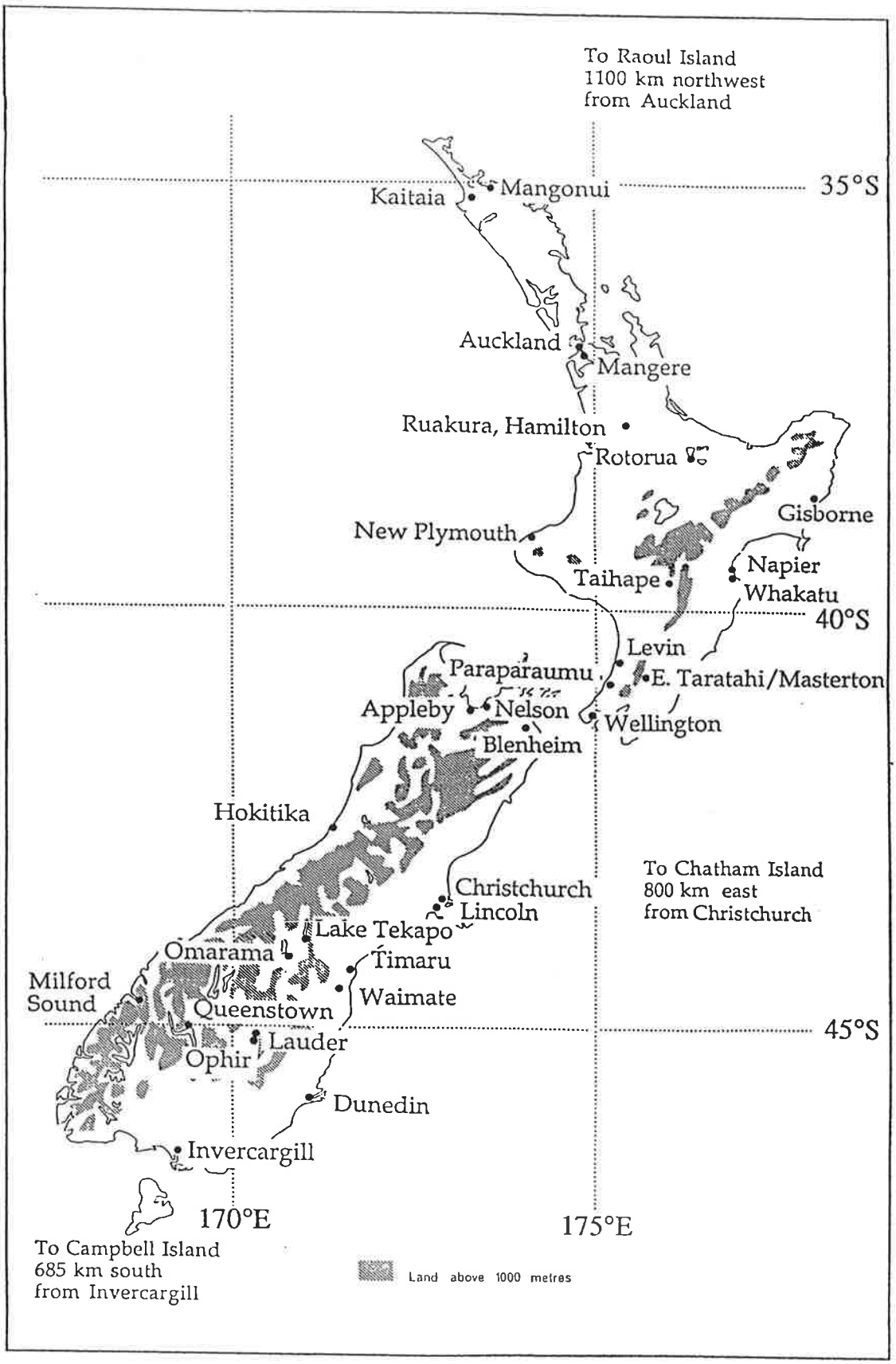


Figure 1 *Locations of the reference climate stations*

Comparisons were also made with neighbour stations using annual values for the entire period of record (Salinger, 1981).

v Make a decision on the correction, if any, to the rainfall series based on the homogenisation tests in step iv, taking into account any relevant information, such as site changes or changes of instrumentation, contained in the climate station histories (Fouhy et al, 1992).

TIME SERIES ANALYSIS

Anomalies of annual and seasonal rainfall were calculated for the station records compared with the reference period taken as 1951-1980, expressed here as the normal period.

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 were examined for any trends (see figures 3-32).

This paper has used the filter but doesn't give any further explanation of it than here.

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 of annual rainfall from New Zealand rainfall stations for the period 1951 to 1975 to identify rainfall *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).

Cluster analysis initially divides the North Island into four districts – northern and central districts; western areas; southern and south-eastern. The South Island is divided into two districts – western and eastern. These main districts can be further sub-divided as shown in figure 2.

When comparing the rainfall 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 climate stations in a response area and no averaging has been done in the present study.

RESULTS

The results of the rainfall homogenising procedures are given in figures 3-32, which show the annual anomalies and the filtered series. Rainfall is expressed as an annual or seasonal anomaly with respect to the 1951-1980 reference period. Anomaly values were calculated as a positive or negative proportional departure from 1951-1980. For example, values of 0.50 represent an anomaly of 50 per cent above the 1951-1980 mean and -0.50 50 per cent below the 1951-1980 mean. Annual and seasonal values of rainfall for the reference period are given in Appendix A. The term "normal" is used to indicate the 1951-1980 reference period. The rainfall 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 filtered curves is discussed.

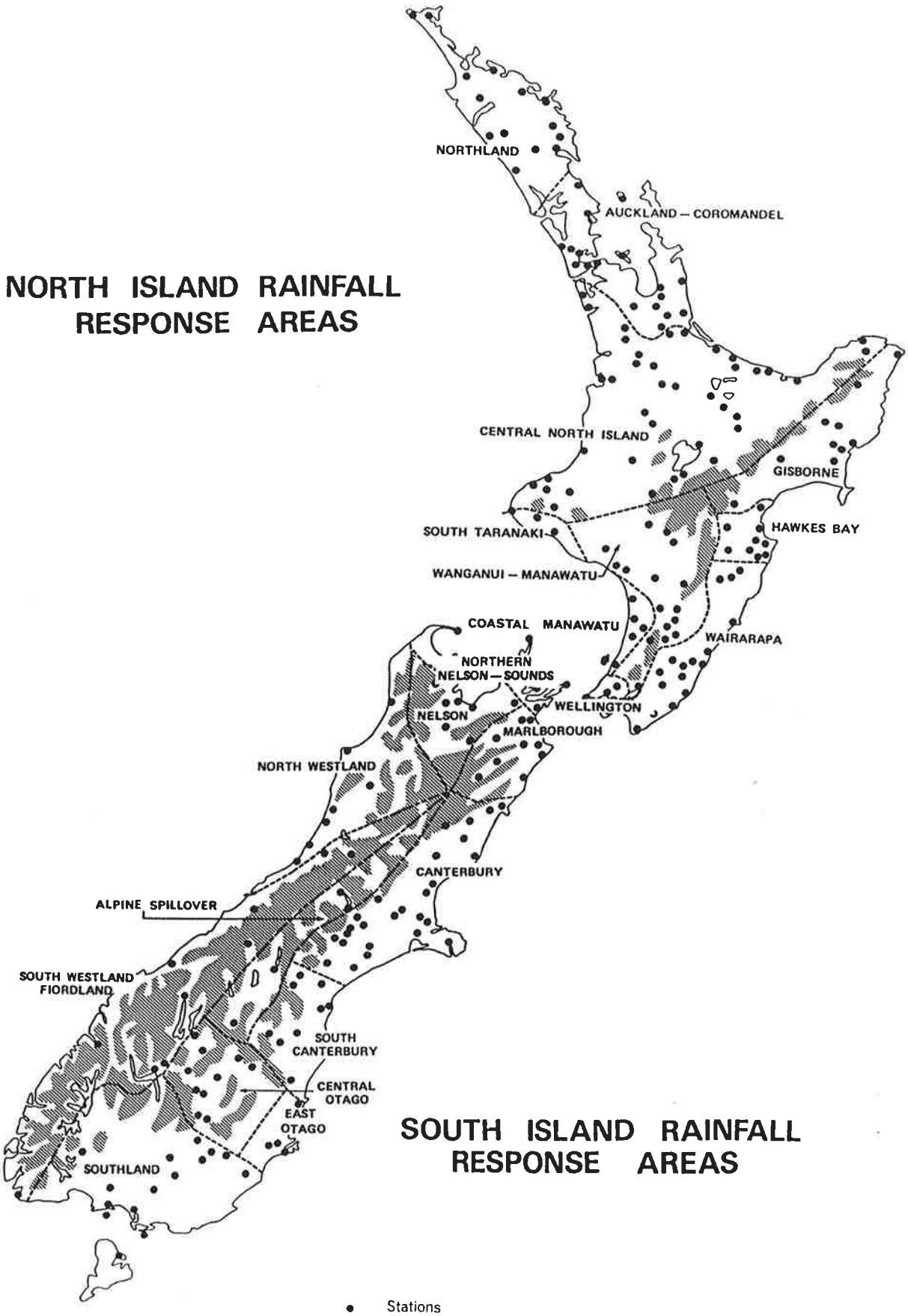


Figure 2 *Rainfall response areas*

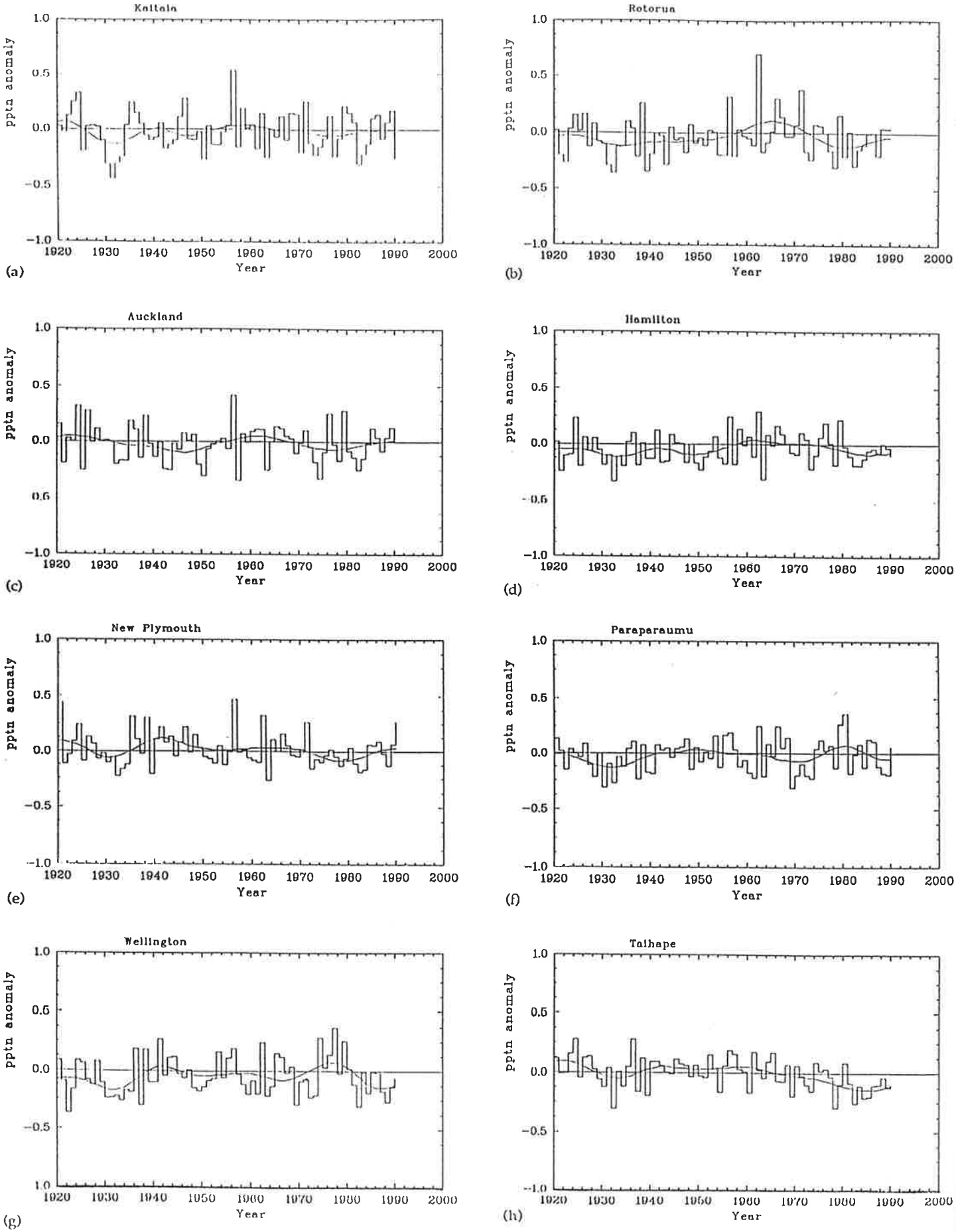
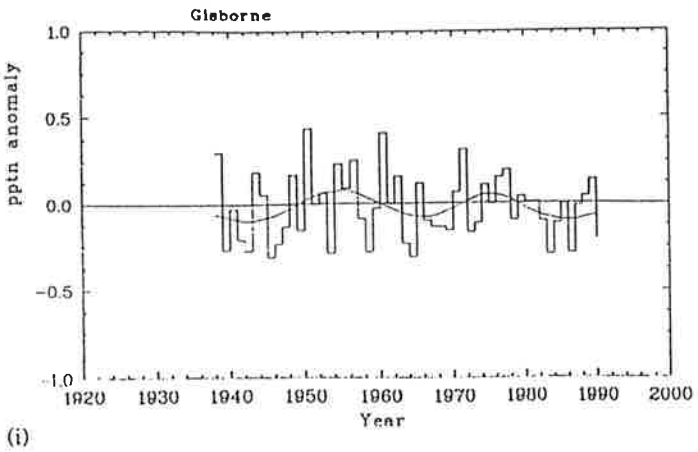
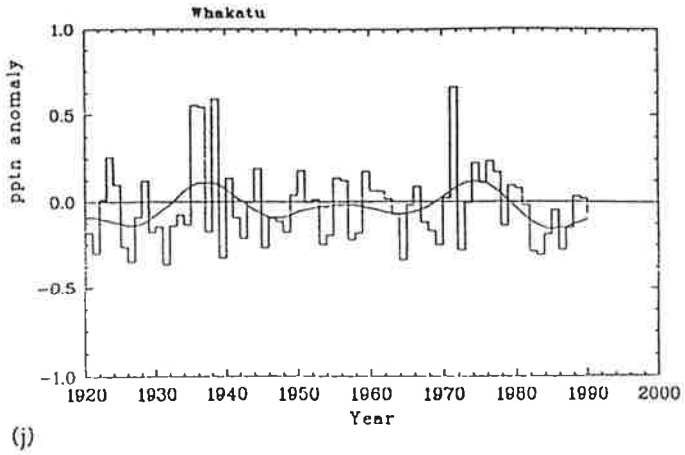


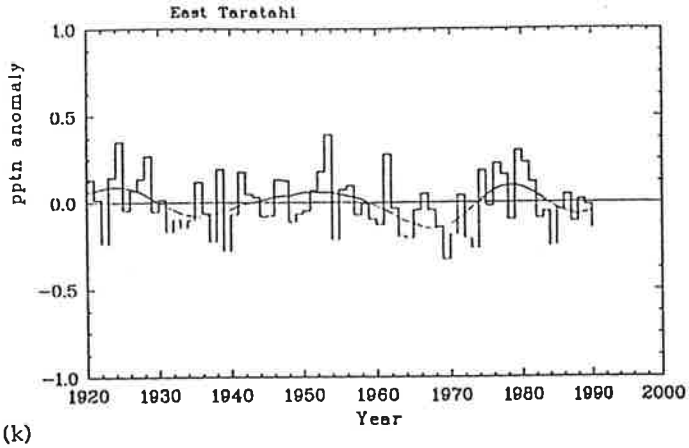
Figure 3 *Mean annual rainfall at North Island stations*



(i)



(j)



(k)

Figure 3 (continued)

Not the mean

~~Mean~~ annual rainfall for North Island stations

The ~~mean~~ annual rainfall graphs for North Island stations are shown in figure 3 a-k. These consist of the individual annual anomalies and the Gaussian filtered series (solid line) relative to 1951-1980. The range of the annual rainfall differences from the 1951-80 reference period was about -15 to +10 per cent. Comparisons (percentages), mentioned below are between the smoothed (filtered) curves and the 1951-1980 reference period. Each station is discussed separately.

At Kaitaia, the greatest differences between filtered and normal rainfall occurred in the 1920s (+5%) and the 1930s (-10%). For most of the rest of the record the anomalies were a few per cent and in the 1980s were close to zero.

The rainfall pattern at Auckland consists of two wetter and two drier than normal periods. The drier periods are longer than the wetter periods and departures below normal were greater (up to 10 per cent) than departures above normal (up to 5 per cent). The rainfall at Auckland was similar to Kaitaia except during the 1930s.

At Hamilton, the rainfall was about 10 per cent below normal up to the late 1950s, then near normal till the mid-1970s and less than 10 per cent below normal in the 1980s.

Rotorua was similar to Hamilton except it was a little wetter in the 1960s, drier in the early 1980s and slightly less dry in the late 1980s compared with normal.

For New Plymouth, the main differences from normal did not exceed 10 per cent and occurred up to 1950, after which rainfall was close to normal till the early 1970s. This was followed by a decrease (less than 10 per cent) in the 1980s.

Rainfall was up to 10 per cent above normal at Taihape until the mid-1960s (apart from a decrease in the 1930s), after which there was a decrease exceeding 10 per cent in the 1980s.

At Paraparaumu, rainfall was more than 10 per cent below normal in the 1920s and 1930s, then near normal from the 1940s to the 1960s. There followed a drier period and a wetter period during the late 1970s and early 1980s. This wet period did not occur at the stations discussed above, such as New Plymouth and Taihape. Rainfall in the late 1980s was slightly below average.

Rainfall characteristics at Wellington were similar to those shown at Paraparaumu. In the early 1930s rainfall was more than 10 per cent below average and there was a wetter than average period in the late 1970s. By the late 1980s rainfall was nearly 10 per cent below average.

In the east at Gisborne successive decades were up to 10 percent above or below average. During the 1980s rainfall was up to 10 per cent below average.

The rainfall patterns at Whakatu are similar to Gisborne, but there are differences in the deviations from average, especially in the 1950s and 1970s. The wetter than normal (over 10 percent) period in the late 1930s did not occur at other North Island stations which were drier than normal at this time. Both Whakatu and Gisborne were wetter than normal during the 1970s while most other stations (except Paraparaumu and Wellington) west of the ranges were drier. Rainfall at Whakatu was up to about 15 per cent below normal during the 1980s, which was greater than at Gisborne.

The pattern at East Taratahi was almost in anti-phase with that at Whakatu and similar to Gisborne in the early part of the record. After about 1960 the three stations east of the mountains had patterns which were in phase, but different magnitudes.

Summary for the North Island

West of the ranges the rainfall departures from normal were small from the 1940s to the 1970s. All stations, except Kaitaia and Auckland, were drier than normal in the late 1980s, particularly in the east. There is no obvious long term trend shown at any station.

Mean annual rainfall for South Island stations

The mean annual rainfall anomalies for the South Island stations are shown in figure 4 a-j. The range of the annual rainfall differences from the 1951-80 reference period is greater than for the North Island.

On the West Coast at Hokitika, successive decades were wetter or drier than normal by up to 10 per cent until 1950, after which rainfall was close to normal. From the mid-1970s into the 1980s there was an increase in rainfall of less than 10 per cent.

At Milford Sound, there were only small deviations from normal until the mid-1970s, after which rainfall increased by up to 15 per cent. The increase in rainfall in the 1980s was similar to Hokitika, but greater in magnitude.

At Appleby, there was a dry period (about 5 per cent below normal) in the early 1930s, after which rainfall was almost normal until 1970. After a dry period (about 5 per cent below normal) in the 1970s, there was an increase (up to about 15 per cent) in the 1980s.

Blenheim had a very dry period (about 20 per cent below normal) in the early 1930s, (similar to Wellington), followed by small deviations about normal till the 1980s, when rainfall was about five per cent below normal. This is the opposite of what happened at Appleby in the 1980s.

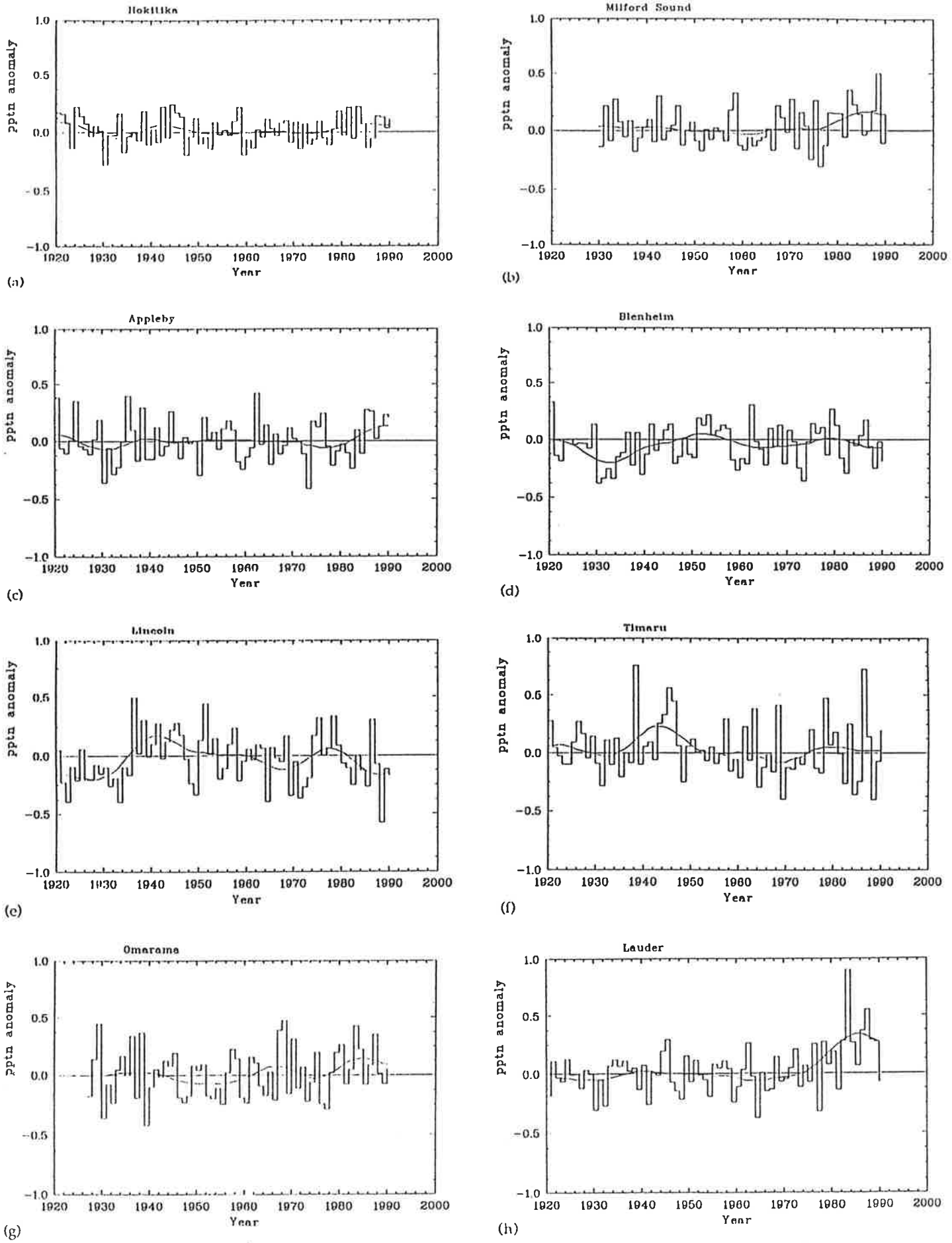


Figure 4 *Mean annual rainfall at South Island stations*

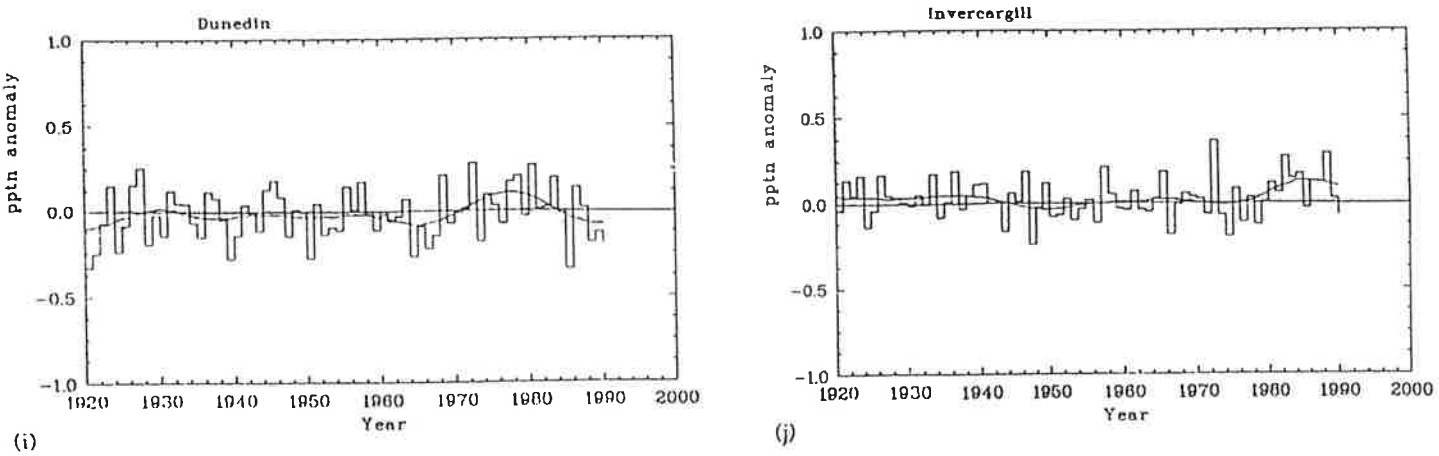


Figure 4 (continued)

Lincoln and Timaru had similar characteristics until the early 1980s. The late 1930s and 1940s were wetter than normal (about 20 per cent at Lincoln and about 25 per cent at Timaru). The 1950s were close to normal at both stations, after which there was a drier period, followed by a period wetter than normal. In the 1980s rainfall was about 15 per cent below normal at Lincoln, but close to normal at Timaru.

For the inland basins, Omarama and Lauder, the deviations from normal were about 5 per cent and were not in phase. However, from the late 1970s, there was an increase in rainfall at both stations, which was much greater at Lauder than Omarama (35 per cent and 15 per cent respectively).

Further south at Dunedin, there was a dry period (up to 10 per cent below average in the early 1920s, followed by a long period close to normal until the 1960s, when there was another dry period (up to 10 per cent below normal). The late 1970s were up to 10 per cent above average, but the late 1980s were drier than normal by less than 10 per cent.

At Invercargill, rainfall was within 5 per cent of normal until the 1980s, when there was an increase of more than 10 per cent above normal. The 1980s were different at Invercargill and Dunedin.

Summary for the South Island

The rainfall for many stations was close to normal for much of the record. In the 1930s Blenheim was very dry, and Timaru was very wet in the 1940s. In the 1980s most stations had rainfall greater than normal, especially at Lauder. Exceptions were Blenheim, Timaru and Dunedin, while Appleby, Milford Sound, Omarama, Lauder and Invercargill recorded the wettest period on record. The stations which recorded greater than normal rainfall in the 1980s tended to be other than those on the east coast.

The annual rainfall patterns do not show any long term trend.

Mean annual rainfall for Raoul, Chatham and Campbell Islands

The annual rainfall graphs for the outlying islands are shown in figure 5 a-c.

Raoul Island

The rainfall was up to 10 per cent below normal in the 1940s and 1960s and more than 10 per cent above normal in the 1970s. In the 1980s rainfall was about 10 per cent below normal.

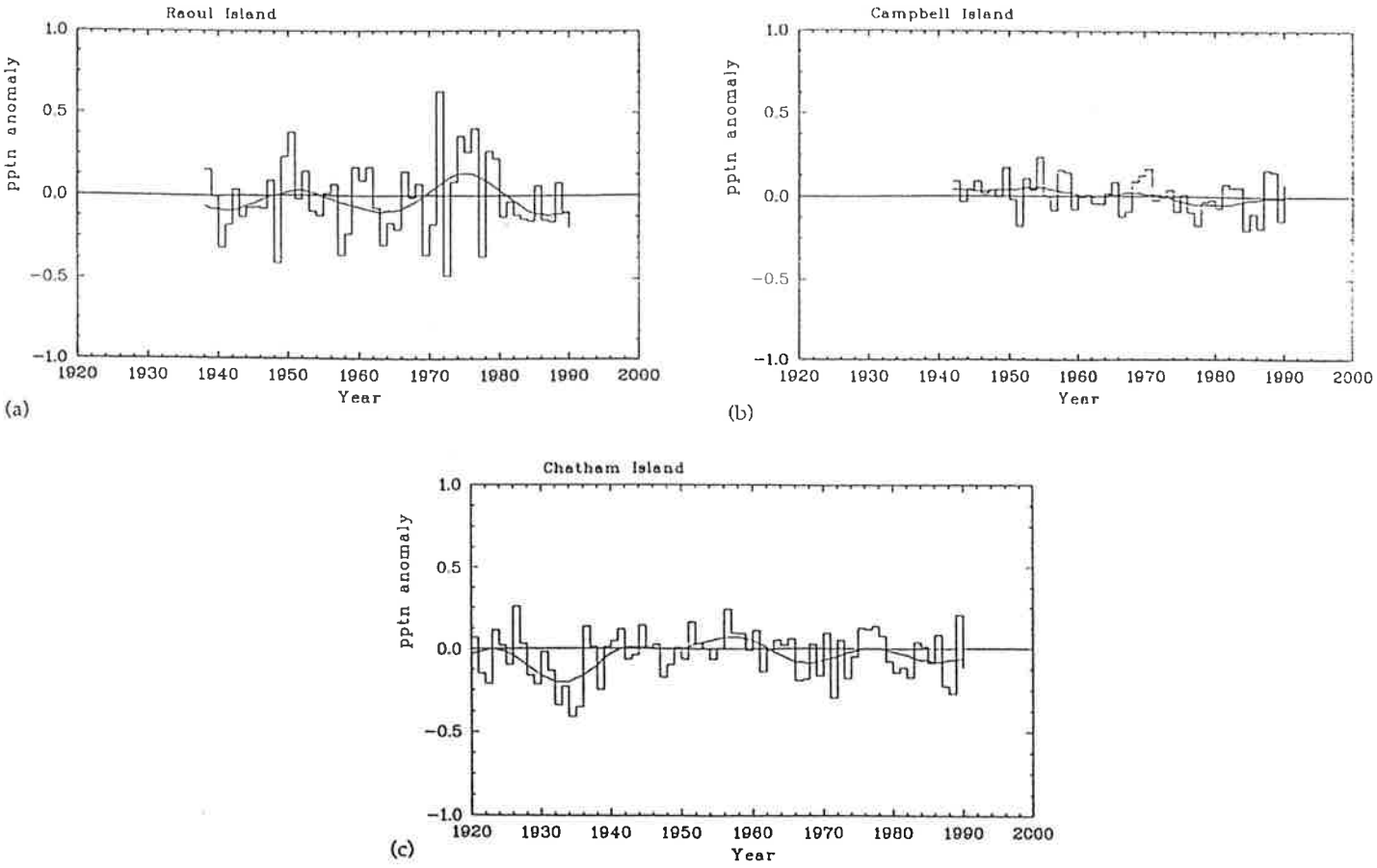


Figure 5 *Mean annual rainfall at Raoul, Chatham and Campbell Islands*

Chatham Island
The driest period in the record occurred in the 1930s when rainfall was up to 20 per cent below normal. This dry period did not occur at South Island stations other than Blenheim. Rainfall was near normal in the 1940s and 1970s. In the 1950s and 1960s, rainfall was within 10 per cent of normal. In the 1980s, rainfall decreased below normal again.

Campbell Island
There is less variability in the rainfall record for Campbell Island than for Raoul and Chatham Islands. Rainfall was up to 5 per cent above normal until the early 1970s and about 5 per cent below normal in the late 1970s and early 1980s. In the late 1980s rainfall was close to normal.

There were no obvious long term trends in rainfall of the offshore islands.

Seasonal variations in the North Island

Figures 6, 7, 8, 9 and 10 a-h, and 11 a-d show the smoothed seasonal rainfall curves for the North Island stations. The format is similar to the annual rainfall graphs. Since there was considerable variation in the individual graphs for the stations, each station is discussed separately. For comparison, the smoothed (filtered) curves for the four seasons are superimposed for each station and shown in figure 12 a-k.

In the north at Kaitaia, summer rainfall has the greatest variability up to the mid-1950s. To a lesser extent autumn is similar. In the late 1930s and early 1940s summer was wetter than average by up to 20 per cent. Summer was up to 35 per cent below normal in the late 1940s and early 1950s. Winter shows only small variations about normal throughout the record. In the 1980s, summer was up to 10

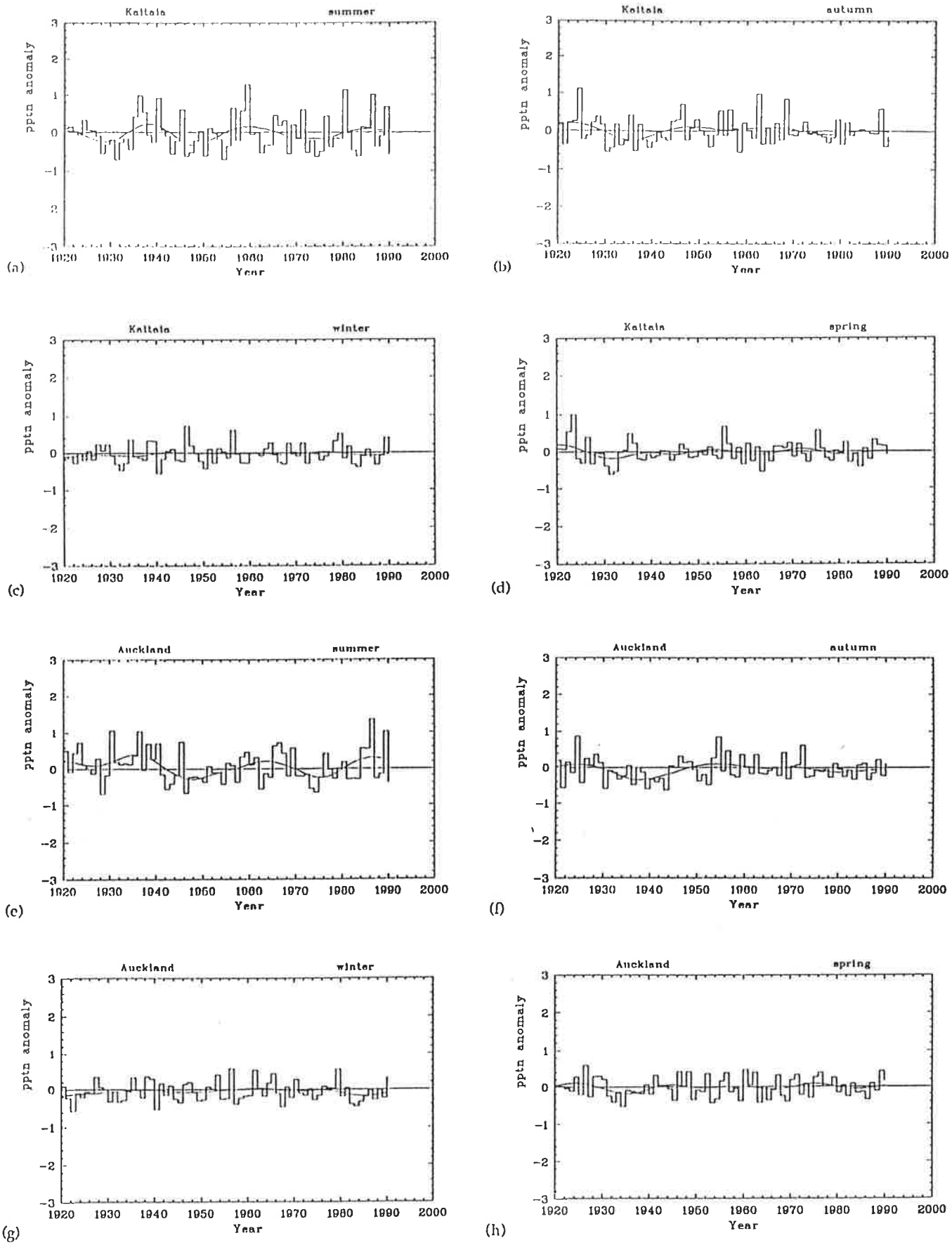


Figure 6 *Seasonal rainfall at Kaitaia and Auckland*

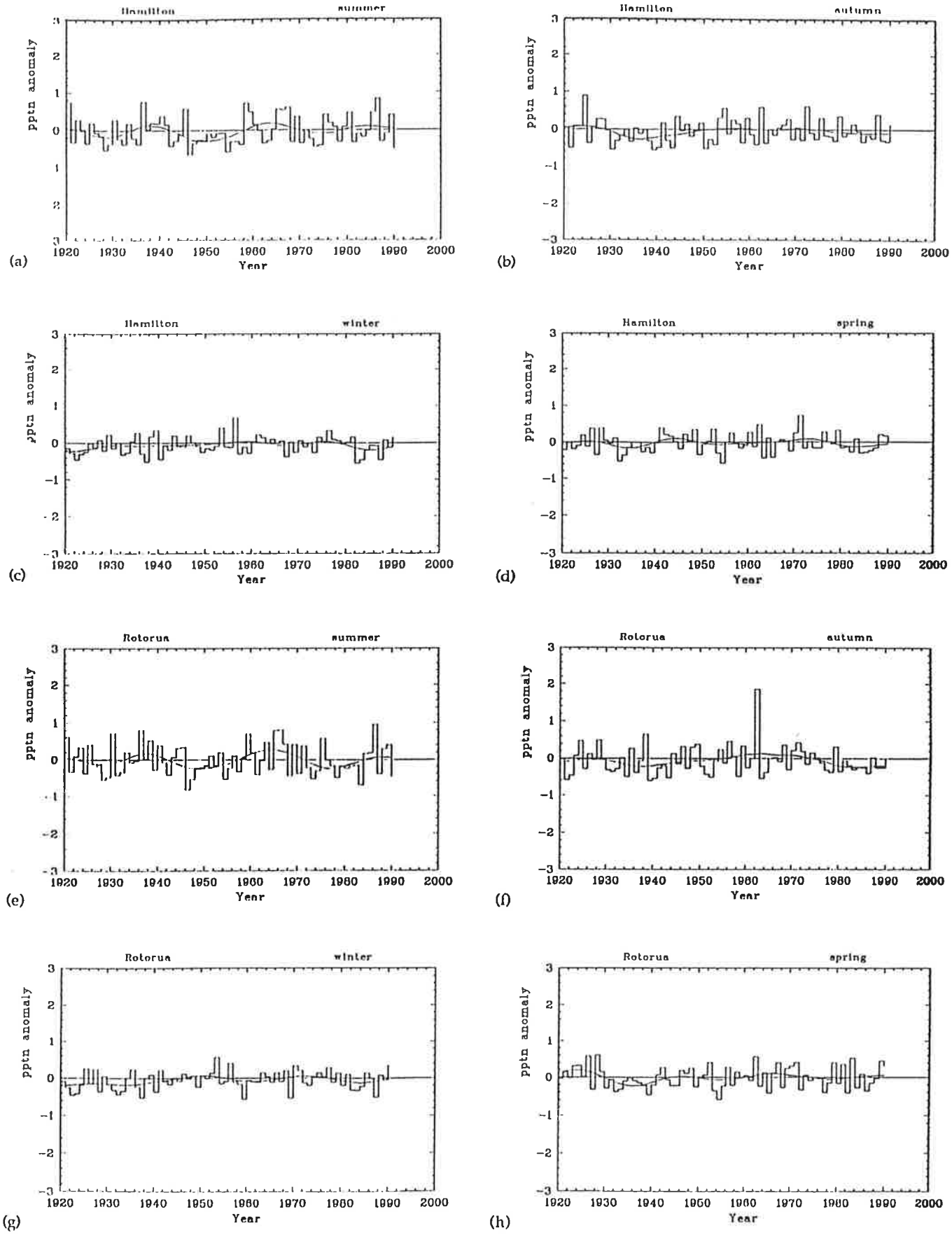


Figure 7 *Seasonal rainfall at Rotorua and Hamilton*

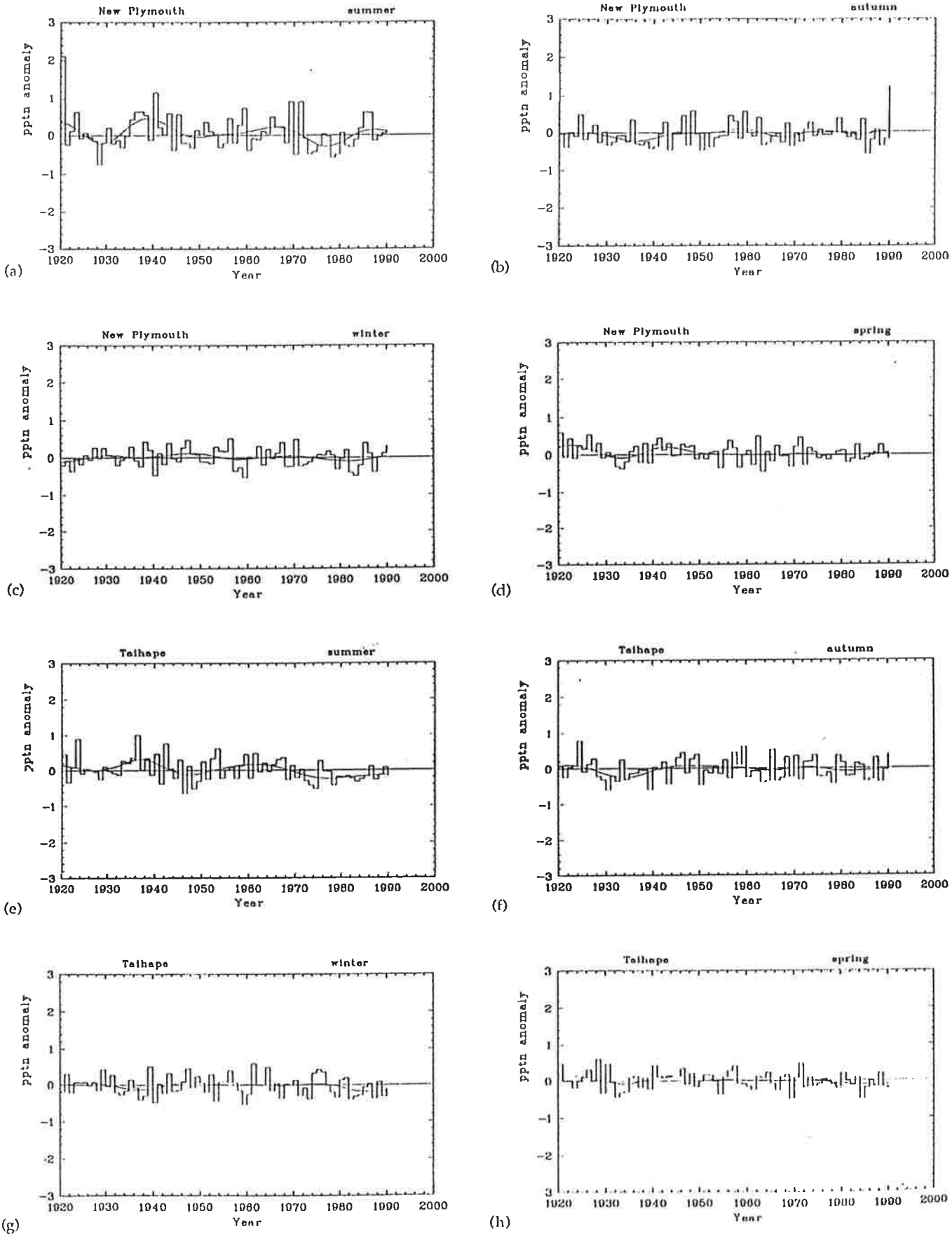


Figure 8 *Seasonal rainfall at New Plymouth and Taihape*

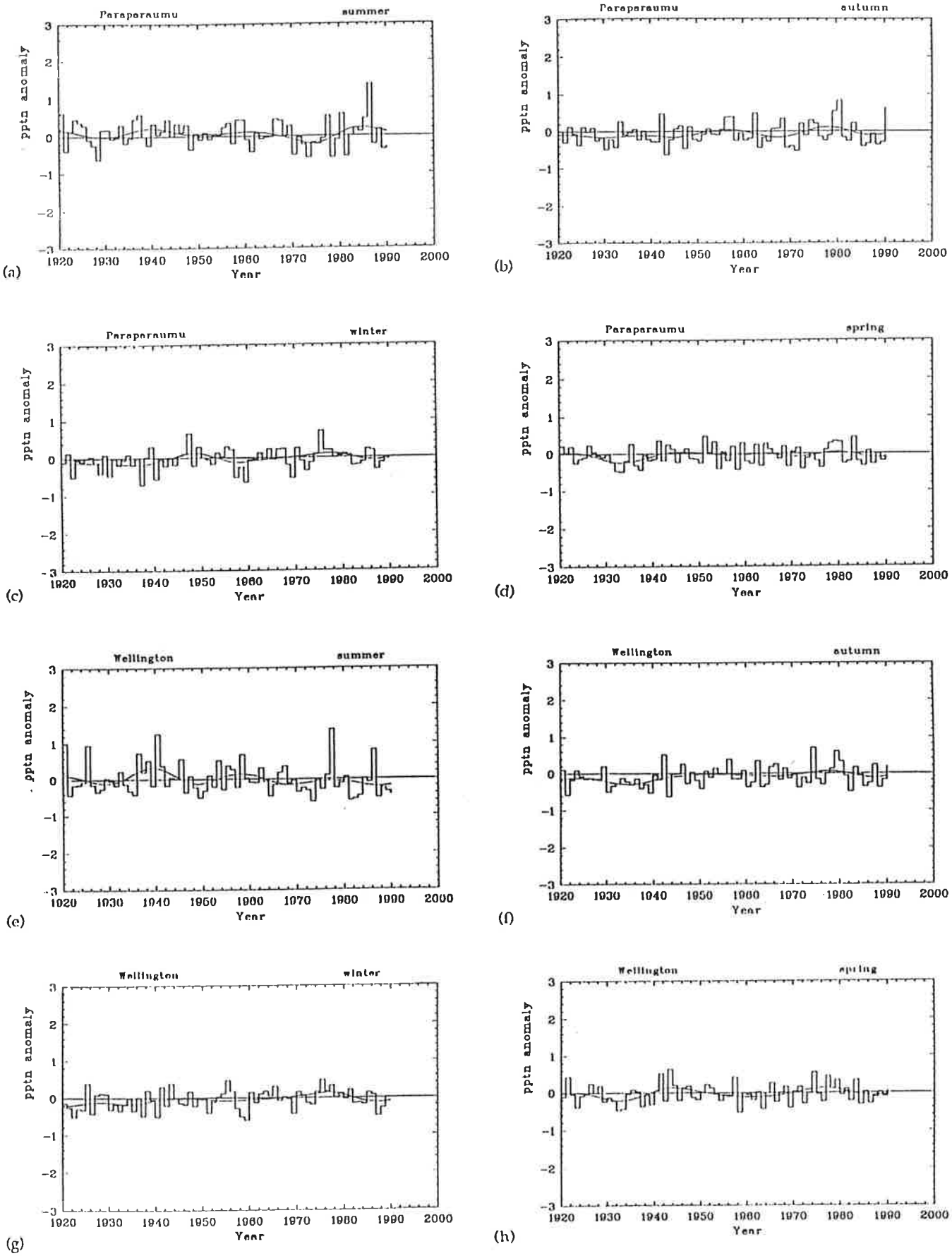


Figure 9 *Seasonal rainfall at Paraparaumu and Wellington*

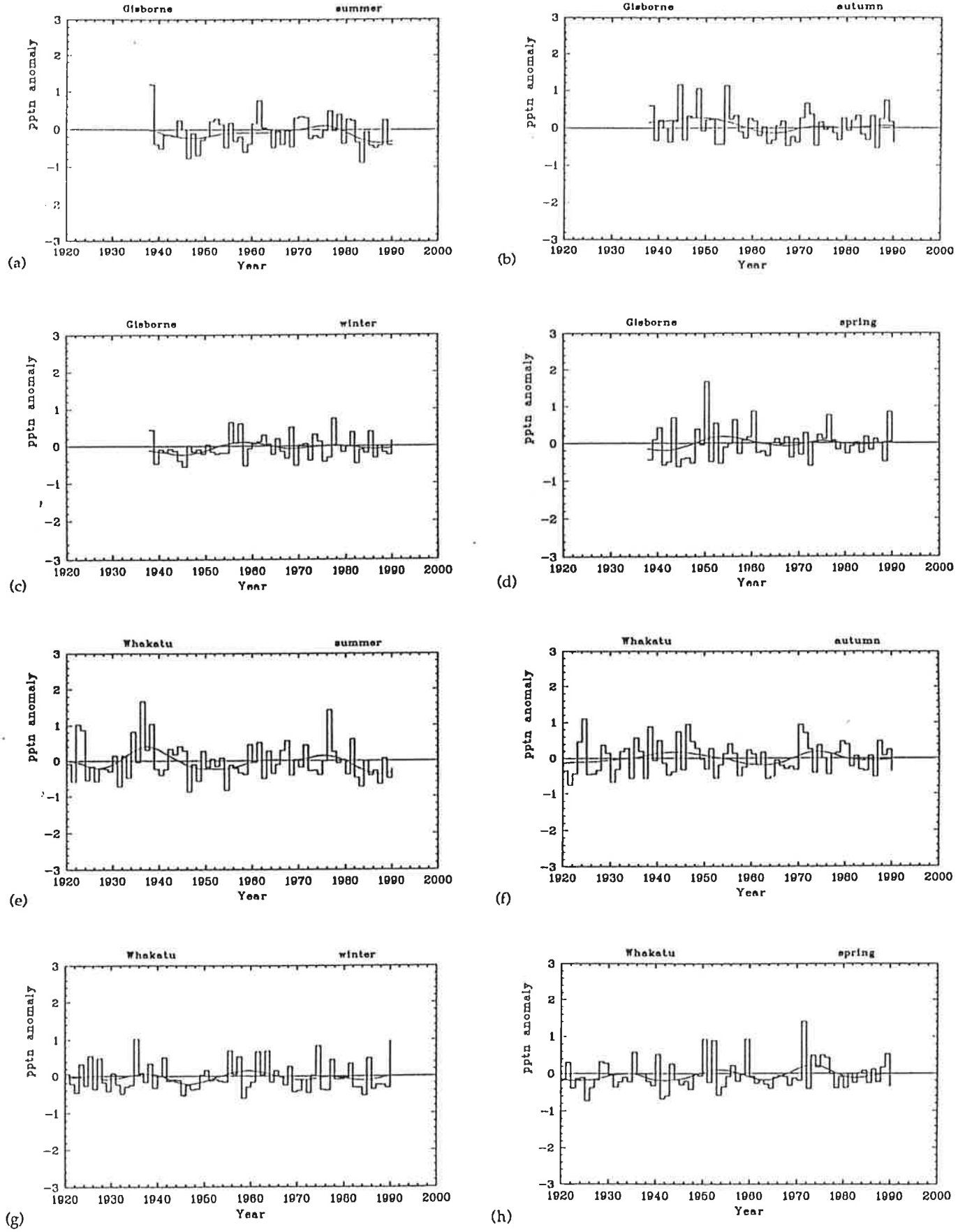


Figure 10 Seasonal rainfall at Gisborne and Whakatu

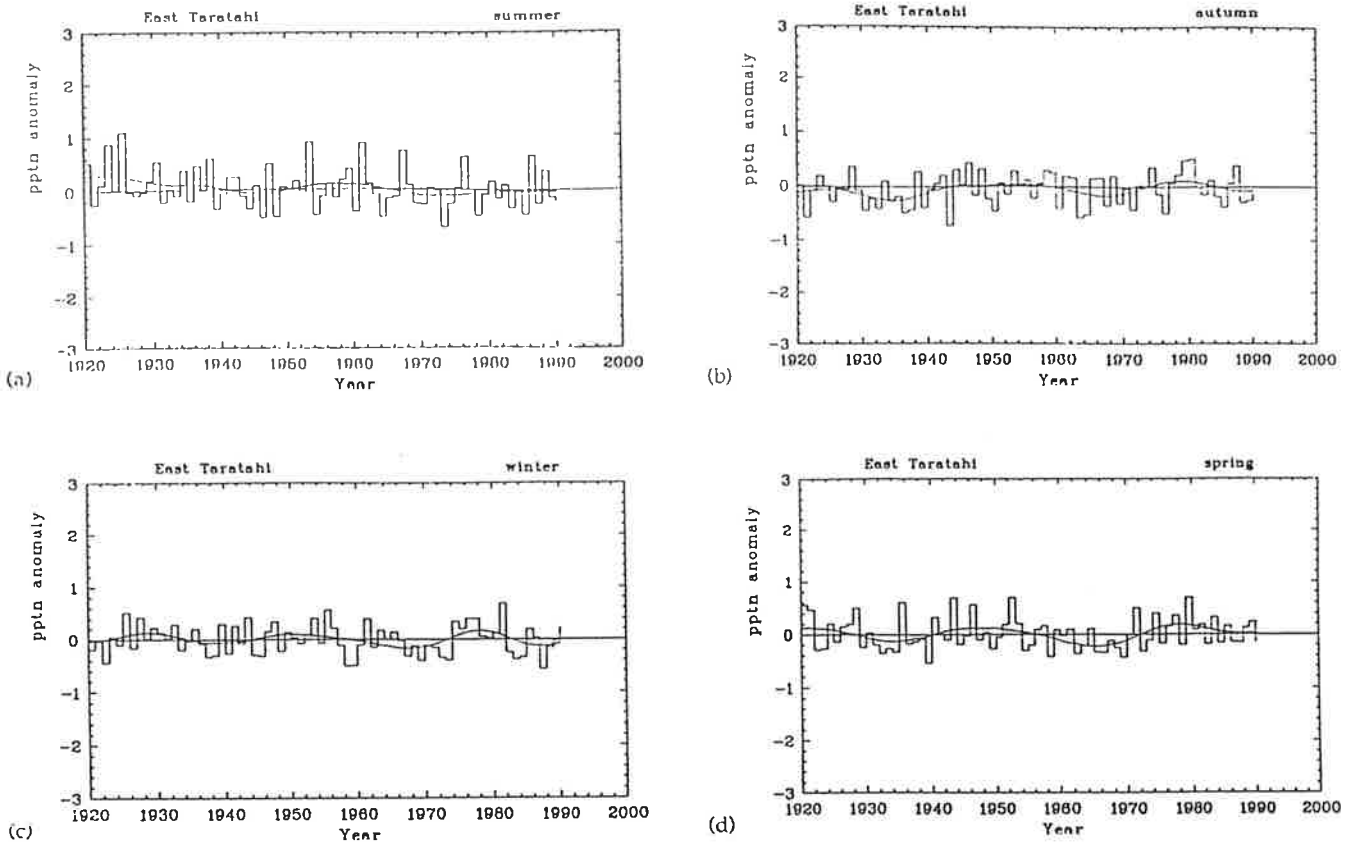


Figure 11 Seasonal rainfall at East Taratahi

per cent wetter than normal. The other seasons were close to normal, except winter which was slightly below normal.

At Auckland, as at Kaitaia, summer shows the greatest fluctuation, followed by autumn. Summer was wetter than normal in the 1930s (up to 40 per cent), followed by large fluctuations (up to 30 per cent) about normal. Autumn was very dry in the 1930s and early 1940s, followed by smaller fluctuations. Winter is essentially drier than normal over the whole record. In the 1980s, summer rainfall is more than 20 per cent above normal, while other seasons, especially winter, are below normal.

Hamilton was very similar to Kaitaia. In the 1920s winters were about 20 per cent drier than normal compared with 10 per cent at Kaitaia. In the 1980s summer was the only season above normal. At both Hamilton and Kaitaia in the 1980s, winter had the greatest departure below normal, but more so at Hamilton. Otherwise winter was mostly close to normal.

Rotorua is similar to Hamilton, apart from being wetter (about 30 per cent above normal) in summer in the 1960s, and drier (more than 20 per cent below normal) in the 1970s. There was slightly more fluctuation of winter rainfall about normal than at Hamilton. In the 1980s, autumn was the season with the greatest departure below normal (about 20 per cent), winter was about 10 per cent below, while spring and summer were both slightly above normal.

There were large fluctuations of summer rainfall (more than 40 per cent above to 20 per cent below normal) at New Plymouth, up to 1950 and smaller ones (about 20 per cent) from 1960. Summers were very wet in the early 1920s and also in the late 1930s and early 1940s. Summer rainfall was more than 20 per cent above normal in the 1960s and more than 20 per cent below normal in the 1970s. In the

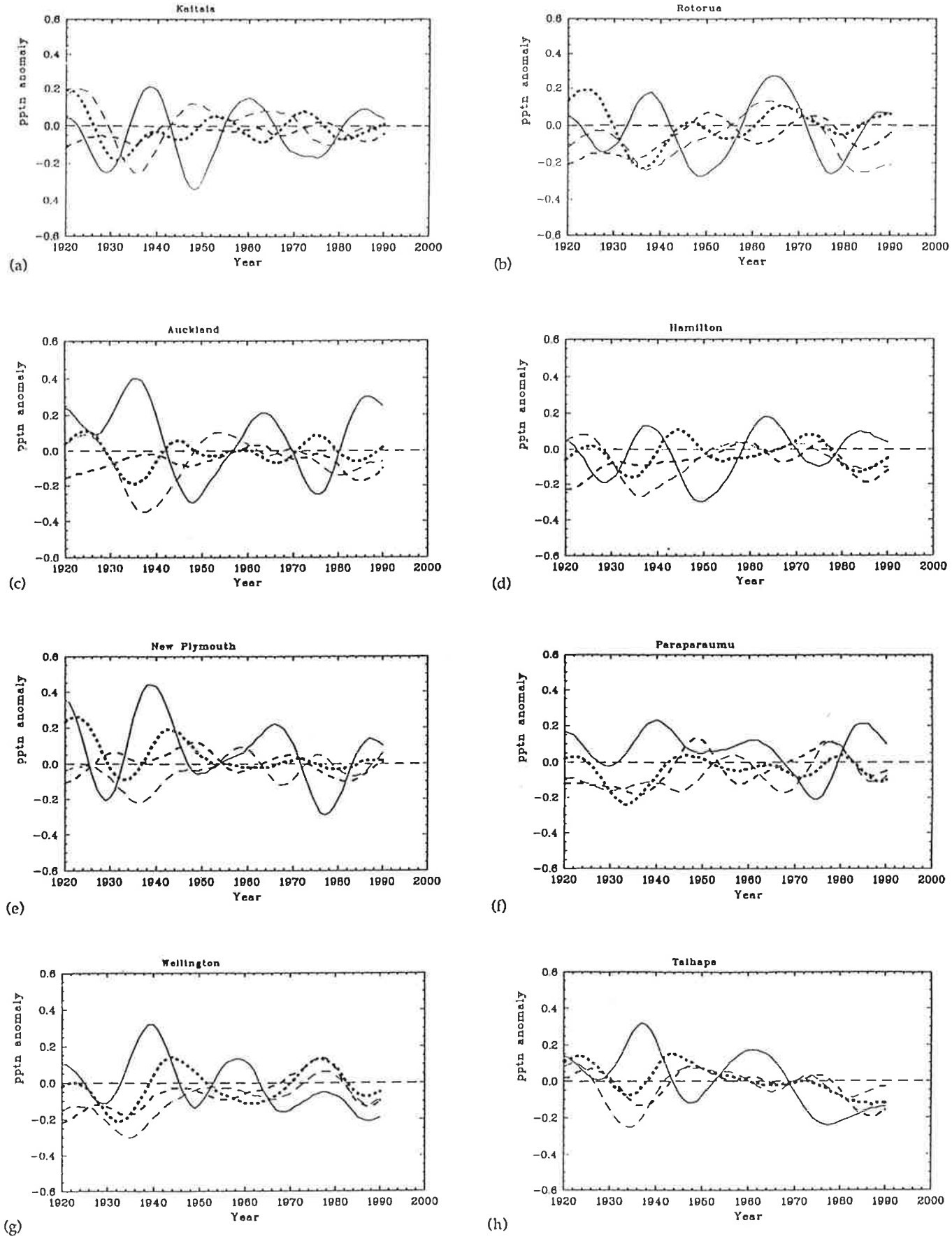


Figure 12 Filtered seasonal rainfall at North Island stations

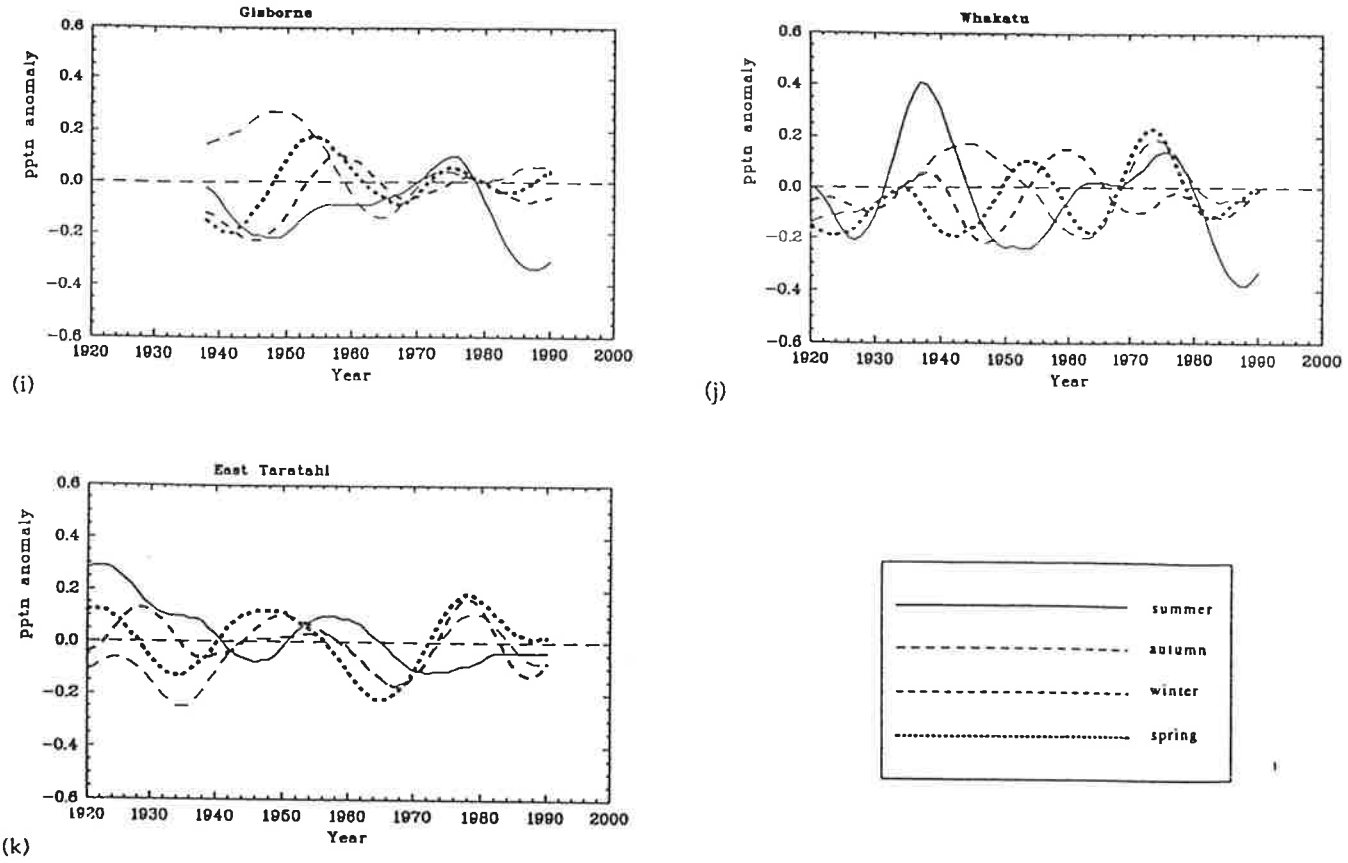


Figure 12 (continued). The key is shown in the lower right corner.

1980s, summer was the only season with above normal (10 per cent) rainfall, whereas the other seasons were less than 20 per cent below normal.

Summer shows the most variability at Taihape. The summers were wet in the late 1930s. Summer rainfall varied 20 to 30 per cent about normal. There was not much fluctuation from normal for other seasons till the 1980s, apart from a dry period (20 per cent below normal) for autumn in the 1930s and drier summers from about 1970 till 1990. In the 1980s all seasons were drier than normal, with autumn the least and winter the most dry. This was different from the other stations.

Paraparaumu differs from the other stations in that summer rainfall was wetter until the late 1960s. Summer is the most variable season. Autumn rainfall was drier until the early 1950s. In the 1980s, only summer was above normal (about 20 per cent), while the other seasons were less than 10 per cent below normal.

At Wellington, summer is the most variable season, especially till the mid-1960s. Summers were very wet in the late 1930s and early 1940s (up to 40 per cent above normal). Autumn and winter were below normal from 1920 to 1950 by up to 30 and 20 per cent respectively. In the late 1970s, all seasons except summer were at least 10 per cent above normal. In the 1980s, all seasons were drier than normal, with summer the most (up to 20 per cent). This behaviour for summer was the opposite of most other stations, except Taihape, Gisborne and Whakatu.

East of the axial ranges, at Gisborne, autumn rainfall was up to 30 per cent above normal until the mid-1950s and was the only season above normal until the late 1940s. Summer remained drier from 1940 to 1970, then briefly became wetter in the 1970s, before becoming drier in the 1980s. Winter was up to 20 per cent below normal until 1950. In the 1980s summer had the greatest departure, up to 30

per cent below normal, while the other seasons were within 10 per cent of normal. This summer variability in the 1980s is similar to both Taihape and Wellington, but is of greater magnitude.

Whakatu is similar to Gisborne over the period 1940-1990. Summer had the greatest variability of all the seasons (about 40 per cent above and below normal). Summer was very wet in the late 1930s, but in the late 1940s and early 1950s it was about 20 per cent drier than normal. In the 1980s all seasons were drier at Whakatu, especially summer (nearly 40 per cent). All seasons except winter were up to 20 per cent above normal in the 1970s.

East Taratahi differs from Whakatu, especially in the early part of the record. Summer at East Taratahi was mostly wetter than normal into the mid-1940s. There were no very wet summers in the late 1930s as was the case at Whakatu and places west of the main ranges. Summers were wettest in the 1920s (about 30 per cent above normal). There were dry autumns in the 1930s when rainfall was more than 20 per cent below normal. Autumn rainfall was dry from 1920 to the early 1940s. Winter was wetter than normal in the 1920s and early 1930s, as at Taihape. The driest seasons were autumn in the 1930s and spring in the 1960s. In the 1980s spring rainfall was slightly above normal, but in other seasons it was below normal by up to 10 per cent.

Summary for the North Island

Summer was the most variable season on both sides of the axial ranges, with very wet summers in the late 1930s and early 1940s, and to a lesser extent, in the 1960s. In the northern part of the North Island in the 1980s summer was wetter and winter drier. In the 1980s Gisborne, Whakatu and Wellington, had their driest summers. Other seasons usually had less variability. Autumn was very dry at most stations in the 1930s. Apart from the large summer increases and decreases in rainfall in the 1980s, there does not appear to be any long term trend in the North Island seasonal rainfall.

Seasonal variations in the South Island

Figures 13, 14, 15 16 and 17 a-h show the smoothed seasonal rainfall curves for the South Island stations. Each station is discussed separately. For comparison, smoothed curves for the four seasons are superimposed for each station and shown in figure 18 a-j which uses the same format as figure 12.

On the west coast at Hokitika, summer was the most variable season. The 1930s and 1940s had summers up to 30 per cent above normal and autumns nearly 20 per cent below normal. In the 1980s summer rainfall was about 20 per cent above normal, and winter and spring rainfall about 10 per cent above normal. Autumn was the only season with below normal rainfall.

At Milford Sound, summer rainfall was above normal by nearly 20 per cent up to the mid-1940s and continued above normal until the late 1960s. Summers were very wet from the late 1970s (more than 40 per cent in the 1980s). Until the latter part of the record summer rainfall was less variable than at North Island stations. Autumn rainfall, on the other hand, was drier from 1940 to 1970 (by more than 15 per cent in the 1940s). This dry period was longer than at Hokitika. In the 1980s autumn rainfall was slightly drier, whereas the other seasons were wetter, especially summer (more than 40 per cent) and winter (up to 20 per cent). Both summer and winter rainfalls at Milford Sound and Hokitika showed similar patterns in the 1980s, but the departures from normal were greater at Milford Sound.

At Appleby, summer was very wet (up to 40 per cent above normal) in the 1920s, 1930s and early 1940s, then was close to normal until the dry period in the 1970s and the wetter period in the 1980s. Autumn was drier, especially in the 1930s and 1940s (more than 30 per cent) and again from the early 1960s to the 1980s. However, in the 1950s, autumn rainfall was more than 20 per cent above normal. Spring showed deviations from normal of more than 20 per cent, especially in the 1920s, 1930s, 1950s and 1980s. Summer had the largest increase above normal (more than 30 per cent) in the 1980s, closely followed by spring. Autumn was the only season with below normal rainfall in the 1980s.

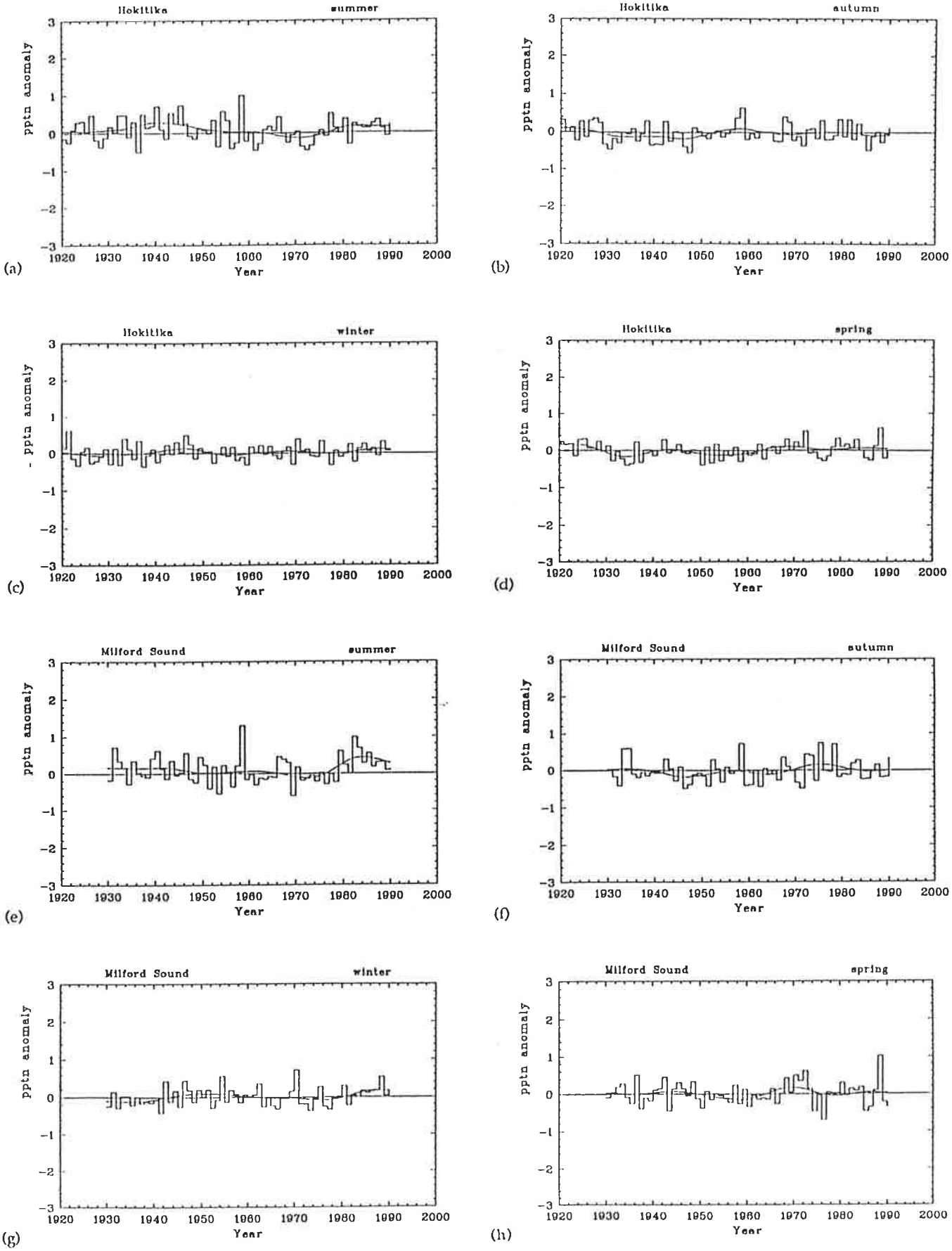


Figure 13 Seasonal rainfall at Hokitika and Milford Sound

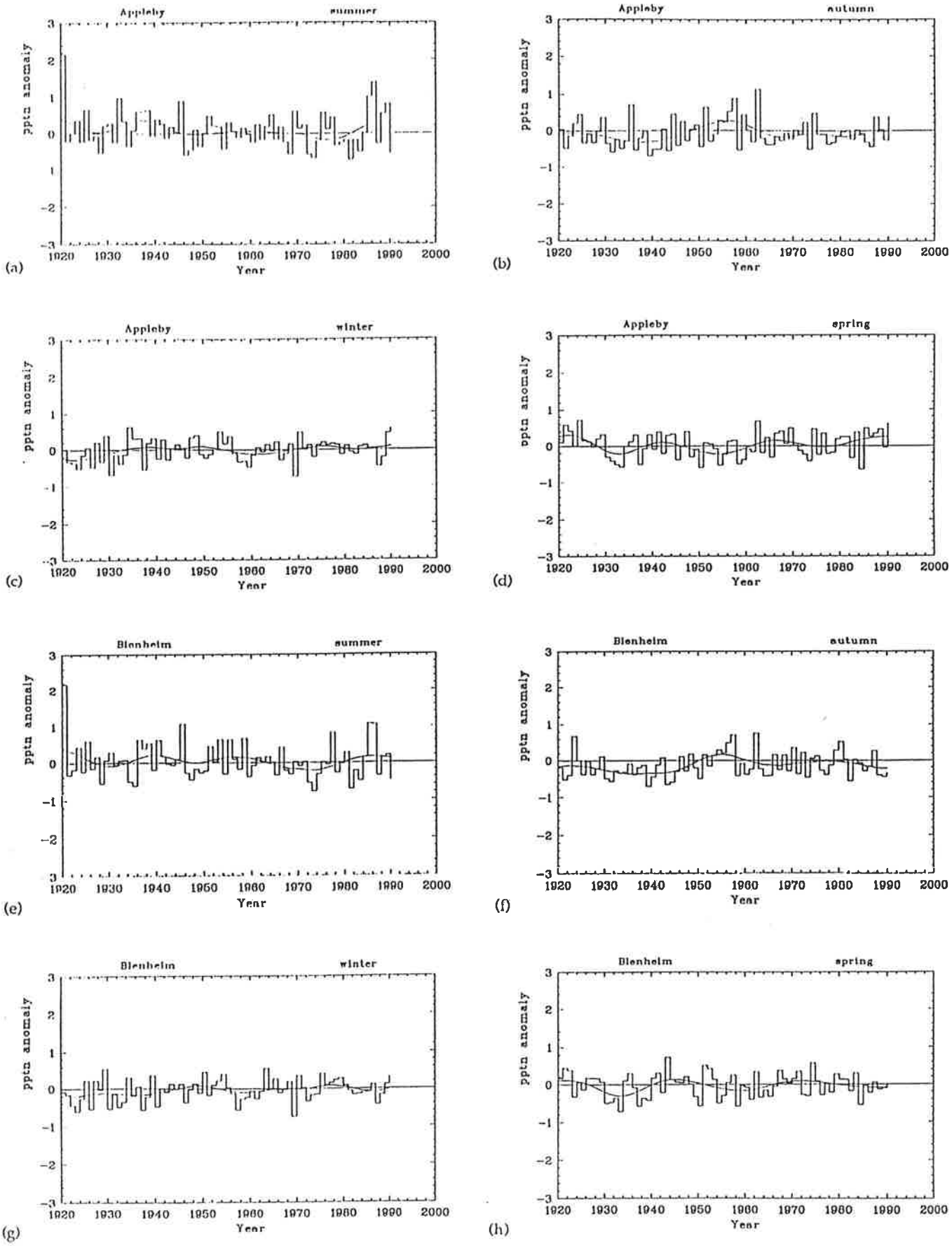


Figure 14 *Seasonal rainfall at Appleby and Blenheim*

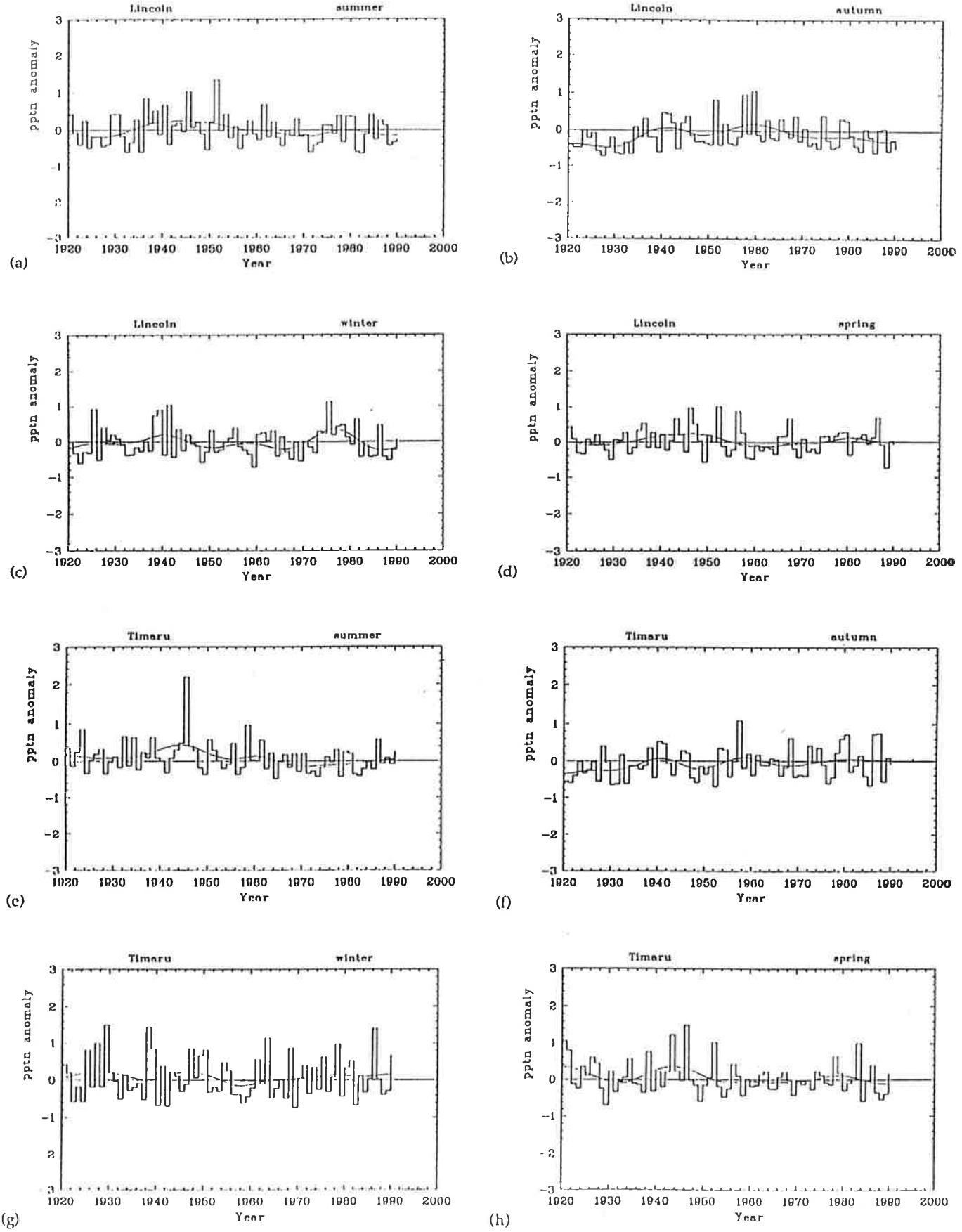


Figure 15 *Seasonal rainfall at Lincoln and Timaru*

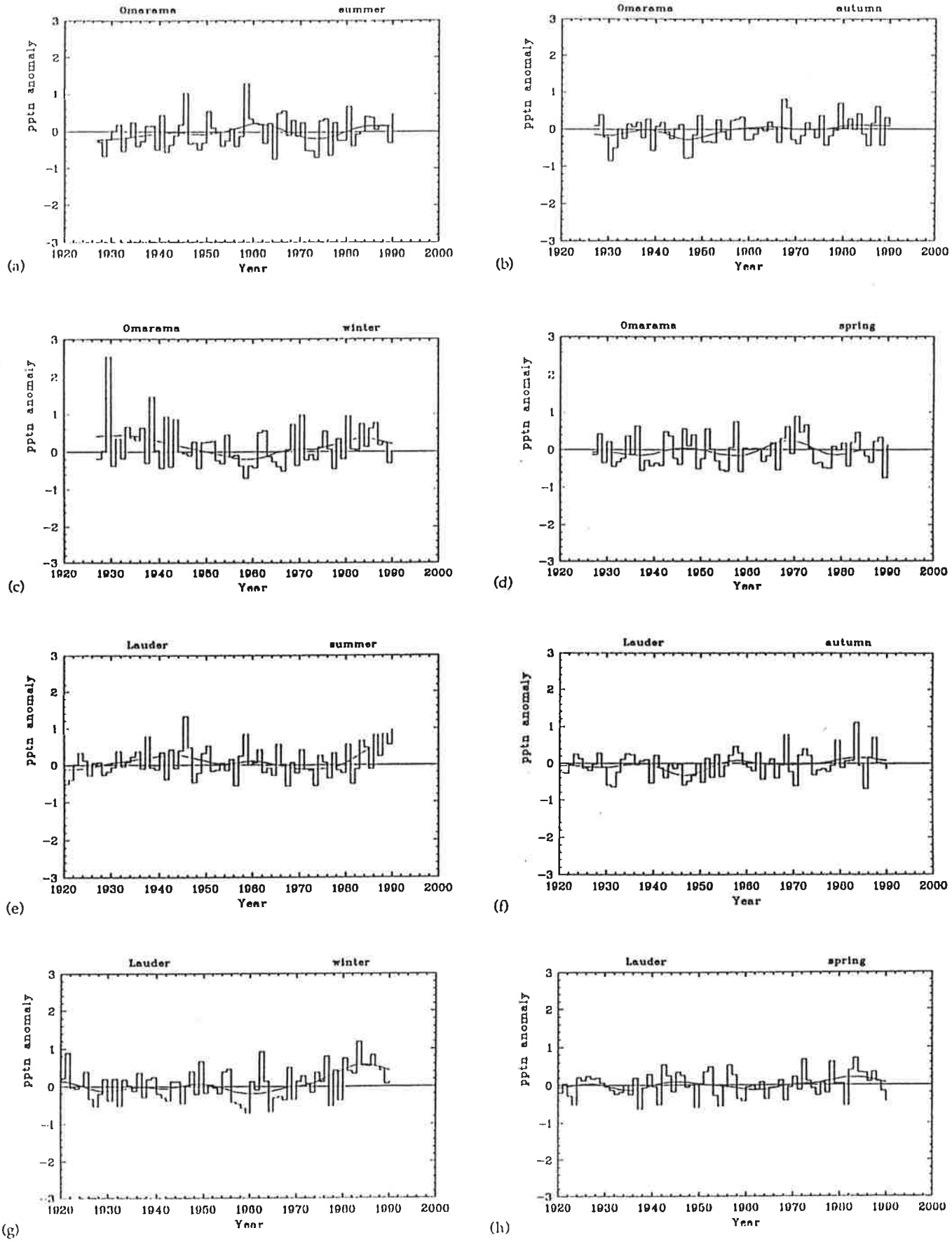


Figure 16 Seasonal rainfall at Omarama and Lauder

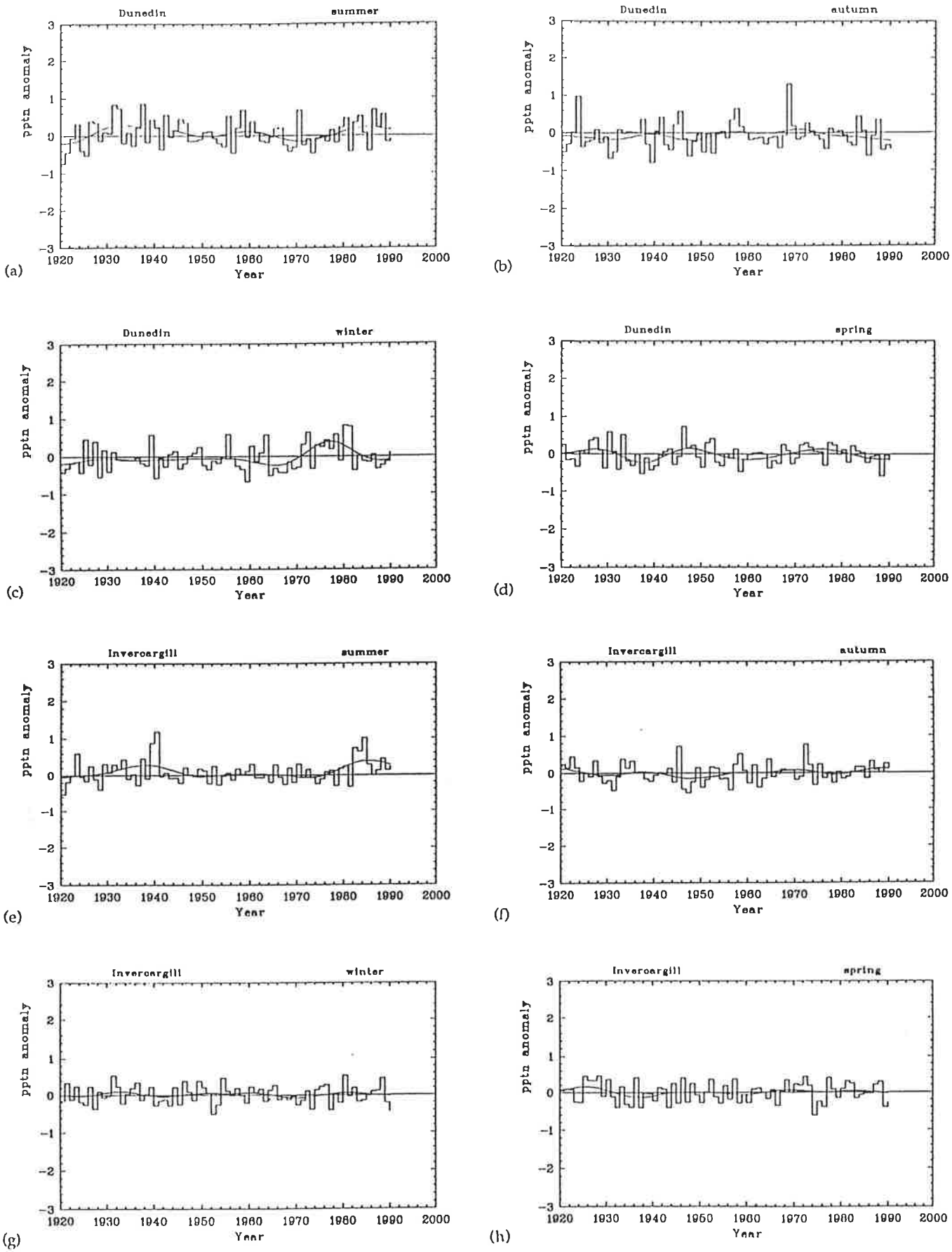


Figure 17 Seasonal rainfall at Dunedin and Invercargill

At Blenheim, the seasonal characteristics are broadly similar to those at Appleby. The main differences include very wet summers in the 1920s and 1950s at Blenheim (close to normal at Appleby) and in the 1980s, when spring and winter at Blenheim were drier (opposite of Appleby). Autumn was up to 20 per cent below normal, which was greater than at Appleby.

At Lincoln, all seasons, especially autumn, were drier from 1920 to the mid-1980s. Summer was wettest in the 1930s, which was similar to Appleby and Blenheim. From the early 1960s summer rainfall was close to normal or up to 10 per cent below normal. The other season with major fluctuations was winter, which was up to 20 per cent above normal in the late 1930s and below normal by up to 20 per cent from the late 1940s until 1970. In the mid-1970s winter was nearly 40 per cent above normal, before decreasing to 20 per cent below normal in the 1980s. This winter maximum did not appear at stations further north, but there was a similar winter maximum at Dunedin. Autumn rainfall was drier from the 1960s, which is similar to both Appleby and Blenheim. In the 1980s spring was the only season slightly above normal and the other seasons were all below normal, with autumn and winter having the greatest departures.

Further south at Timaru, most of the major fluctuations of the seasonal rainfall occurred prior to 1960. Summer was much wetter (more than 40 per cent) than normal in the 1940s. Spring was wetter than normal (more than 30 per cent) in the 1920s and 1940s. In fact all the seasons had maxima in the 1940s making this decade the wettest in the record. Autumn was mostly drier than normal (more than 30 per cent) from 1920 to the mid 1950s, while the other seasons were mostly wetter than normal till the mid-1950s. In the 1980s summer was drier in the early 1980s and slightly above normal by the late 1980s, the opposite of spring. Of the other two seasons, autumn was close to normal (different from Lincoln and Blenheim) and winter was the wettest (different from other stations east of the ranges).

At Omarama, winter rainfall was up to 40 per cent above normal in the 1930s and remained above normal until 1950. The other seasons were mostly below normal till 1950. The summer maximum, evident at other stations in the 1930s or 1940s, did not occur at Omarama, although there was a summer maximum in the 1940s at Lauder. There was a small summer maximum at Omarama about 1960 which also showed up in the records of Timaru and Lauder. Autumn rainfall was more than 20 per cent below normal in the late 1940s. In the 1980s, spring was close to normal, while the other seasons were wetter, especially winter (about 30 per cent).

The rainfall patterns for Lauder and Omarama had some similarities and some major differences. Both stations had their driest autumns in the 1940s, although departures were large at Lauder. Winter rainfall was similar in the 1980s, (although departures at Lauder were up to 60 per cent compared with 30 per cent at Omarama), but quite different in the early part of the record, when Omarama had much wetter winters. At Lauder summers were wet in the 1930s and 1940s (while Omarama was drier) and a large increase, similar to winter, in the 1980s. All seasons were wetter in the 1980s, with winter and summer showing the largest increase (up to 60 per cent) and spring and autumn a similar, but lesser increase (up to 20 per cent).

At Dunedin, the main features were the wet summers in the 1930s and 1940s and again in the 1980s, as well as the very wet winters in the late 1970s. Winter, in fact, is below normal for the whole record apart from the wet period in the 1970s and autumn remains below normal until the mid-1950s. In the 1980s, summer had the largest departure above normal, while winter, which was initially wetter in the early 1980s, became drier along with spring and autumn.

Wet summers at Invercargill occurred in the 1930s and 1980s, corresponding to those at Dunedin. The wettest summer seasons occurred at both stations in the 1980s. The period 1950 to the mid-1970s did not have large departures from normal at Invercargill. In the 1980s, summer was the wettest season, up to 40 per cent above normal, and autumn about 10 per cent above normal. The other seasons were slightly drier by the end of the 1980s.

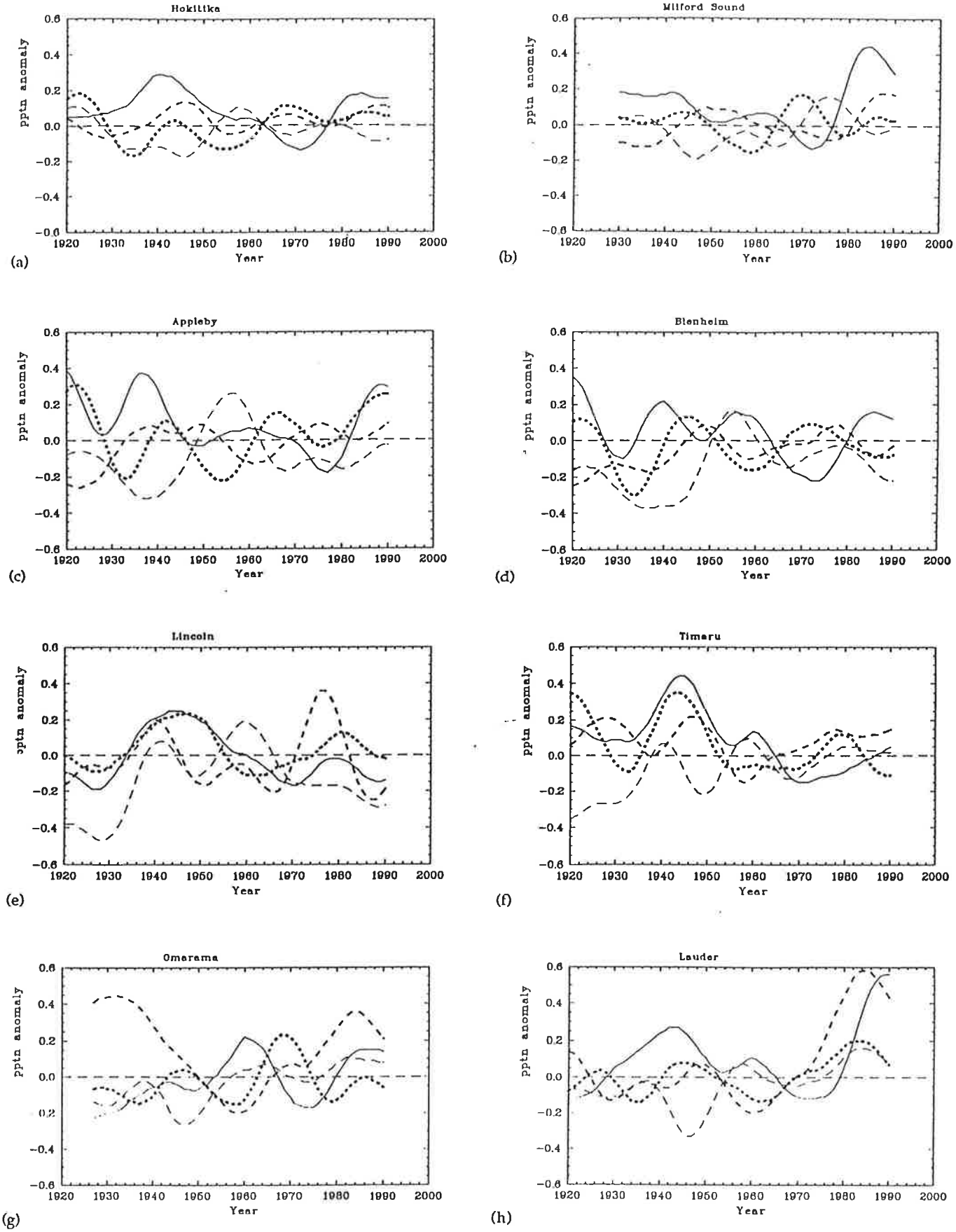


Figure 18 *Filtered seasonal rainfall at South Island stations*

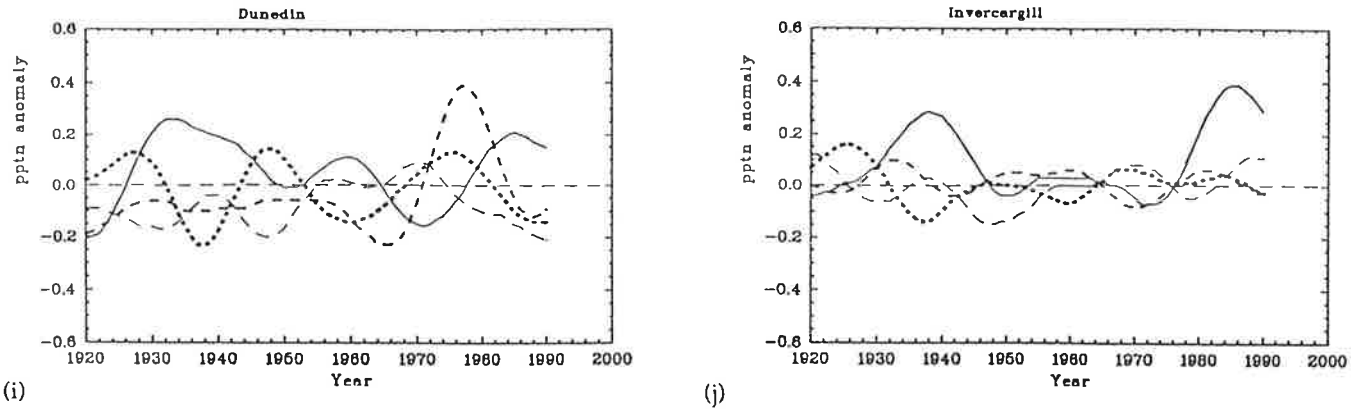


Figure 18 (continued)

Summary for the South Island

Summer was much wetter than normal in the 1930s and 1940s at most stations. Summer was also the most variable season and also the wettest (highest departures above normal at Milford Sound, Lauder and Invercargill) in the 1980s, except at Timaru where it was the second wettest and Lincoln, where summer was drier than normal. Winters were very wet in the late 1970s at Lincoln and Dunedin. There were long periods in the early part of the record when autumn was drier than normal In the early and later part of the records there was often more variability than in the middle part for some stations. There is no obvious trend in the seasonal rainfall, although there are some large fluctuations about normal, especially in the early and later parts of the record.

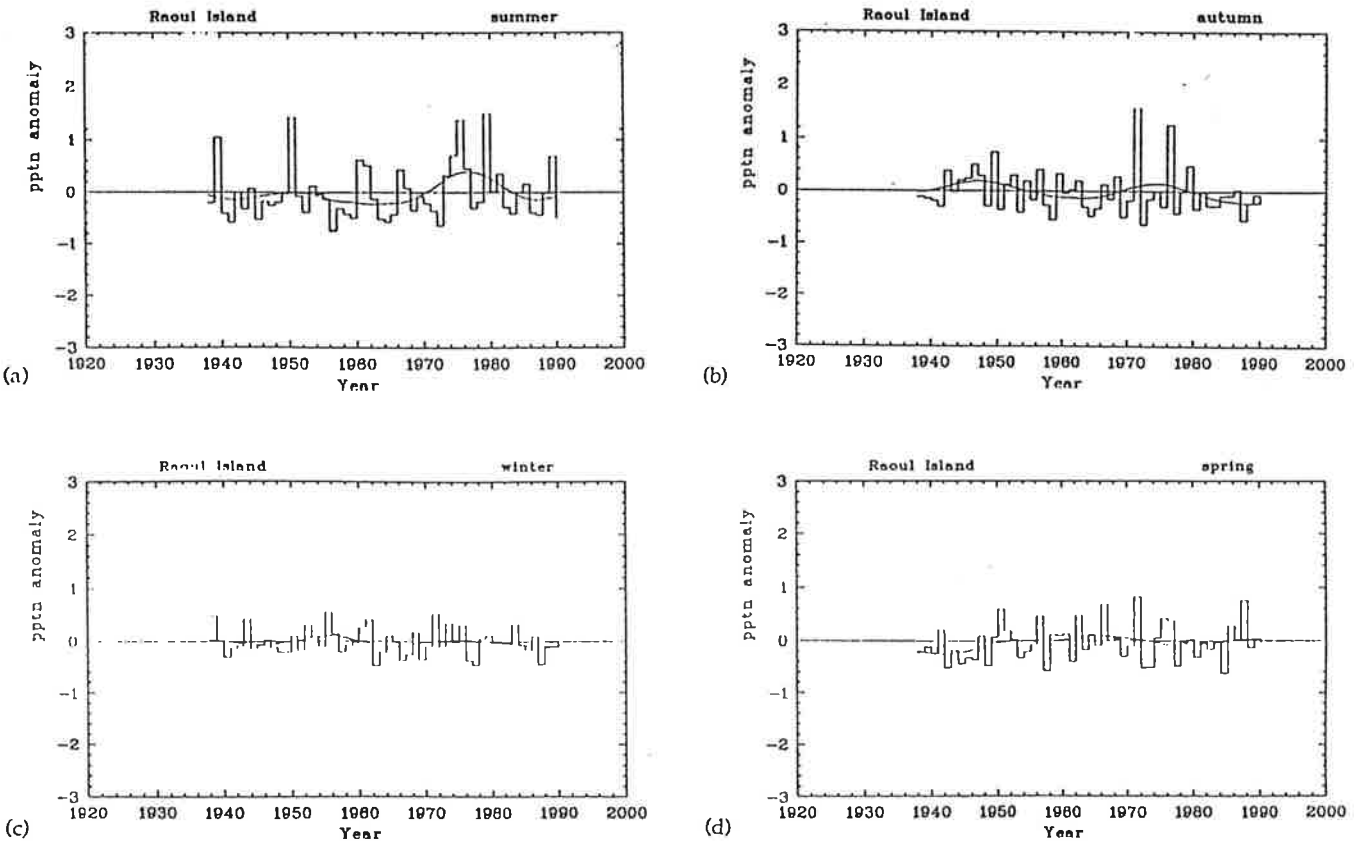


Figure 19 Seasonal rainfall at Raoul Island

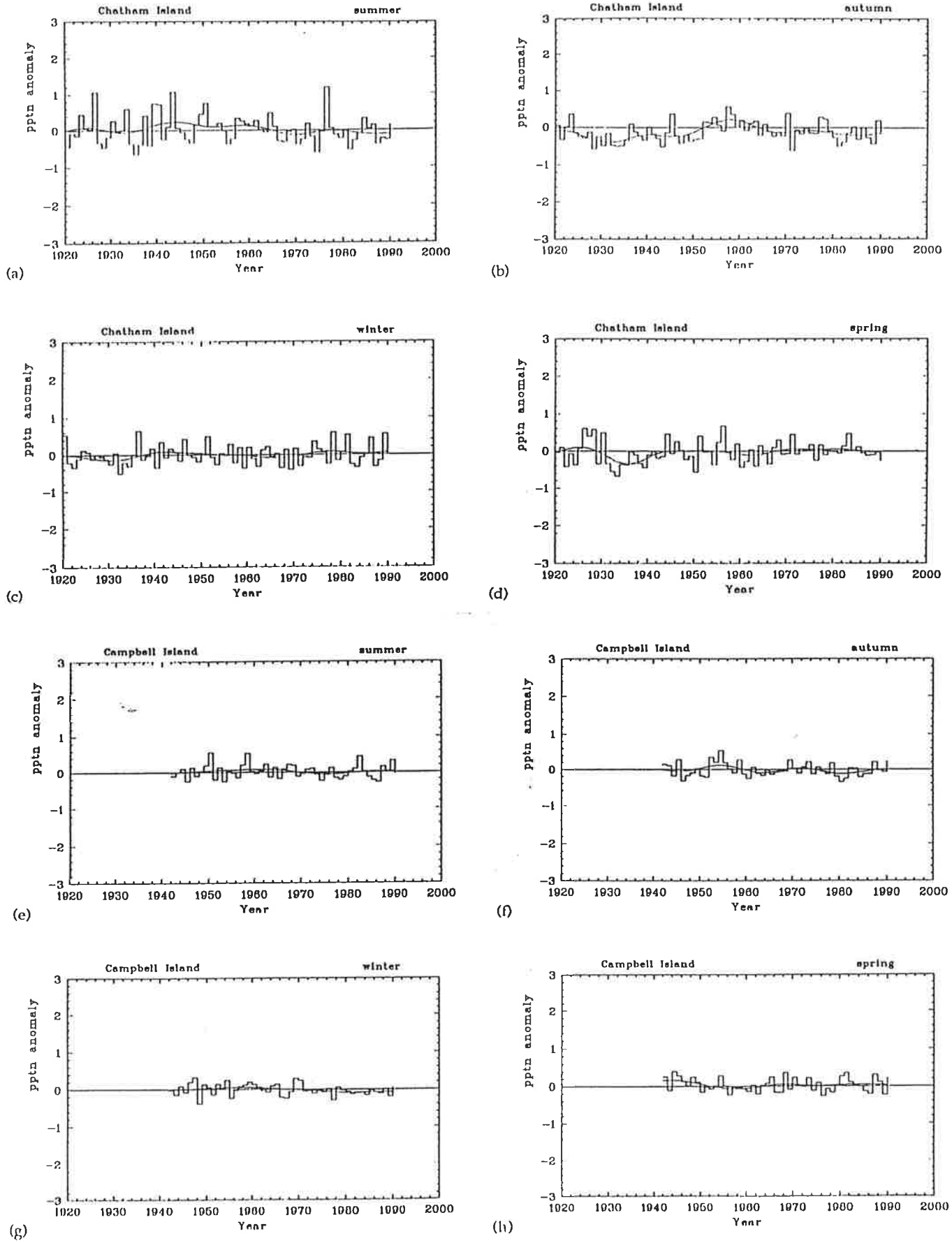


Figure 20 Seasonal rainfall at Campbell Island and Chatham Island

Seasonal variations at Raoul, Chatham and Campbell Islands

Figures 19 a-d and 20 a-h show the smoothed seasonal rainfall curves for Raoul, Chatham and Campbell Islands Each station is discussed separately. For comparison, smoothed curves for the four seasons are superimposed for each station and shown in figure 21 a-c which uses the same format as figure 12.

Raoul Island

In the 1940s, autumn rainfall at Raoul Island was up to 20 per cent above normal while the other seasons were below normal, with spring having the greatest departure (up to 20 per cent). Summers were mostly drier (up to 20 per cent) to 1970, after which the wettest summers occurred (up to 40 per cent) in the 1970s. In the 1980s spring was the only season above normal and autumn has the greatest departure below normal (up to 20 per cent).

Chatham Island

The driest seasons prior to 1940 were autumn and spring. In fact, autumn only rose above normal from the mid-1950s to mid-1960s, when it was the wettest season (up to 20 per cent above normal). Spring and winter were close to normal for most of the record. The wettest seasons were summer in the 1940s and autumn from the mid-1950s to mid-1960s. In the 1980s, winter and spring were slightly wetter, while summer and especially autumn (up to 20 per cent) were drier.

Campbell Island

At Campbell Island there are no major fluctuations of the seasonal rainfall about normal. In the 1980s winter and autumn were drier and spring and summer slightly wetter.

As with the North and South Islands there does not appear to be any apparent trend in the seasonal rainfall for the outlying islands.

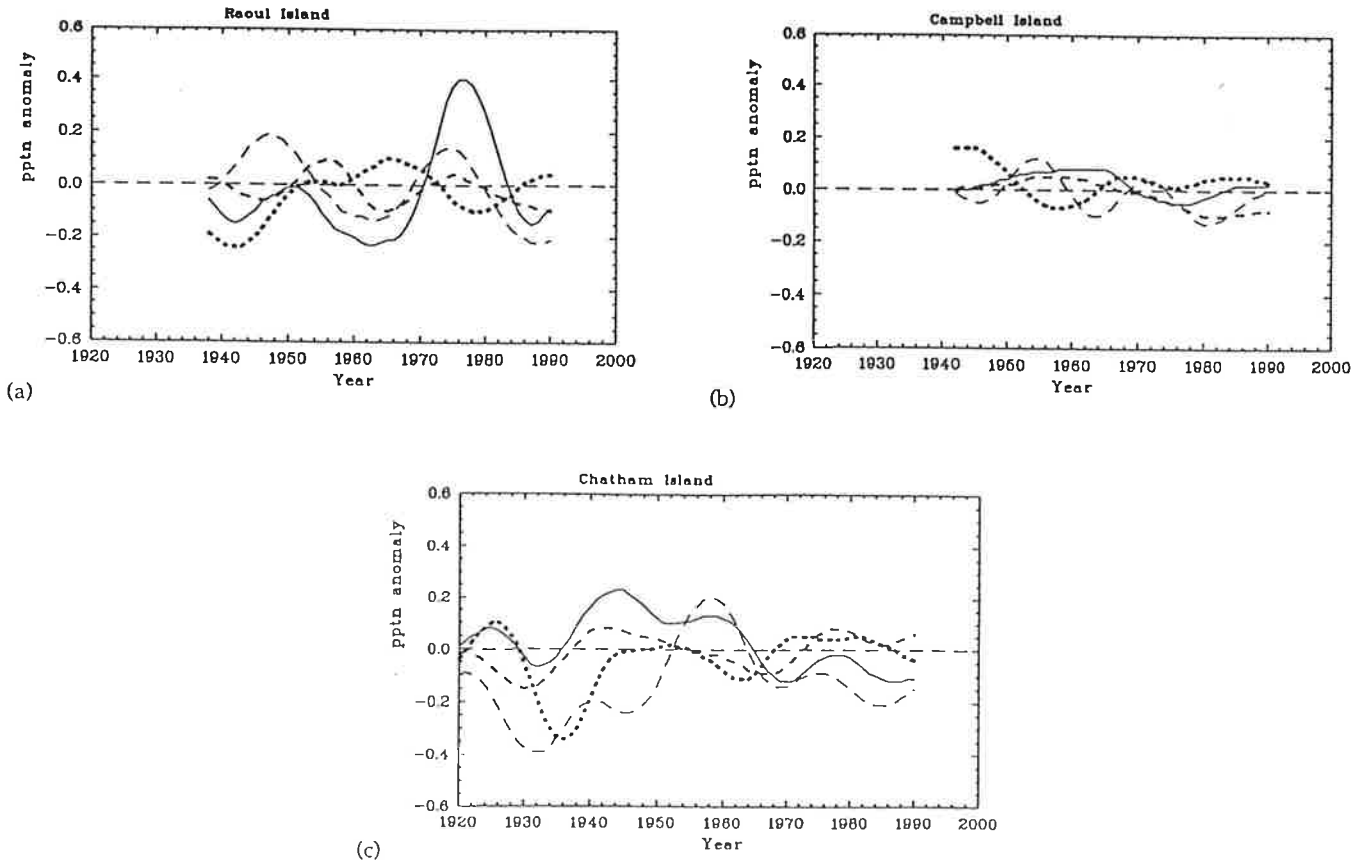


Figure 21 Filtered seasonal rainfall at Raoul, Campbell and Chatham Islands

CONCLUSIONS

The smoothed annual rainfall graphs show sequences of years which were wetter and drier than the 1951-80 reference period. The last decade in the rainfall series shows most North Island stations were drier than normal by up to 20 per cent. On the west coast of the South Island, stations were wetter than normal in the 1980s, as were stations east of the ranges. However there were exceptions such as Blenheim, Lincoln and Dunedin, which were drier than normal. Raoul and Chatham Islands have similar characteristics to the land stations, while Campbell Island does not show much variation in its smoothed rainfall curve. There does not appear to be any long term trend in either the North Island, South Island or outlying islands rainfall series. Appleby, Milford Sound, Omarama, Lauder and Invercargill recorded their greatest departures above normal in the 1980s.

Seasonally, summer is the most variable season. Often seasons at the stations are not in phase, resulting in summer, for example, being wetter than normal at some North Island stations in the 1980s such as Auckland, New Plymouth, Paraparaumu, and drier at others such as Gisborne, Whakatu and Wellington. For some stations in the South Island most of the seasonal fluctuations occur in the early and later part of the record and the years in between are less variable. There does not seem to be any overall long term trend in the seasonal rainfall other than a tendency in some parts of the record, for example the 1980s, when Gisborne, Whakatu and Wellington recorded their driest summers Milford Sound, Lauder and Invercargill recorded their wettest summers. Some seasons, for example autumn, have smoothed curves which remain below the 1951-1980 normal for long periods.

There was some geographical coherence in annual rainfall trends in the 1980s. The last decade (1981-1990) was drier at Raoul Island, and in most of the North Island except Kaitaia and Auckland. It was particularly dry in Taihape, Wellington and the east. In the South Island Blenheim and Lincoln were drier, but Appleby, Invercargill and stations in western and inland areas recorded their wettest decade. Chatham Island was drier, but their was no trend at Campbell Island.

Raoul Island showed no seasonal trends in rainfall. Summers were wetter in northern North Island areas but drier in Taihape, Wellington and the east in the 1980s. Summers were particularly wet in the west of the South Island in the 1980s. All areas of the South Island except at Lincoln (which was drier) were wetter. Timaru summers were average in the 1980s. Chatham Island summers were drier but no summer rainfall trend occurred at Campbell Island. No other seasonal rainfall trends were apparent.

It is not possible to compare directly the rainfall graphs in this report with the response areas of Salinger (1979). The data used in this report are for individual stations and the response areas are averages over a number of stations in the response area. In general there are some agreements and some disagreements in the detail.

It is strongly recommended that observations continue at the reference sites so that rainfall 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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APPENDIX A

Rainfall normals (mm) for the reference stations

1951 - 1980

Station	Lat	Long	Totals (mm) Annual	Seasonal			
				Sum	Aut	Win	Spr
Kaitaia	35 08 S	173 16 E	1429	291	330	478	330
Auckland	36 58 S	176 46'E	1259	240	327	407	285
Hamilton	37 47 S	175 19 E	1236	260	300	380	296
Rotorua	38 07 S	176 19 E	1475	348	374	415	338
New Plymouth	39 01 S	174 11 E	1514	316	388	454	356
Taihape	39 41 S	175 48 E	1001	252	236	265	248
Paraparaumu	40 54 S	174 59 E	1078	212	271	305	270
Wellington	41 17 S	174 46 E	1305	255	339	413	298
Gisborne	38 40 S	178 00E	1079	244	277	363	214
Whakatu	39 37 S	176 55 E	795	173	204	261	157
East Taratahi	41 01 S	175 37 E	915	178	237	299	201
Hokitika	42 43 S	170 59 E	2809	653	727	653	776
Milford Sound	44 40 S	167 55 E	6213	1569	1765	1173	1706
Appleby	41 18 S	173 06 E	971	190	278	280	230
Blenheim	41 30 S	173 58 E	747	151	210	206	180
Lincoln	43 38 S	172 28 E	736	170	208	201	157
Timaru	44 18 S	171 14 E	736	1170	208	201	157
Omarama	44 32 S	169 54 E	526	145	142	83	125
Lauder	45 03 S	170 31 E	498	148	142	83	125
Dunedin	45 54 S	170 31 E	802	198	228	193	183
Invercargill	46 25 S	168 20 E	1040	252	265	282	251
Raoul Island	29 19 S	177 55 E	1556	377	407	471	301
Chatham Island	45 57 S	176 34 W	895	174	273	297	182
Campbell Island	52 33 S	169 09 E	1361	327	380	332	322